PRODUCTIVITY IMPROVEMENT THROUGH THE USE OF A
3-D DIGITIZER IN THE PRODUCTION OF PERSONAL
CUSTOMIZED ORTHOTIC ACCESSORIES

by

WYLIE HUGH MCADAM

A Thesis
Submitted in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Mechanical Engineering
(Industrial Engineering Program)
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Canada

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ABSTRACT

Many individuals require specialized, contoured and individually tailored seating systems due to injuries sustained or congenital deformities. The majority of custom seating systems are presently hand crafted to fit individual needs. This process is expensive, complicated, time consuming and often results in the individual waiting months for a seating system.

This thesis presents an alternative method to the manufacturing system presently used by Otto Bock Orhthopedics Industry of Canada Ltd., a manufacturer of custom seating systems. The alternative manufacturing system incorporates the use of a micro-computer based three-dimensional digitizing system for the measuring of body contours. A micro-computer based Three Axis Router was designed and built for the manufacture of molds, replicating the body contours measured through the three dimensional digitizing system. A number of surfaces were digitized using the three-dimensional digitizing system. The resulting surfaces were modeled on a micro-computer and the resulting surfaces were carved using the Three Axis Router. This alternative manufacturing system offers the promise of higher quality, lower cost custom seating systems delivered within much shorter time frames.

ii

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

iv

LIST OF FIGURES

CHAPTER I.   GENERAL BACKGROUND

1.1 Introduction

Many individuals require specialized, contoured and individually tailored seating systems due to injuries sustained, disease or congenital deformities. This is also true for the rapidly increasing elderly proportion of our population. Multiple Sclerosis, Cerebral Palsy and Muscular Dystrophy are just a few of the diseases which can result in disabilities that increase the demand for custom seating systems. For example: studies have shown that approximately 2 out of 1000 school aged children suffer from Cerebral Palsy [1,2,3]. Incidence rates of Muscular Dystrophy range from 14.00 per 100,000 male population to 27.90 per 100,000 male population for different parts of the world [4]. It should be noted however, that the primary injuries that cause long-term disabilities requiring customized seating systems are injuries to the head.

More than 75,000 Americans per year sustain head injuries which resulted in long term disability. This includes approximately 2,000 people who remain in a persistent vegetative state [5]. With improved emergency

1

services, diagnostic and neurosurgical techniques, the survival rate of persons with severe head injuries is increasing [6,7]. The consequent large number of severely disabled survivors has been termed a "disease of medical progress" [8]. Elderly people, particularly those in institutions, often suffer from pressure sores in areas of unrelieved pressure over body prominences [9]. These sores occur because of poor sitting posture in badly fitting wheel chairs, combined with infrequent position changes and normal reduction of body padding due to age.

The use of specialty seating can help numerous people in the above noted groups. For example, a great deal of progress has been made in specialized seating for Muscular Dystrophy sufferers. The use of custom seating systems allows people to maintain a comfortable upright seating posture and may slow the progression of spinal deformities [10].

At present the majority of custom seating systems are hand crafted to fit individual needs. This process is expensive, complicated and time consuming and often results in the individual waiting for months for a seating system. A survey of custom seating techniques can be found in reference [11].

Otto Bock Orthopedic Industry of Canada Ltd. presently manufactures a modular seating system that is designed to reduce the above- mentioned problems. A typical Otto Bock Modular Seating System is shown in figure [1]. Although these systems are very good, they however do not meet the requirements of all individuals. People with additional requirements still require custom-contoured cushions to accommodate their particular concerns. This is shown in figure [2]. A major feature of the Otto Bock custom contoured cushions is that they are mounted in the same frame that is used for the more standard seating systems. This feature greatly reduces the amount of time required to produce a custom seating system. Otto Bock has developed a proprietary custom-contoured seating production system. The system involves vacuum forming a custom cushion around a cast of an individual body surface. The cast is obtained manually from the "bead bag" - forming technique which involves obtaining the cast shape from a surface which holds the negative of an individual's shape. Currently this process is restricted to the immediate Winnipeg area with some limited use in other locations in Canada. The major constraint to the wider use of this technique is due to the difficulty of manufacturing the positive cast.

Fig. 1 - The Otto Bock Modular Seating System

Fig. 2 - Custom Contoured Cushions in the Otto Bock Seating System

4

The present measurement techniques and manufacturing processes are time consuming, expensive and relatively complicated, requiring considerable experience to produce acceptable seating systems.

In order to address these existing problems and to reduce costs and delivery times while making the product better suited for the disabled user population, Otto Bock Orthopedic Industry of Canada Ltd. approached Professor Ostap Hawaleshka of the Industrial Engineering Program at the University of Manitoba to investigate ways and means to improve their existing methods of producing individually tailored, customized seating for use in the standard, modular Otto Bock framing system. After reviewing possible avenues it was decided to concentrate on the development of a microcomputer-based system for the measurement of body contours and for the production of the positive cast.

This thesis outlines the developments and testing of a prototype system which can produce the casts used for the custom seating system.

5

1.2 Otto Bock Background

Otto Bock Orthopedic Industry of Canada Ltd. was incorporated in January 1978 in Manitoba. The Parent company Otto Bock Orthopaedische Industries K.G. was founded in 1919 by Otto Bock and is based in Duderstadt West Germany. World wide, the parent company employs approximately 1100 people with three manufacturing plants and distribution centres in thirteen countries. Major product lines include prosthetic and orthotic components as well as polyurethane foam resins for the auto industry for general purpose molding.

The Canadian operation began as a warehousing and distribution centre for products manufactured by the parent company. However in 1980 the decision was made to include manufacturing. Presently there is approximately 40,000 square feet of manufacturing space with an additional 30,000 square feet of warehouse and office space.

In 1982, Otto Bock Orthopedic Industry of Canada Ltd. had begun a three year research and development project for the development of medical and industrial foam products. The Canadian operation's present successful line of seating products for the severely disabled is a direct consequence of this initial project. The Canadian engineering research

6

and development group is considered by the parent company to be the most dynamic and progressive of the three company research and development facilities. Considering the above statements the Canadian facility is presently involved a large number of research areas. Two areas of research are custom seating and orthotic/prosthetic component redesign using advanced techniques such as finite element analysis. The Department of Industrial/Mechanical Engineering is presently involved in a number of projects because of their involvement and experience in advanced manufacturing techniques.

1.3 Present Manufacturing System

The present method of the Otto Bock custom seating system uses the "bead bag" vacuum molding system to provide a negative of a persons surface anatomy. A person can not be repositioned until a satisfactory posture is obtained. A plaster cast of the "bead bag" mold is then taken to obtain a positive mold of the person's surface anatomy. This very heavy and cumbersome mold is used to fabricate vacuum drawn cloth covered foam cushions which are representative of the negative surface obtained through the "bead bag" vacuum molding system.

7

The cushions are then inserted into the standard Otto Bock modular seating system components. A detailed sequential analysis of the present manufacturing technique follows:

1.3.1 Fitting Operation

A summary of the fitting operation is as follows:

1. The fitting chair is adjusted to the proper size for the person being measured.

2. The proper "bead bags" are positioned in the fitting chair. The size of the bead bags selected is a function of the size and measurements of the person being measured. The fitting chair with bead bags is shown in figure [3]. The bead bags are one-piece thin latex rubber bags filled with expanded styrofoam beads and fitted with an air valve. When air is removed from the bead bag the beads consolidate and form a semi-rigid matrix that maintains the molded shape of the patient's anatomy. A small vacuum pump is used to evacuate the air.

3. The patient is seated in the fitting chair.

4. The patient is positioned and the bead bags are evacuated with air to hold a negative of the surface

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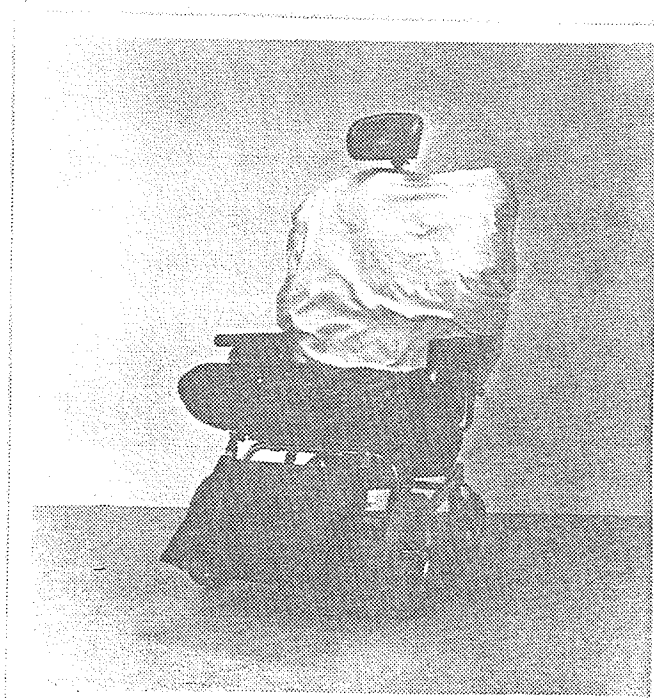
Fig. 3 - Fitting Chair
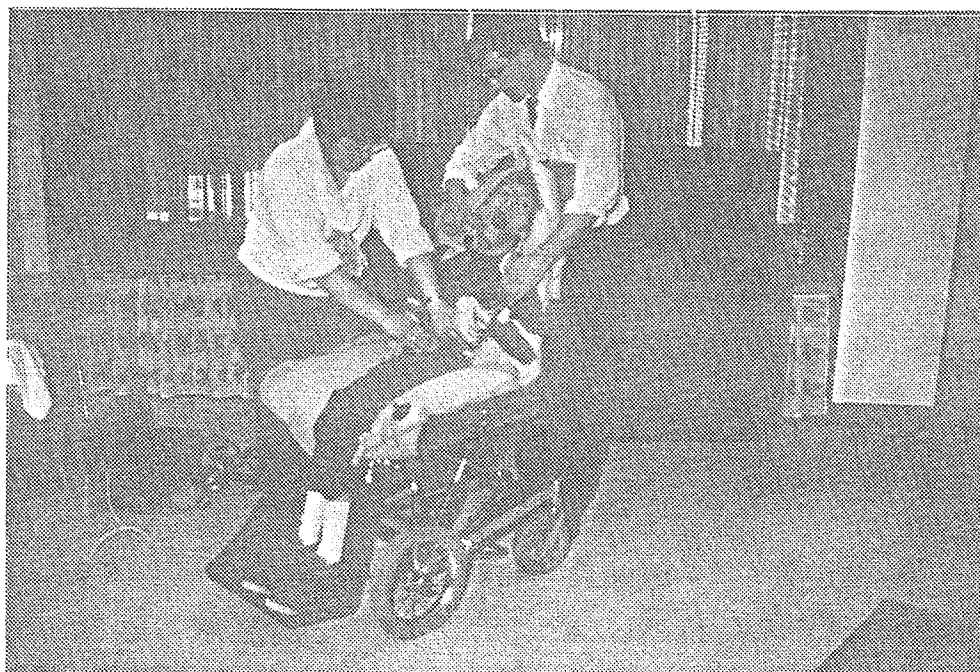
Fig. 4 - Fitting Operation

anatomy.

5. This process is repeated until a satisfactory position
   is obtained. The fitting operation is shown in figure
   [4].

   (It should be noted that two cushions are usually
   required for each patient - one for the seat and one
   for the back).

1.3.2 Casting and Marking Operation

1. A plaster wrap is placed over the bead bag surface.
   This is shown in figures [5a-5d].

2. Reference positions for patient center line, cushion
   width, seat length, parting line, back height are
   placed on the plaster surface.

3. The seat/back frame of the fitting chair is removed
   from the wheel base of the fitting chair.

4. A marking jig is used to complete lines used for
   reference positions.

5. The cast is removed from the bead bags and trimmed
   along the reference lines with a cast cutter.

6. Casts are orientated in the proper reference positions
   in a casting box. A rigid foam is poured into the
   casting box to form the base of the mold.
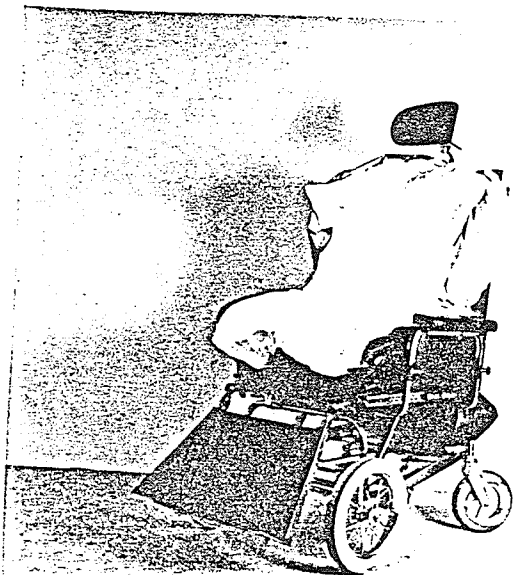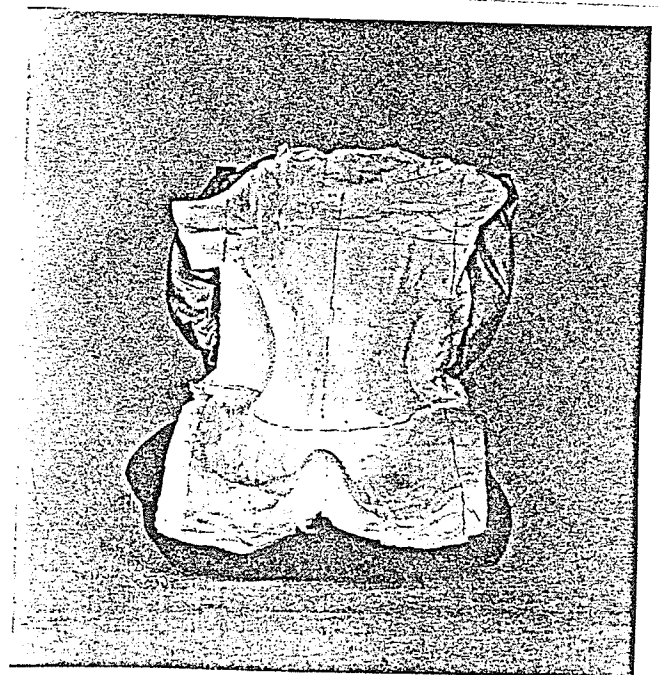
Fig. 5 - Plaster Wrap Application
(a) Molding vacuum bags in fitting chair.
(b) Applying plaster wrap.
(c) Finished cast shell in the fitting chair.
(d) Plaster shell in seat/back ready for marking.
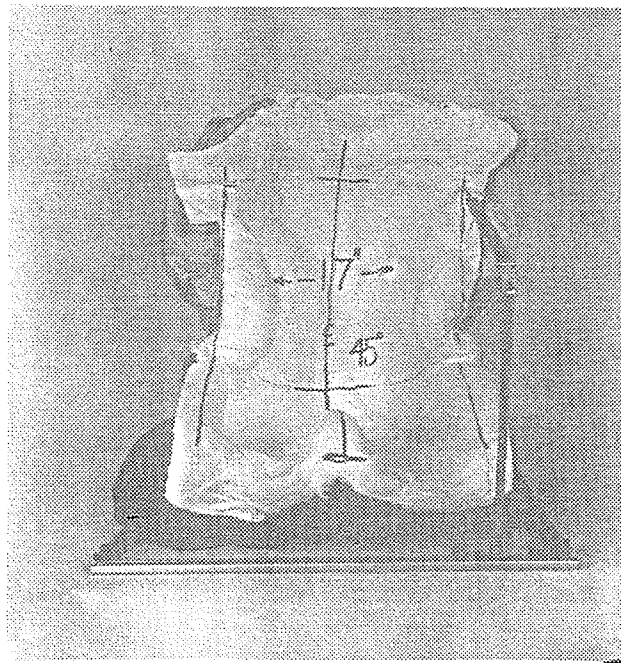
(a)
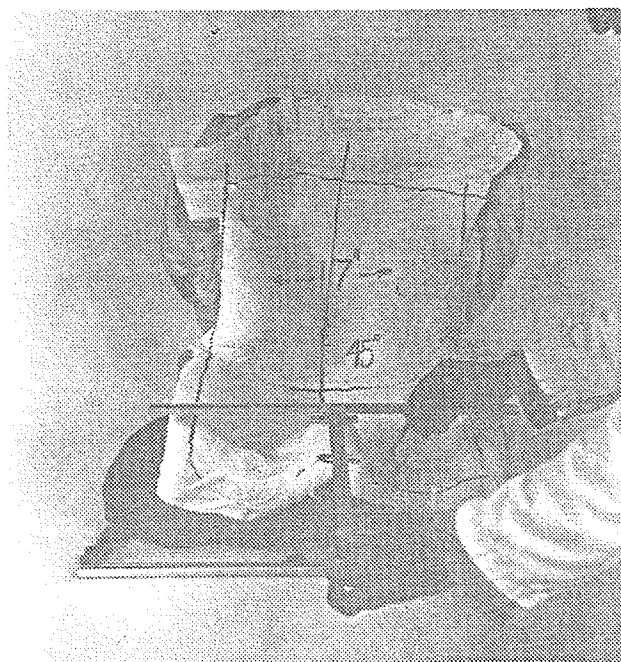
(b)

Fig. 6 - Marking of Reference Positions
    (a) Marking width trim lines in marking jig.
    (b) Marking seat lenght with straight edge.

Fig. 7 - Trimming the Cast
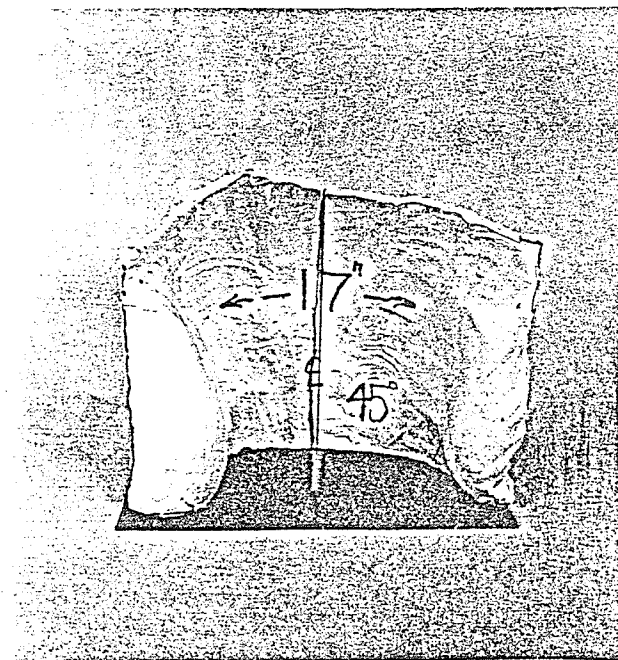
Fig. 8 - Lay-Up of Plaster Cast on Cardboard
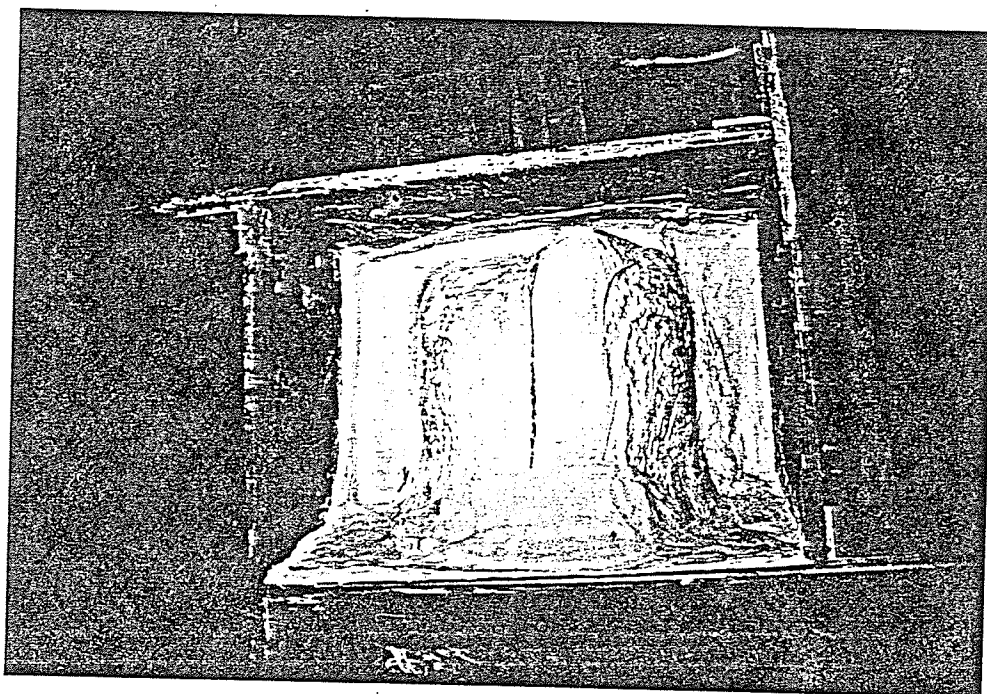
Fig. 9 - Plaster Cast in Mold Box
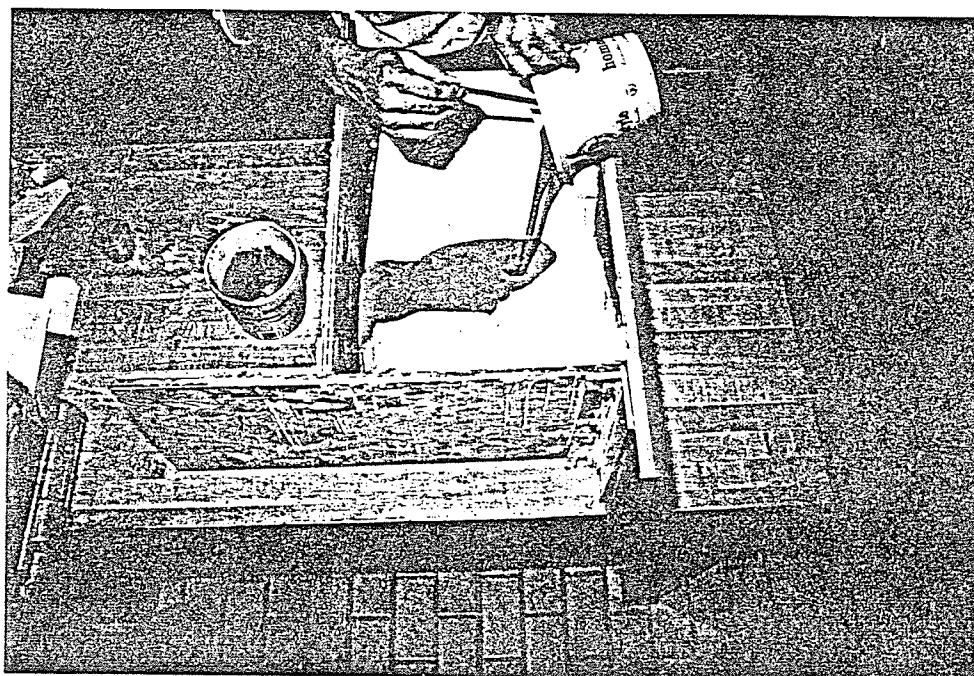
Fig. 10 - Reinforcing Plaster Cast with Rigid Foam
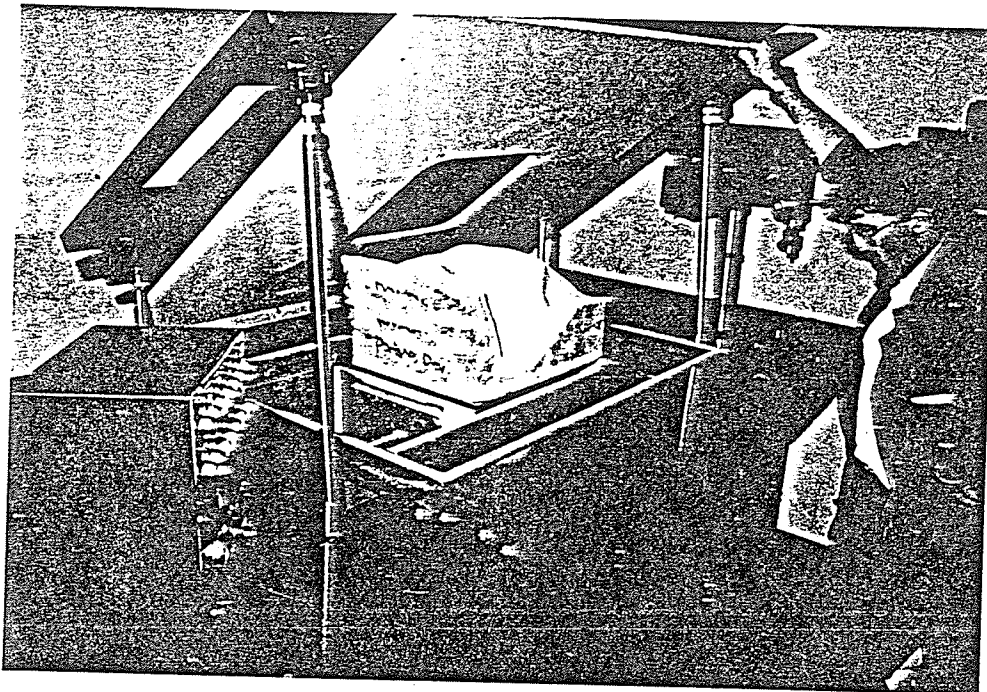
Fig. 11 – Preparing Vacuum Molding Machine
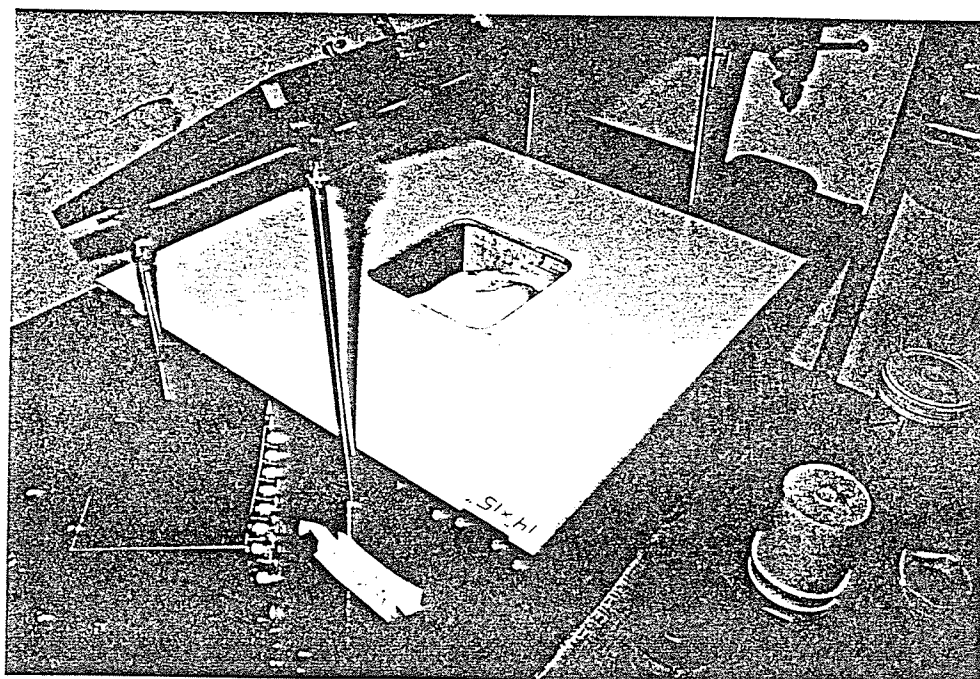
Fig. 12 – Positioning Plaster Cast and Die Plate

15
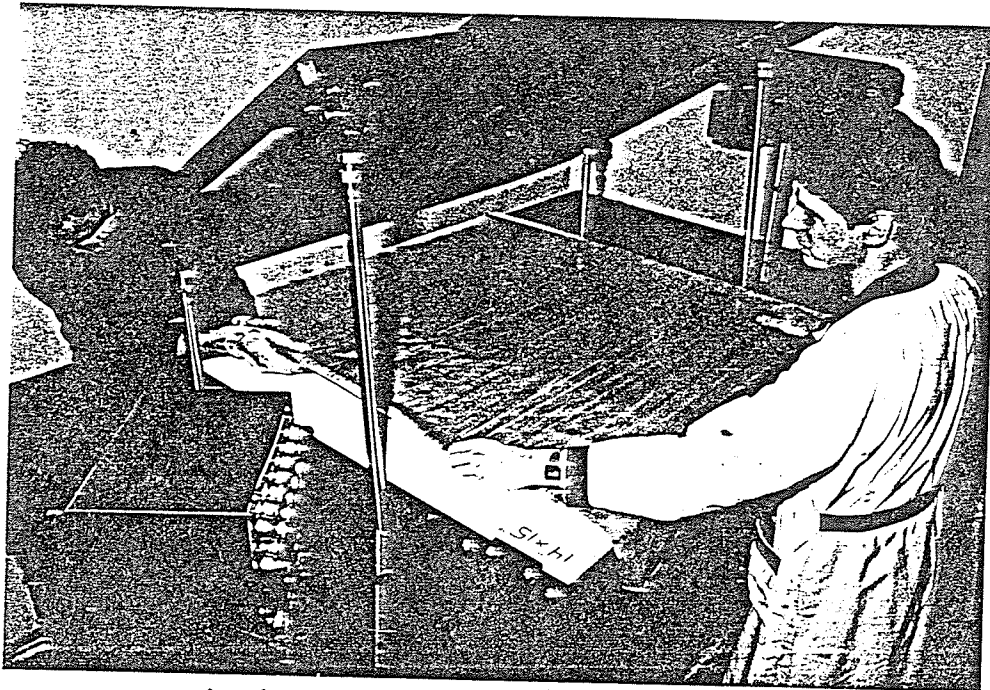
Fig. 13 - Cloth Placement Onto Die Plate
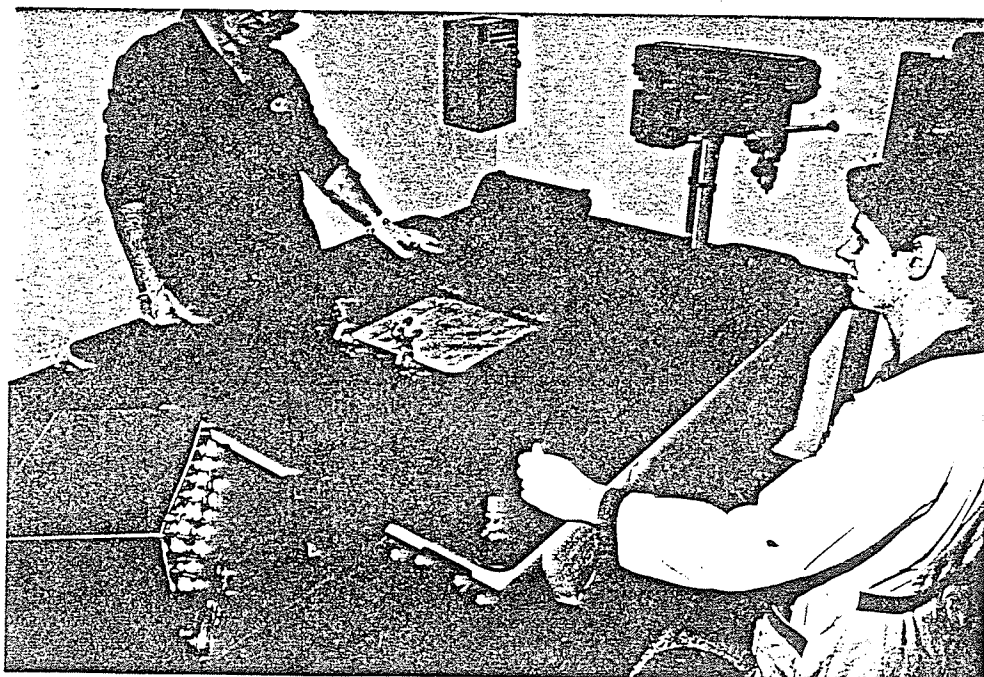
Fig. 14 - Clamping Plate Lowered
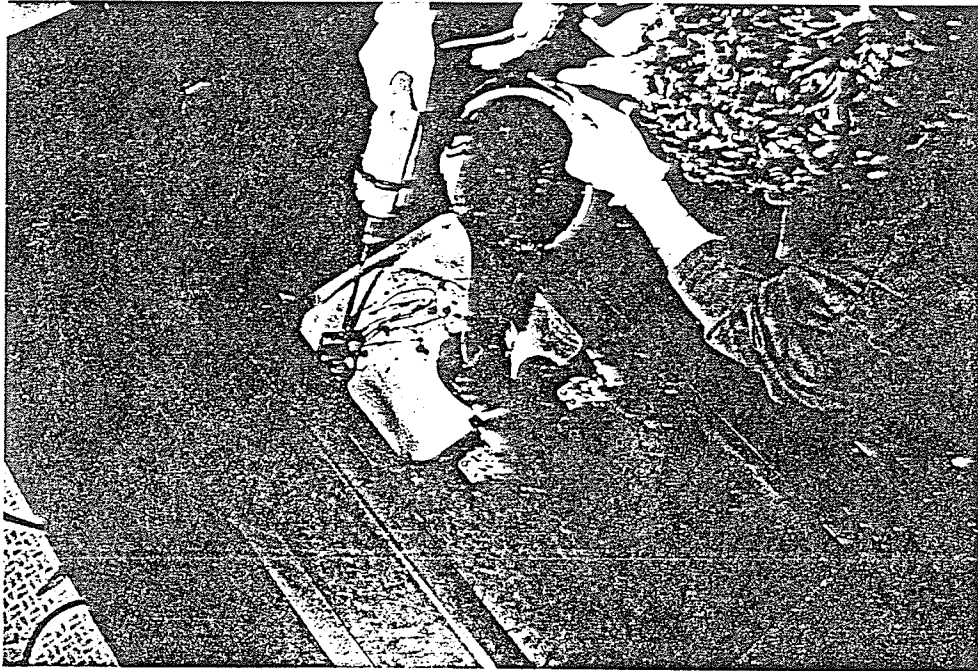
Fig. 15 - Foam Being Poured into Negative of Plaster Cast
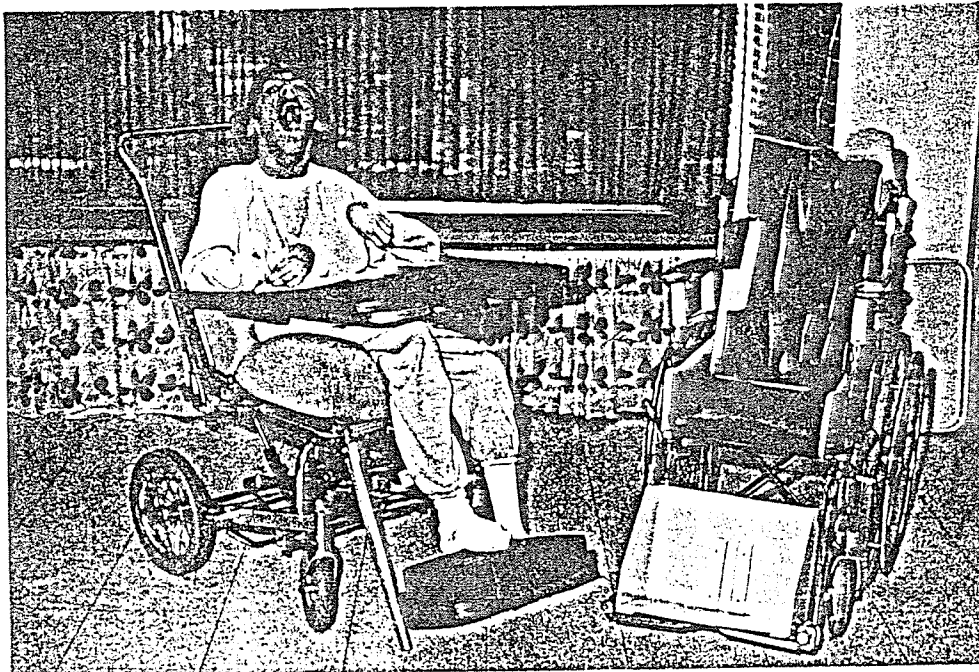
Fig. 16 - Complete Otto Bock Seating System

17

7. The mold surface is finished with plaster to make a smooth surface.

    Steps 2-7 are shown in figures [6] - [10].

1.3.3 Cushion Production

1. The cushion is produced by the Otto Bock vacuum molding machine. Fig [11] - [15].

2. The cushion is mounted in an Otto Bock modular seating system. Fig. [16].

1.3.4 Disadvantages of Present Manufacturing System

The present manual technique of obtaining the molds is extremely cumbersome and has many disadvantages. The major difficulties are listed below:

1. The manual technique is very labour intensive. The average cushion takes approximately 8 hours to manufacture. For a complete seating system the total time would be 16 hours.

2. Due to the inherently complex human factors involved with the selection and design of the correct seating posture of the patient, it is usual to require the knowledge and skills of a physical therapist or rehabilitation expert during the positioning and

measuring/casting procedure. The same type of knowledge and skill is needed when the plaster cast is manufactured. Persons of this skill level would - if possible - choose to minimise their time spent working with the "messy" materials used in the plaster cast manufacture.

3. A large work area is required for the manufacture of the plaster casts. Such space may not be available in the facility where the casting is to take place.

4. The completed casts are bulky, very heavy and difficult to transport. The manufacture of the custom cushion does not occur at the same location as the fitting operation occurs. The fitting operation for example, may occur in Toronto while the cushion would be made in Winnipeg. As a result, the cast would have to be transported to Winnipeg. This has numerous disadvantages including the possibility of losing the cast in transit, damaging the cast and the significant additional cost of transportation.

5. If for any reason a cast must be remade, the cycle time, cost and general inconvenience to the company and to the client could become intolerable.

1.4 Proposed Manufacturing System

Considering the disadvantages of the present manufacturing technique, an alternative manufacturing technique is proposed to minimise existing problems.

The steps of the proposed manufacturing system are:

1. The surface contour of the person requiring a custom seating system is obtained through the use of the fitting chair. The same techniques are used in the present manufacturing system as in the proposed manufacturing system.

2. Points on the surface are measured and digitized by one of the following techniques such as Coordinate Measuring Machines, Laser Ranging, Sonic Ranging, etc. The data will be captured on a microcomputer.

3. The digitized surface is then modeled on a microcomputer. The user may manipulate the surface by moving points around, pulling the surface in or out etc. This is the same function that a person would use in the manual technique when modifications are required. The difference is that the function is now performed on a computer. This step is complete when the user is satisfied that the surface has been modeled properly.

4. The surface information is couriered or sent over an electronic modem to an Otto Bock Central Fabrication Facility.

5. At the Otto Bock Central Fabrication Facility a tool path file is generated from the surface information. This tool path file allows the physical reproduction of the digitized surface by means of a suitable machine.

6. The surface is reproduced on a milling machine or contouring machine from the tool path file.

7. The cast is used in the Otto Bock Vacuum Forming process to manufacture the finished custom cushion. This again is the same as in the present manufacturing technique.

    Figure [17] flow charts the proposed manufacturing system.

The initial implementation of the manufacturing system has the following limitations:

1. The surfaces to be digitized will be single valued, therefore undercuts will not be modeled. (A single valued surface is one for which there is only one z-value for every x,y pair on the surface, a multi-

CUSTOM SEATING
SYSTEM IS
REQUIRED

SURFACE IS
GENERATED
IN FITTING
CHAIR

HEALTH
FACILITY

SURFACE IS
DIGITIZED

TOOL PATH
IS GENERATED
FOR CAST

OTTO BOCK
CENTRAL FAB.

SURFACE IS
MODELED ON
A
MICROCOMPUTER

CAST IS
MANUFACTURED

SURFACE
INFORMATION
SENT TO
CENTRAL
FABRICATION

CUSTOM
CUSHION IS
MANUFACTURED

CUSTOM SEATING
SYSTEM IS DELIVERED
TO CUSTOMER
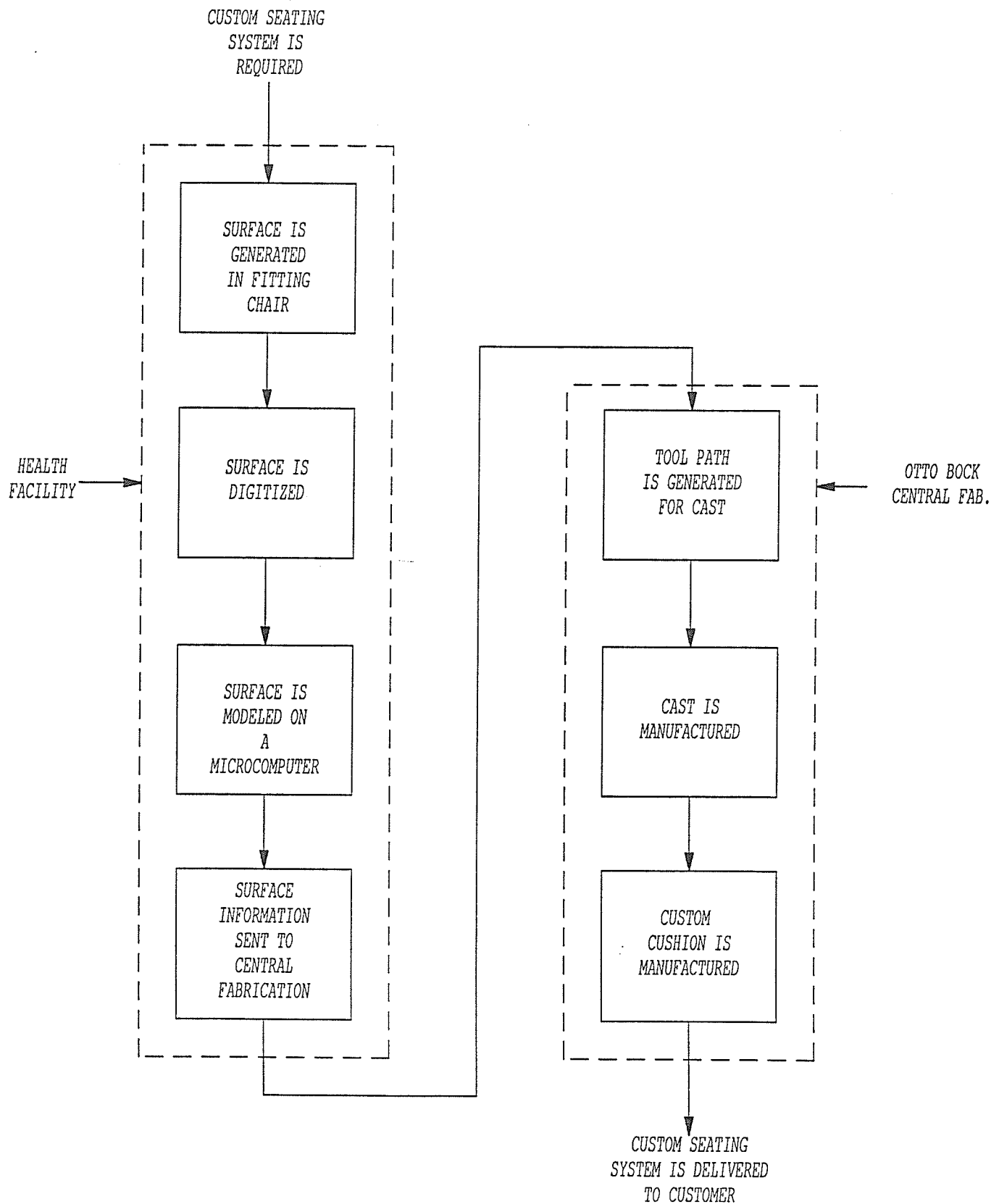
Fig. 17 - Proposed Manufacturing System

22

valued surface has more than one z-value for any x,y pair on the surface; an undercut implies a multi-valued surface). This simplifies surface modelling and the manufacturing of the casts. This is illustrated in figure [18].

2. A minimal amount of surface editing will be possible with the proposed manufacturing system. There will be no features which allow for easy modification of surfaces.

3. Actual plaster casts are the objects that are to be digitized. This will allow for the physical comparison of the plaster cast versus a cast which was digitized. The fitting chair at Otto Bock is still under development and is not yet available for testing with the proposed manufacturing system.

These features may be implemented after the proposed manufacturing system is proven and tested. The following three sections describe the surface measurement, surface modelling/tool path generation and surface reproduction developments of the proposed manufacturing system.

Surface

Cross Section

Undercut Region

Z

Y   X

Z

Under Cut Region

X
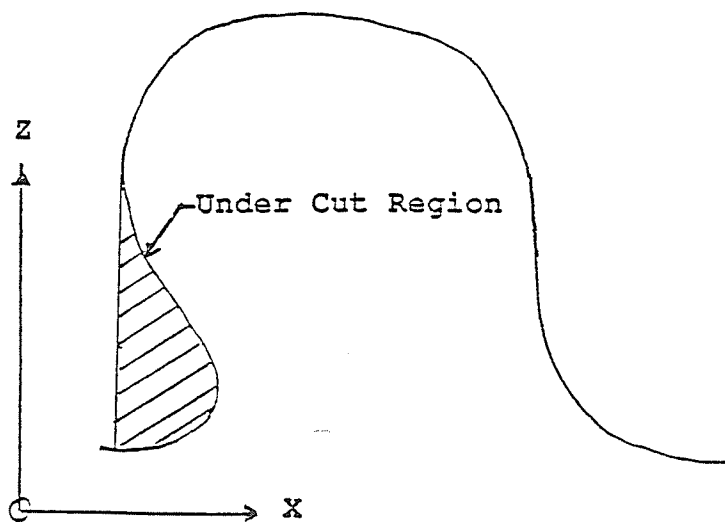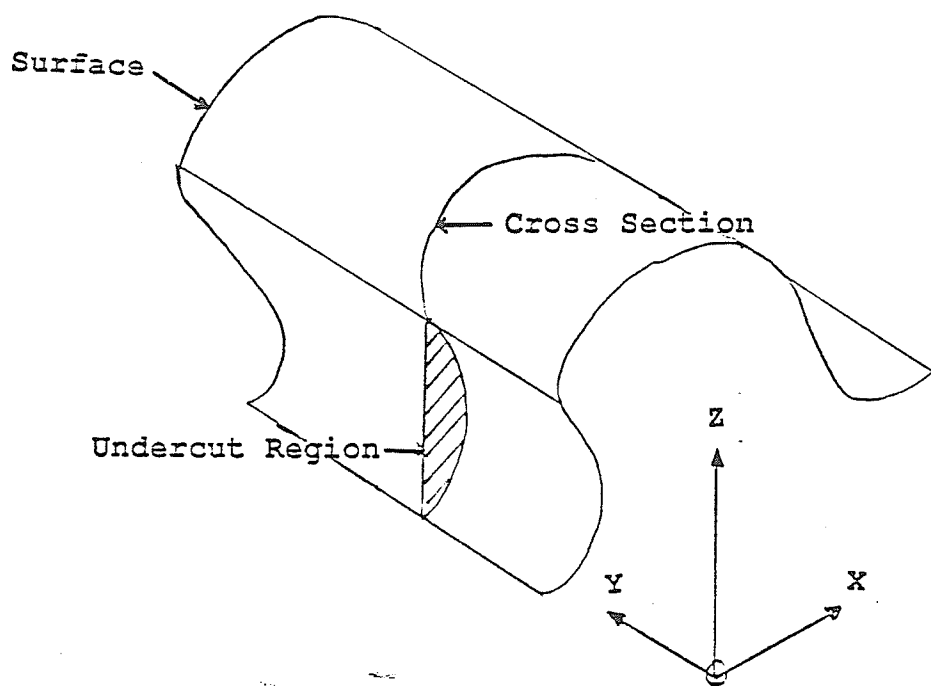
Fig. 18 - Undercut surface

2.1 Introduction

A method of obtaining three dimensional surface points was required for the proposed manufacturing system. The basic requirements of the surface measurement system were specified as follows:

1. Provide an accuracy to within one quarter of an inch of the true position of the surface. (A quarter of an inch tolerance is acceptable, because of natural body shape variations and consequent varied repeatability of the subject's body surface during successive fittings and repeated measurements.)

2. Equipment selected should be commercially available.

3. The system developed must be able to edit the obtained surface data, store the data in a usable format and visually present the surface data on a computer monitor.

4. Ergonomics must be considered in the design of the surface measurement system work station and procedures.

5. The cost of the surface measurement system must be less than ten thousand dollars.

The following section is a literature search covering three dimensional digitizing techniques. A survey is then presented of commercially available surface measurement

equipment and the measurement technique selected. The final section outlines the measurement system developed.

2.2 <u>LITERATURE SEARCH</u>

<u>THREE DIMENSIONAL DIGITIZING TECHNIQUES</u>

A literature search was performed to compile information on different methods of three-dimensional digitizing. The techniques covered are:

1. Ultrasonic Methods
2. Magnetic Field Technology
3. Coordinate Measuring Machines
4. Moire Contourography
5. Laser Techniques

Let us describe the basic measuring theory of the various methods. More detailed explanations can be found in the sources referred-to in each section.

2.2.1 <u>Ultrasonic Methods</u>

Ultrasonic techniques use principles based on the known characteristics of sound. If some source produces a sound wave, a return echo will be registered at a sensor after the sound wave has been reflected back from an object. Knowing the velocity of sound waves, the distance can be found from the pulse-echo elapsed time produced in a ultrasonic measuring system. The basic principle is shown in figure [19].
The distance D can be found through a function dependent on

26

DISTANCE D

SOURCE   SENSOR

SURFACE

ELAPSED TIME T
VELOCITY V

$$D = F(V,T)$$
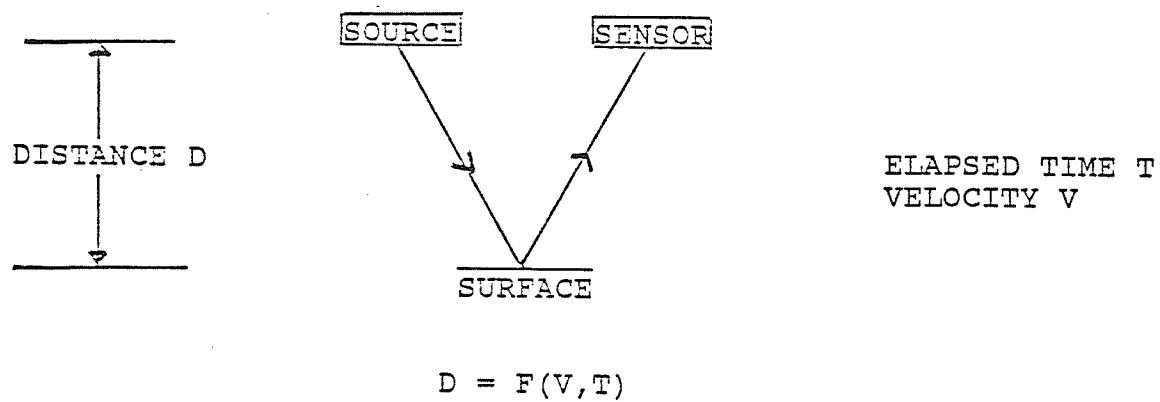
Fig. 19 - Ultrasonic Measuring Principle

the ultrasonic device being used, a known constant velocity V and a calculated elapsed time T.

The basic ultrasonic system has been applied in several areas. One present research area addresses depth perception for robot systems in factories. Another application studied is the measurement of fluid levels in oil tanks. This is presently being done by a commercially available ultrasonic ranging unit. The unit can determine perpendicular distance within a range of .9 feet to 35 feet with an accuracy of 1.2 inches [12].

The basic ultrasonic principle in the above examples is designed for one dimensional measurement, but can be applied to three-dimensional measurement as well. This is shown in figure [20]. An ultrasonic source emit ultrasonic impulses at its tip. At precisely the same moment four clocks are activated and each stops when the sound wave reaches its corresponding sensor. The four resulting time measurements are then converted to X,Y,Z Cartesian coordinates by a computer. More detailed information on ultrasonic methods can be found in references [12] and [13].
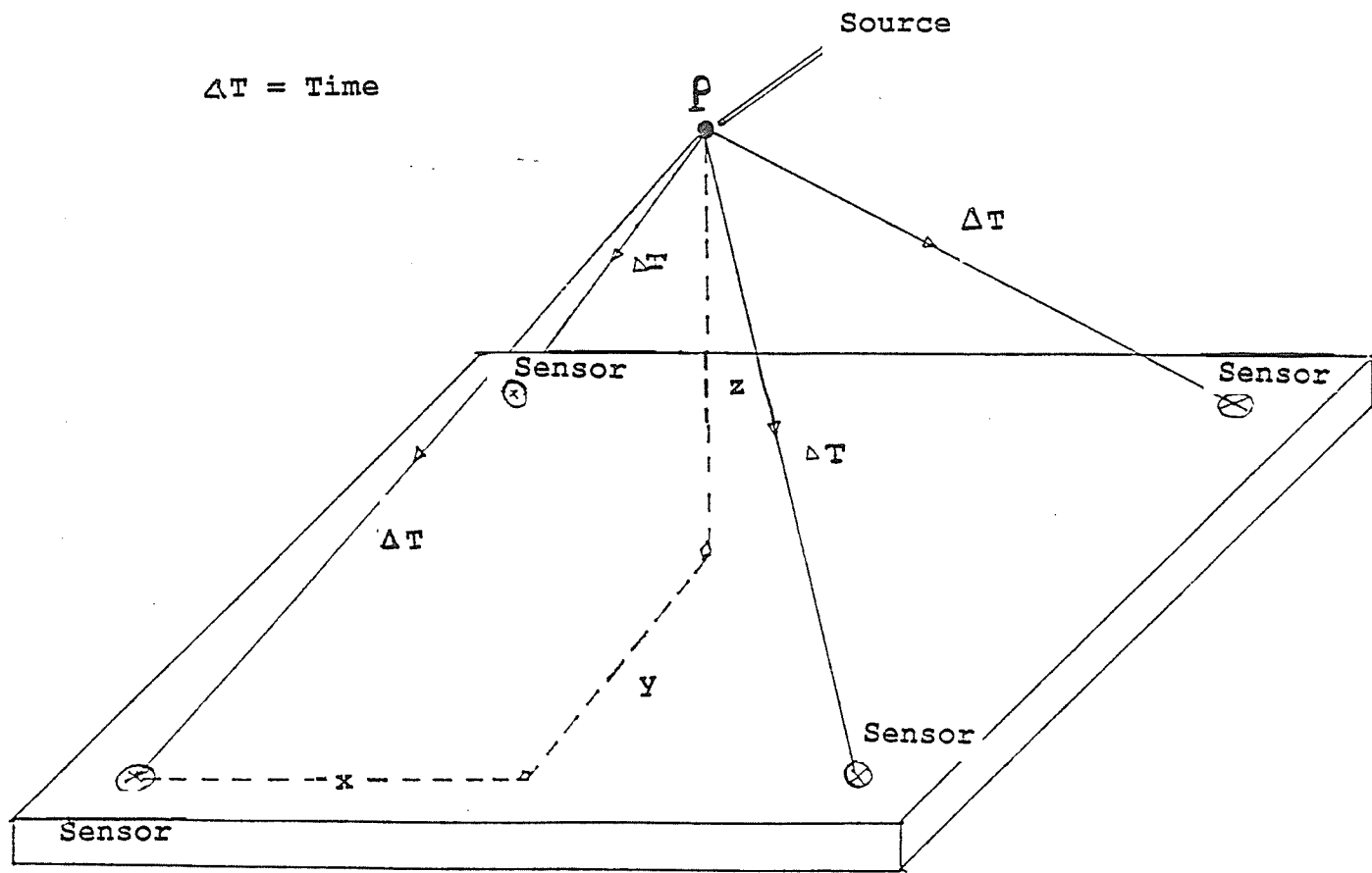
Fig. 20 - Ultrasonic 3D Digitizing System

2.2.2 Magnetic Field Technology

In digitizing systems using magnetic field technology a low frequency magnetic field is produced by a source. A sensor senses this magnetic field and the potential difference between the sensor and the source is proportional to its distance from the source.

For this principle to work in digitizing three-dimensional surfaces a modification is needed. A source containing three small sources is used with a sensor containing three small sensors. Each sensor is only influenced by its matching source. This is accomplished by orienting the sensors in different planes and by the use of electronic circuitry which allow only one magnetic field to influence the sensors output. The X,Y,Z positions are calculated internally in the Magnetic Field Digitizer by a dedicated microprocessor. A basic three-dimensional digitizer using magnetic field technology is shown in figure [21].

McDonnell Douglas Corp. developed this technology over the last ten years. Its first use was in the control of the gun sights of military aircraft by placing the sensors in the pilot's helmet. The pilot, by turning his head towards a target, would orient the gun towards the target as well. Recent applications of this digitizing technique include three dimensional echocardiography being researched at the Medical

30
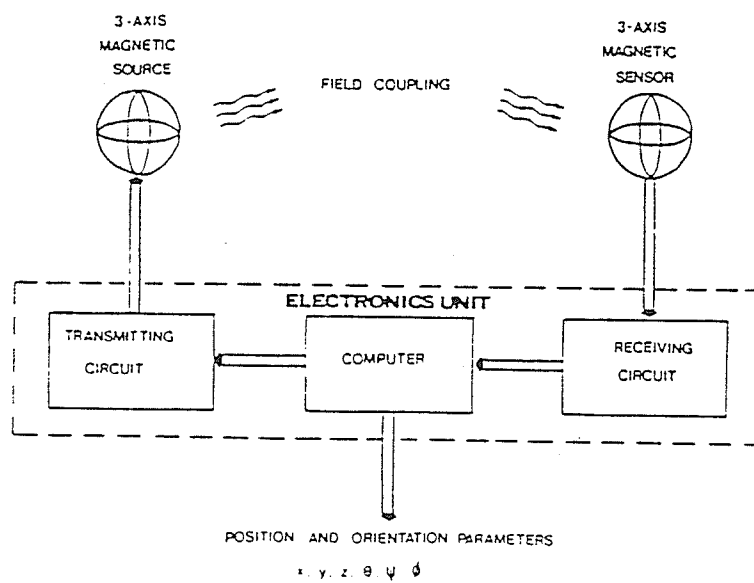
Fig. 21 - Magnetic Field Digitizer   Ref. [14]

Center Hospital of Vermont [15]. Another application is the three dimensional wrist imaging being developed by the Washington University School of Medicine [16].

2.2.3 Coordinate Measuring Machines

A coordinate measuring machine is a contact type of digitizing equipment used to determine the position of a point on a object. A probe mounted on the coordinate measuring machine makes contact with the surface of the object being digitized. Coordinate measuring machines are used primarily in areas where high accuracies are needed. Brown and Sharpe [17] offer the "Validator", a horizontal coordinate measuring machine. The machine can digitize and inspect surface characteristics to tolerances of .0004 inches.

A coordinate measuring machine is best suited as an inspection device. A coordinate measuring machine being used at Ford's European plants can now check sixty five dimensions in only three minutes. Previously, this took four hours using height gages and other manual techniques [18].

2.2.4 Moire Contourography

Moire Contourography was first developed in Japan by Takaski [19], Terada [20], and others as a medical technique for the tracing of changes in body shape following surgical

32

operations. This technique was first applied to engineering surfaces by Theocaris [21] in 1969 in strain analysis and Duncan [22] in 1973 for the measurement of three dimensional surfaces.

The Moire principle is quite straight forward. A basic Moire equipment setup consists of a light source, a camera, a grating and the object to be measured. The equipment is shown in figure [22]. As shown in figure [23], the grating shadow falls on the surface of the object and the object is viewed through the same grating. The grating and its shadow interfere to generate a Moire fringe contour pattern as illustrated in figure [24]. By suitable mathematical analysis a depth value can be found. This derivation is detailed in reference [24]. In recent years with the advance of vision systems, there has been much work in the area of 3-D machine vision using Moire techniques. The speed of dimensional analysis can be greatly speeded up with the use of vision systems. References [26] and [27] describe this development in detail. Moire techniques are being used extensively in Canada [28]; at the recent Symposium on Surface Topography and Spinal Deformity held in Lac Ste Marie Quebec, seven out of nine papers presented on surface measurement involved Moire techniques [28].
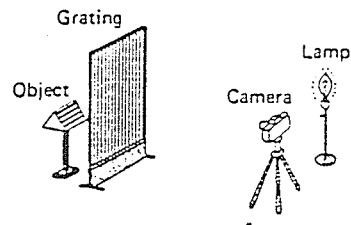
Fig. 22 - Moire Principle   Ref. [23]
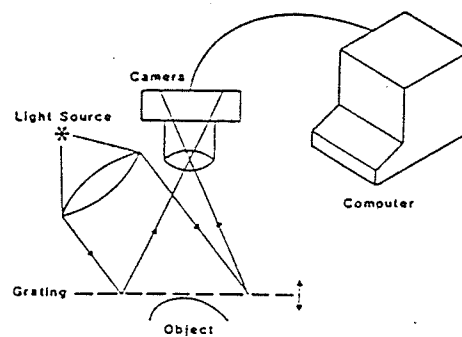
Fig. 23 - Moire Operation   Ref. [25]
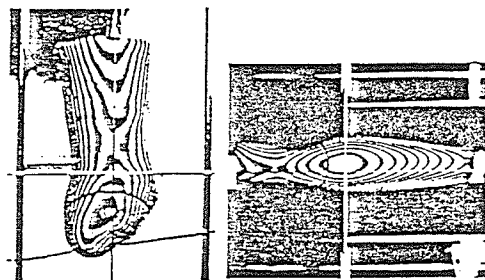
Fig. 24 - Moire Fringe Contours   Ref. [23]

2.2.5 Laser Techniques

The use of laser techniques for the measurement of three-dimensional objects has been developed extensively in the last decade. Laser triangulation considering reflectance angles of a light beam produced by a laser are used to calculate height. General Motors at its Orion Assembly Center, has developed a sophisticated laser based system using 126 lasers to perform 100 percent on-line measurement of four different auto-body styles [29]. Laser Triangulation is highly accurate with tolerances of .002 cm being reported [30]. Other three dimensional digitizing techniques using lasers involve the use of vision systems. Using laser triangulation a small point of laser light is directed at an object and a camera mounted at a 45 degree angle to the source detects the reflected light. Because the camera is at an angle to the laser, two dimensional coordinates can be obtained. A large number of these points can be assembled to provide a three dimensional map of the object's surface.

Another approach using laser triangulation employs what is called structured light [31]. It directs a thin line of laser light (rather than a point) at the object to be digitized as illustrated in figure [25]. The systems camera views the object at a 45 degree angle from the laser line, and detects a two dimensional contour of the object as illustrated

35
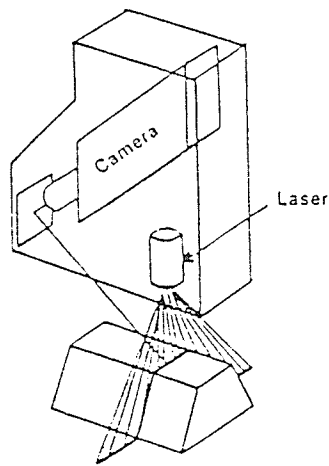
Fig. 25 - Basic Laser System   Ref. [31]
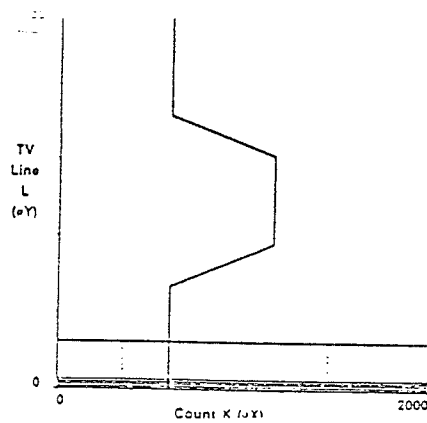
Fig. 26 - Camera View   Ref. [31]
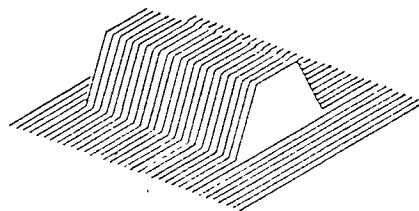
Fig. 27 - Contours Produced   Ref. [31]

36

in figure [26]. The resulting three-dimensional image is made up of closely spaced two dimensional contours (figure [27]). This method (using a larger number of laser points) is faster than triangulation methods using a single laser point. Development in this area was first done by the Weyerhauser Company [31]. The recent availability of gallium arsenide lasers and miniature TV cameras has allowed the development of small systems based on these principles. Applied Scanning Technology markets a system employing this technology. It includes a camera, laser, and electronics contained in a 6.1 by 2.5 inch package weighing 3.5 lbs. [31]. Developments such as this make laser techniques a potentially useful form of three dimensional digitizing.

2.3 Survey of Commercially Available

Surface Measurement Equipment

A survey of commercially available digitizing systems was carried out. Results of the survey follow. A letter was sent to fifty manufacturers of digitizing equipment. The letter asked these companies to send information on products capable of performing three dimensional digitizing. As of February 1987 four potential systems had been identified. More systems may be available but were not found in this survey. Coordinate measuring machines have been left out of the survey

because of the high cost.

The four available digitizing systems are available from American companies. The prices quoted are in Canadian dollars.

The Applied Scanning Technology's "VLS-200" 3-D Vision System is capable of digitizing 14,400 three dimensional data points per second. It can digitize objects moving in its field of vision up to 40 in/sec. The accuracy of the system is one thousandth of an inch per inch of field width. The cost of this digitizing system is very high, a basic system including computer is $100,000. This equipment is presently being used by a number of companies including 3M, Ford Motor Co. and Weyerhauser.

Polhemus Navigation Sciences, a division of Mcdonnell Douglas Corp. manufactures two digitizing systems. These systems work on the principle of magnetic fields. The accuracy of the "3Space Isotrak" unit is one quarter of an inch. The more expensive "3Space Tracker" has an accuracy of one tenth of an inch. The costs of these systems are $5,000.00 and $20,000.00 respectively. Both these systems are capable of digitizing at a rate of sixty samples per second. The units can be connected to any computer having an RS-232 connector. These systems are currently being used by companies such as Bell Labs, Chevron and Lucasfilm Ltd. A

limitation of this system is that no metallic objects may be located near the digitizing system.

The final digitizing system surveyed is manufactured by Science Accessories Corporation. The product is called the "3-D Sonic Digitizer". The system works on the principle of sound waves. The unit can be connected to any computer having a RS-232 connector. Current users of this equipment are the United States military and some Research Hospitals. The cost of the system is $20,000.00.

The Mcdonnell Douglas product "3Space Isotrak" was selected as the digitizing system to be used for the surface measure requirement. It is the only system falling within the budget proposed. The accuracy of the system is also within required tolerances.

2.4 Surface Measurement System Development

The Polhemus 3Space Isotrak digitizing system utilizes low-frequency magnetic fields to determine the position and orientation of a sensor in relation to a magnetic field source. This information can be transmitted to a host computer over a RS232 serial line. The Isotrak unit consists of a Systems Electronics Unit (S.E.U.), one source and one sensor. The S.E.U. consists of analog circuitry to generate and sense the magnetic fields and to digitize the sensor

analog signal. A CPU controls the analog circuitry and performs all necessary computations. The source generates the low - frequency magnetic fields measured by the sensor. The sensor measures the low - frequency magnetic fields generated by the source. Figure [28] illustrates the Polhemus 3Space Isotrak unit.

The digitizing work station developed by us is illustrated in figure [29]. The digitizer source is mounted underneath a wooden surface. The wooden surface is the digitizing table and is the X-Y measuring plane. Because of the effects of metal objects on the performance of the 3Space Isotrak unit all metal objects are located outside a radius of four feet of the digitizing system source. The only metal object contained inside the four foot radius is the "mouse" controller. The small amount of metal contained in the mouse should have minimal effect on the performance of the digitizing system. A PC type microcomputer is located at right angles to the digitizing table. A video monitor is located at an angle which enables its viewing while an operator is using the digitizing system or microcomputer. The digitizing table is located in a location that is easily reached by an operator in a sitting position. This work station design employs standard ergonomic considerations to minimize operator fatigue.
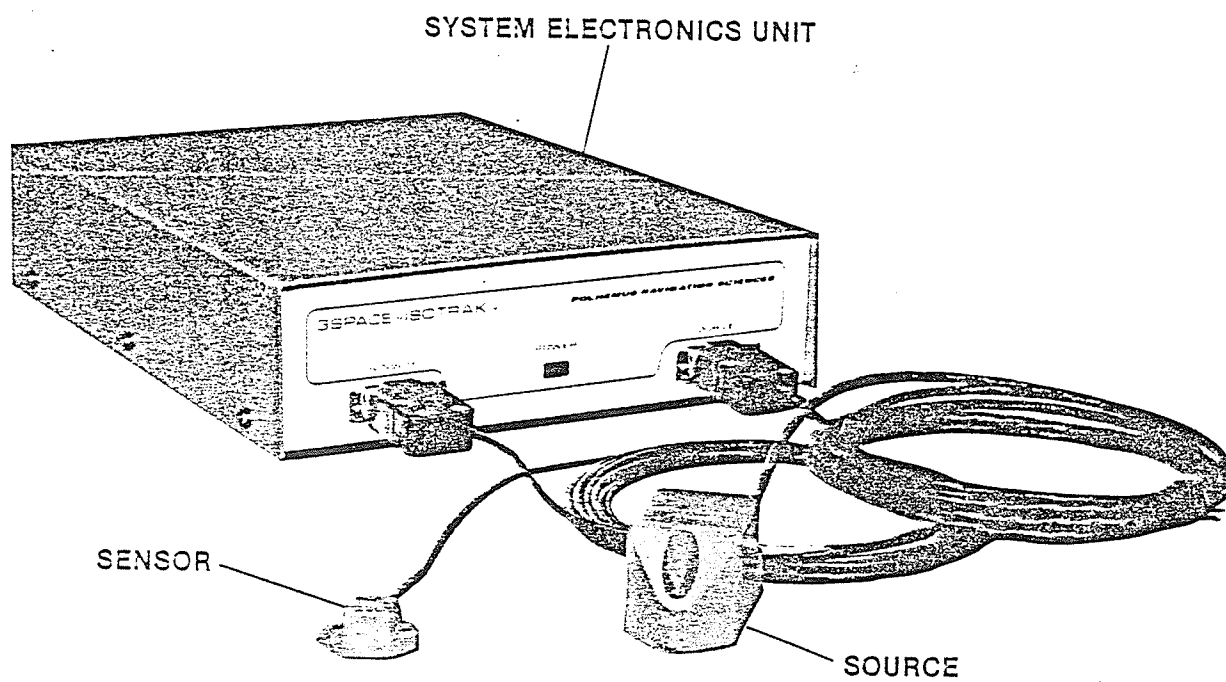
Fig. 28 - Polhemus 3Space Isotrak Unit   Ref. [14]
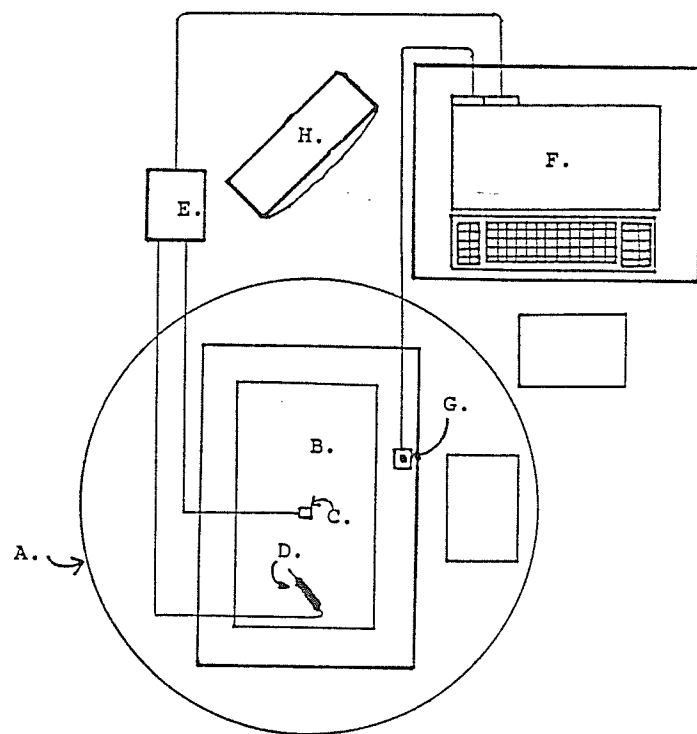
A. Four foot radius
B. Digitizing Work Volume
C. Source
D. Sensor
E. Digitizing Unit
F. Micro-computer
G. Mouse Controller
H. Video Monitor

Fig. 29 - Digitizing Work Station

Objects which are to be digitized are placed on the digitizing table directly above the source. The accuracy of the digitizer decreases with increasing distance between the sensor and source, therefore for best results the centroid of the object in the X-Y plane should pass through the Z axis of the source.

2.5 Surface Measurement Software Development

A computer program was developed by the author for the collection of three dimensional surface points from the 3Space Isotrak unit. The program is written in Fortran with assembler code for the communication between a PC based microcomputer and the 3Space Isotrak unit over a RS232 serial port. An operator can define the digitizing limits required, enter digitized points and delete digitized points. To speed up the entering of data points and deleting of data points we encourage the use of the "mouse". Surface points can be entered in a random order. If points are entered which fall outside the digitizing limits they are not recorded. The program listing is contained in Appendix A.

2.6 Accuracy Testing of the 3Space Isotrak Unit

The positional resolution accuracy of the Polhemus 3Space Isotrak digitizer is stated to be .13 inches for a source-to-sensor separation of 4 to 15 inches [14]. From 15 to 30 inches the position accuracy degrades linearly to .25 inches at 30 inches [14]. A 9" by 16" matrix of surface points was digitized for three planes of varying heights above the surface of the digitizing table. A localized origin was set for each plane. The grid is spaced with one inch increments of X and Y. The Z axis is held constant. This is shown in figure [30]. The heights of the planes selected was 2 inches, 14 inches and 22 inches above the surface of the digitizing table. The different heights represent the possible typical regions that may be required for digitizing surfaces. The vector distance of the origin of the three planes to the source is 25 inches, 28 inches and 33 inches respectively. Two tests were ran for each height. The results of the tests are contained in Appendix B. The accuracy of the digitizer was within specifications for the survey done 2 inches above the digitizing table. For the survey performed at a height of 14 inches above the digitizing surface seven points were outside the stated specifications. The points were out of specification by a maximum of .06 inches. The tests performed at 22 inches above the digitizing had twenty two points with

44
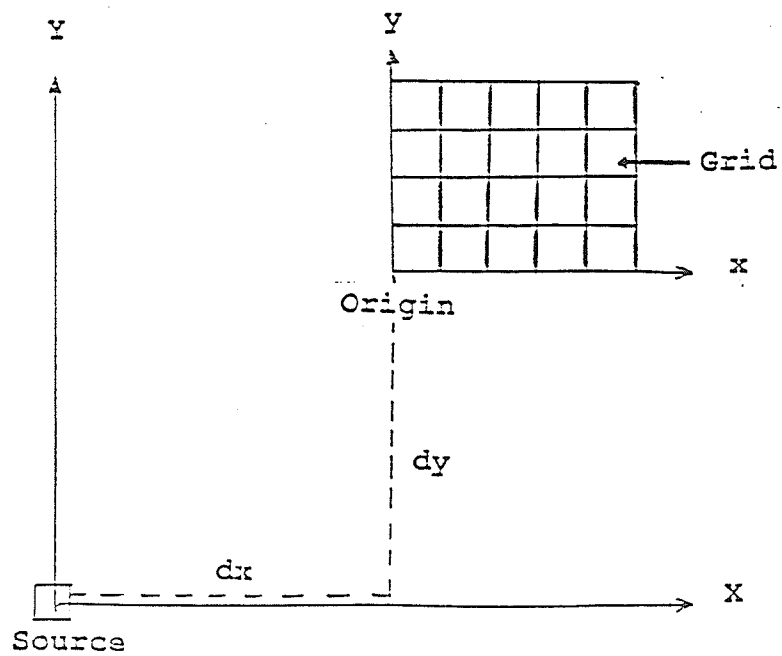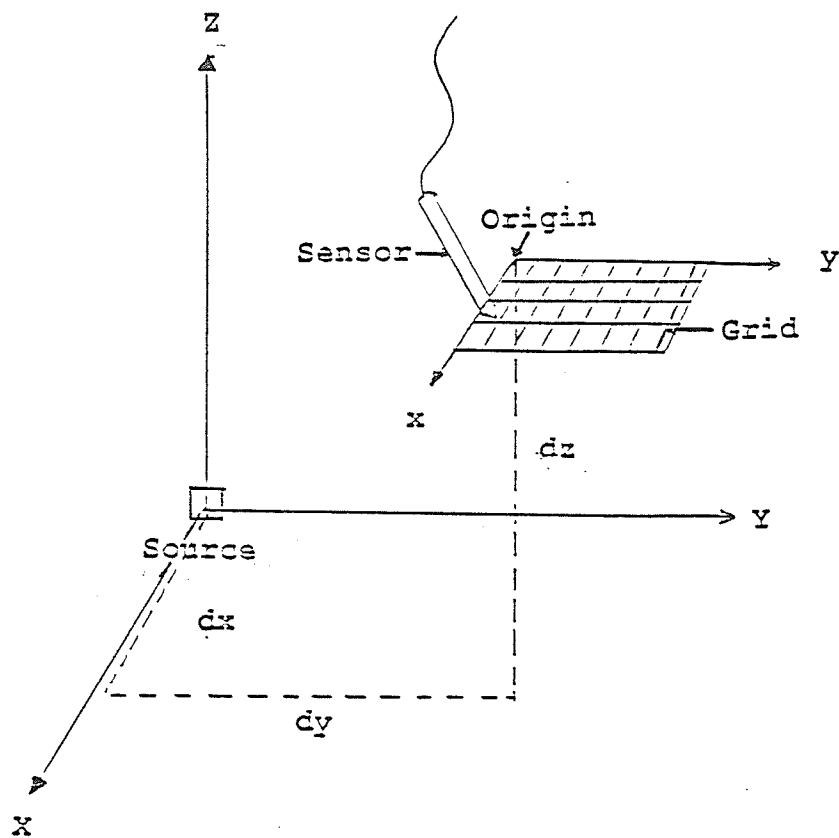
Fig. 30 - 3Space Isotrak Accuracy Test

a position error greater than .25 inches. The points were out of specification a maximum of .11 inches. Considering the results of these tests the digitizer is within the stated accuracies for distances less than 30 inches for source to sensor separation. The accuracy of the digitizer is higher the closer the surface being digitized is to the source.

CHAPTER III   SURFACE MODELLING/TOOL PATH GENERATION

3.1   Introduction

The surfaces typically encountered in Engineering and Medicine may be classified either as "designed" or "natural". A designed surface may be described easily by a known continuous function. These functions can describe points on the surface. An example of a designed surface is the straight side of a computer. Surfaces which are described as natural, such as a human back can not be described as easily. There are an infinite number of independent surfaces which make up a natural surface and thus to describe the surface, points on the surface itself must be measured. These measured surfaces points can then be used to approximate the actual surface. The greater the number of measured surface points the better the natural surface can be described. The Polhemus 3Space digitizer provides three dimensional data points that can be used by surface modelling software. The surface generated by means of the surface modelling software can then be used to generate a tool path file by appropriate Tool Path generation software. The tool path file is then used in the actual mold production machine.

3.2 Surface Modelling

The basic requirements of surface modelling for the proposed manufacturing system are:

1.   A surface must be generated from a file of random x,y,z data points.

2.   The data input must be compatible with data from the digitizer program.

3.   The software should be micro-computer based. (ie: the surface can be modeled within the capabilities of a micro-computer)

4.   The cost of the software should be minimal and commercially available.

Considering the outlined requirements for surface modelling a literature search was performed of commercially available surface modelling packages. The software packages researched were "Surfer" by Golden Software [32], "Graftool" by 3-D Visions [33] and "Truepers" by the Department of Energy, Mines and Resources, Canada [34]. All three software packages met the requirements outlined. The "Truepers" software was selected because of its additional modules which allowed for tool path generation.

"Truepers" is a general surface fitting program used to fit random 3 dimensional data points to a gridded surface of constant increments of X and Y. Points specified randomly

over an X-Y grid are use to extrapolate Z values at nodes of a rectangular X,Y grid. Local interpolation by iteration, using the equation of an elliptical paraboloid and a fourth order differential equation with stiffness "K", a user selectable value, are used to calculate surface-point heights at nodes in the X-Y plane [34]. A smooth surface passes through these interpolates and the original data points. More information on "Truepers" can be found in the reference "Sculptured Surfaces in Engineering and Medicine", Duncan J.P and Mair, S. G., Cambridge, 1983.

To visualize the surface produced by the "Truepers" output, "Plot3d" is used to plot a perspective view, with hidden line removal of the "Truepers" output. The program uses a ray tracing method to determine the visibility of each point. The "Plot3d" program is contained in the Polyhedral NC system which is discussed below.

3.3 Tool Path Generation

The basic requirements of Tool Path generation software for the proposed manufacturing system are:

1. Compatible with data generated from surface modelling software.

2. Micro-computer based.

49

3. Ability to generate a toolpath file that closely follows the modeled surface.

4. Toolpath files generated to be compatible with standard N/C machines.

A literature search was performed of commercially available tool path generation programs. From the survey it was found that the majority of toolpath generation programs powerful enough to meet the outlined requirements ran on engineering workstations or mainframe computers. The only package surveyed that met the outlined requirements including the ability to run on a micro-computer was the Polyhedral NC package by J.P. Duncan [35]. This package was just being introduced to the micro-computer market. It had been running in the past on I.B.M. mainframe computers. Included with the Polyhedral NC package was the "Truepers" surface modelling software.

The Polyhedral NC method was developed by J.P. Duncan at the University of British Columbia in the years 1969-76. With the gridded data from the "Truepers" software, Cutter Location Data (CLD) can be obtained through the use of the Polyhedral NC program "Supersue". The Supersue program is a machining program based on the passage of a spherically-ended tool (ball end mill) passing over a geometrically rectangular grid. The Cutter Location Data (CLD) can then be used to run an N/C

controlled machine. The main feature of the Supersue program
is that no spacial surface node is within the volume of the
spherically ended tool which passes over the surface (i.e. no
interference). At every node Supersue will check all
neighboring nodes under the projected area of the tool. If
any of the neighboring nodes is inside the volume of the tool,
interference would occur. The tool is lifted sufficiently
such that interference is minimised or "avoided". The process
is repeated for all nodes. The program monitors each node and
records the difference in height between what was actually
machined and the actual surface. Smaller tool bits result in
less smaller error but more machining time is required for a
given surface. The Polyhedral NC method works only on single
valued surfaces i.e. surfaces without overhang or undercut.

3.4   Test of the Polyhedral NC Software

To test out the potential of the surface modelling/tool
path generation software a surface was selected to be
digitized, modeled and machined using the Polyhedral NC
technique. The surface selected was the plaster cast of the
trunk surface of a small boy. The trunk surface is shown in
figure [31]. The surface was first digitized with the Isotrak
3Space digitizer. Surface data was obtained randomly
approximately for every quarter inch of the surface. This

51
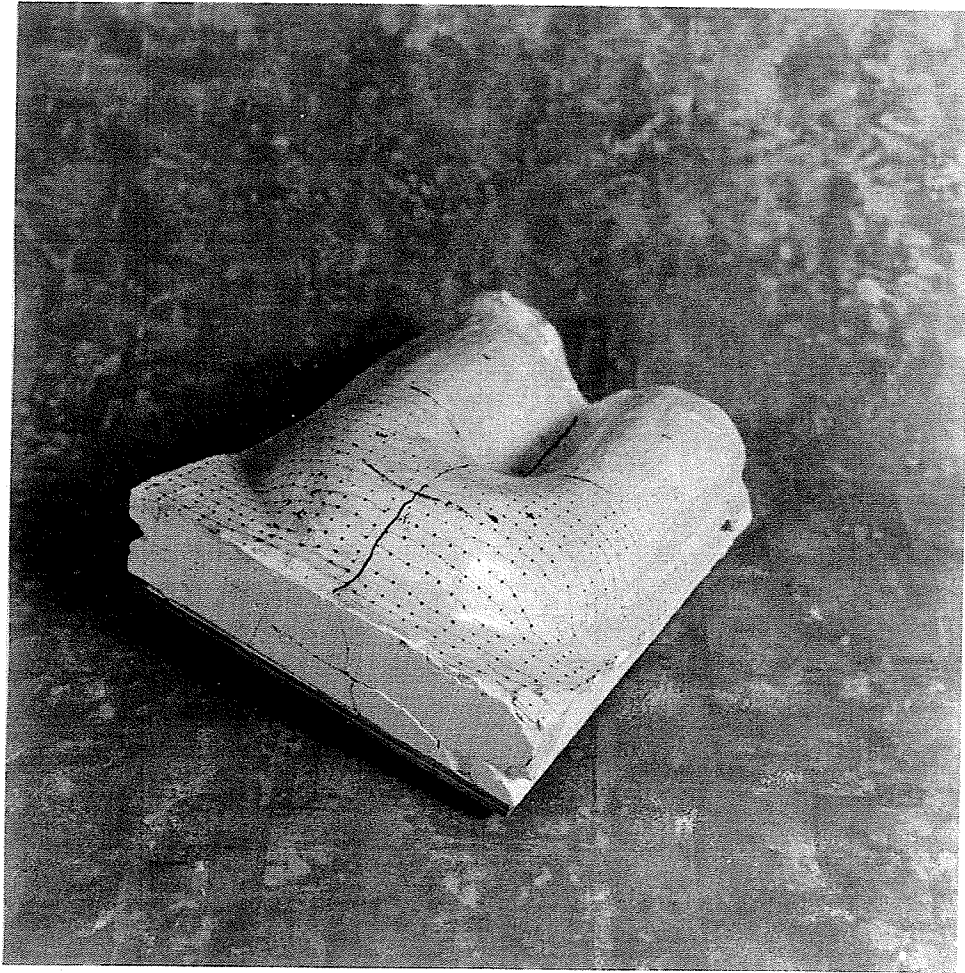
Fig. 31 - Cast of Trunk Surface

information was recorded on disk and sent by courier to Dr.
J. P. Duncan at the University of Victoria. Pictures were
also taken of the surface and sent to Dr. Duncan. Dr. Duncan
ran the data points through the Truepers program. The surface
generated through the Truepers software closely matched the
actual trunk surface. A plot of the Truepers output is shown
in figure [32]. To test the Polyhedral NC Supersue software
a visit to the University of Victoria was arranged for the
author and an Otto Bock representative. This visit occurred
in early April 1987. Cutter Location Data was generated by
the Supersue package. The trunk surface was then carved on
a three axis milling machine at the University of Victoria.
Figure [33] shows the surface that was machined on the milling
machine. The milled surface closely matched the plaster cast
surface.   This test demonstrated that the Polyhedral NC
package met the requirements of surface modelling and tool
path generation. It also showed the potential of the 3Space
digitizer as a potential measuring system. More testing is
needed to check the digitizer and Polyhedral NC software for
other casts.

cast2a
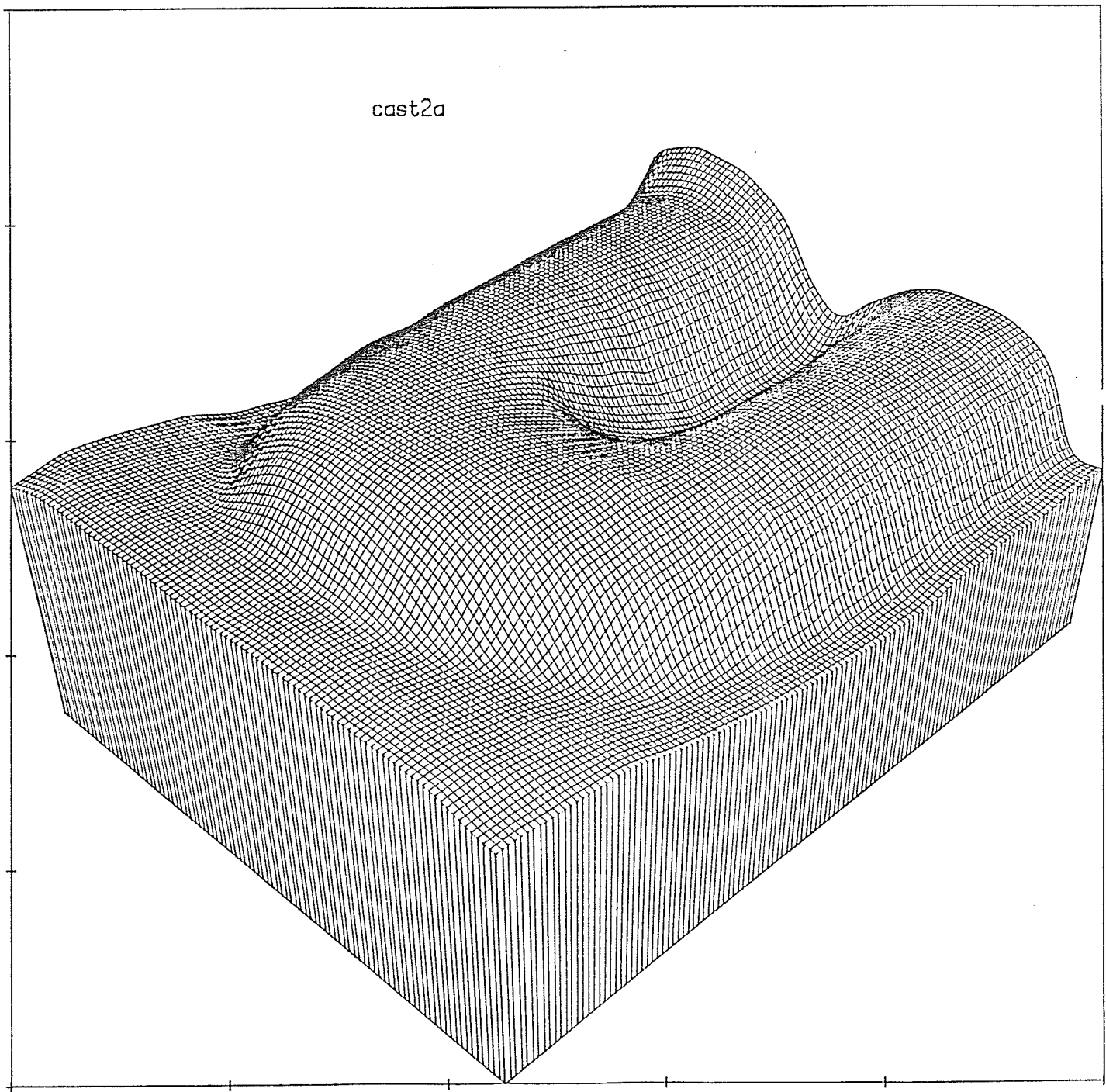
Fig. 32 - "Truepers" Plot of Trunk Surface
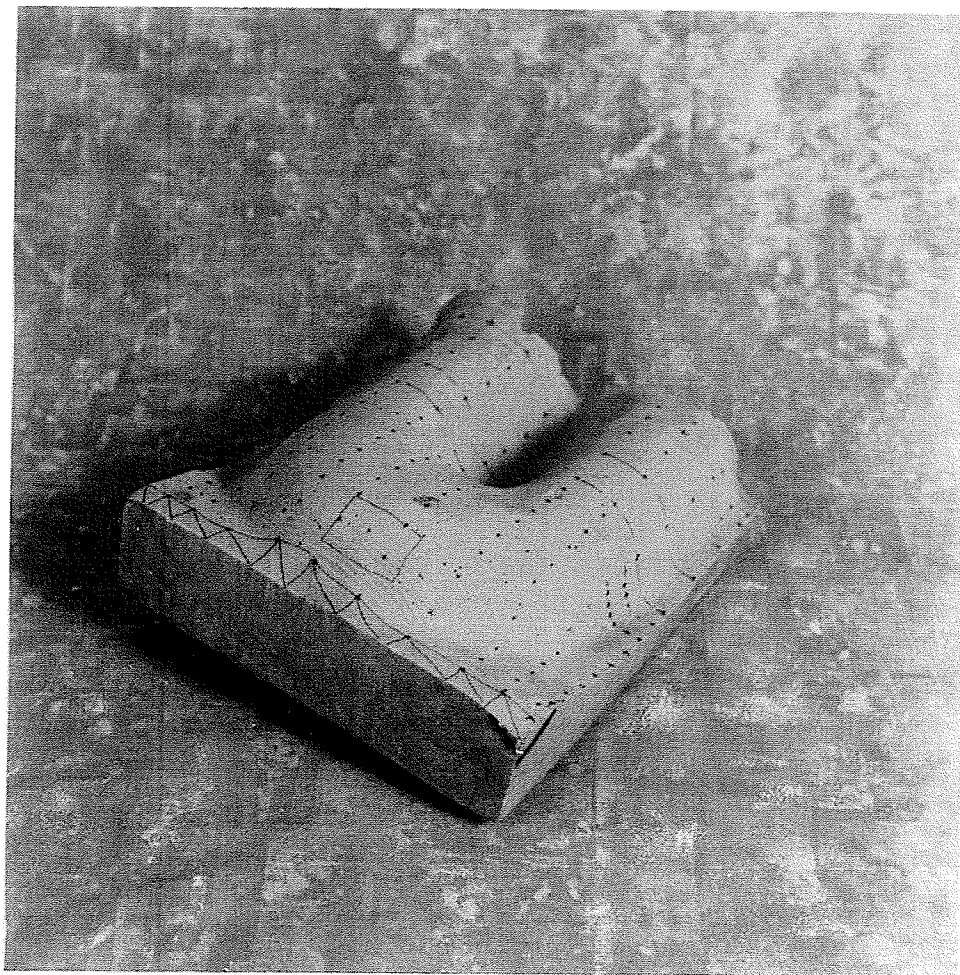
Fig. 33 - Trunk Surface Reproduced

4.1   Introduction

The milling machine used in the test of the Truepers and Supersue software packages at the University of Victoria was, at over $100,000., relatively expensive and beyond our budget. In addition a micro-computer was required for the down loading of tool path files. For the proposed manufacturing system to be a cost effective solution, a less expensive method was required for the manufacture of the foam molds.   For this reason it was decided that a Three Axis Router would be built by ourselves to meet the surface reproduction requirement. The basic requirements set out for this Three Axis Router are:

1.   Motion control of three axes with linear interpolation of two axis simultaneously.

2.   Communication with a micro-computer.

3.   Sufficient machine rigidity to prevent excessive vibration when the workpieces are being carved. (The required rigidity is less than a standard milling machine because the material that will be used in the mold manufacture is a foam material and is easy to cut, unlike metal or wood which would require a machine of much higher rigidity).

4. Have sufficient travels in the X,Y,Z directions to enable the majority of foreseen molds to be milled out in one setup.

5. Use commercially available products when possible.

6. Provide sufficient accuracy.

4.2 Three Axis Router Development

The three axis router allows for the manufacture of foam molds from a tool path file generated through the Polyhedral NC Supersue software package. A router head moves across the surface of the mold moving up and down following the contour of the surface generated through the Truepers software package. The author designed, assembled and assisted in the manufacture of the three axis router. The months of May and June were used for its design, while its constructions covered the period form July to September 1987. All components used in the design were specified and ordered by the end of June. The components that could not be ordered were manufactured over the period of July and August 1987. The ordered components and manufactured components were assembled in the first two weeks of September 1987. The router was first tested in the third week of September 1987. This time period coincided with a visit of the upper management of the parent company from West Germany.

The three axis router specifications are contained in Appendix C. The three axis router was modeled after a 'Gantry' style milling machine. A 'Gantry' style milling machine (figure [34]) has the work piece moving on a X table underneath a cutting head which runs on a Y-Z gantry. The Gantry style was selected because it would allow for the smallest machine to be manufactured for the given X,Y,Z travel requirements. Figure [35]-[38] illustrates the three axis router. Outlined below are the main features of the three axis router.

4.2.1 X Axis

The X axis is the movement of the work clamping table along the base of the three axis router. The table is mounted on recirculating ball bushings which run on hardened linear ways mounted on a blanchard ground steel base plate. This base plate is mounted to the machine base. The work clamping table is driven by a ball screw mounted underneath the table. The ball screw is driven by a brushless AC servo motor/resolver powered by a servo amplifier. The movement has end of travel limit switches and a home switch.
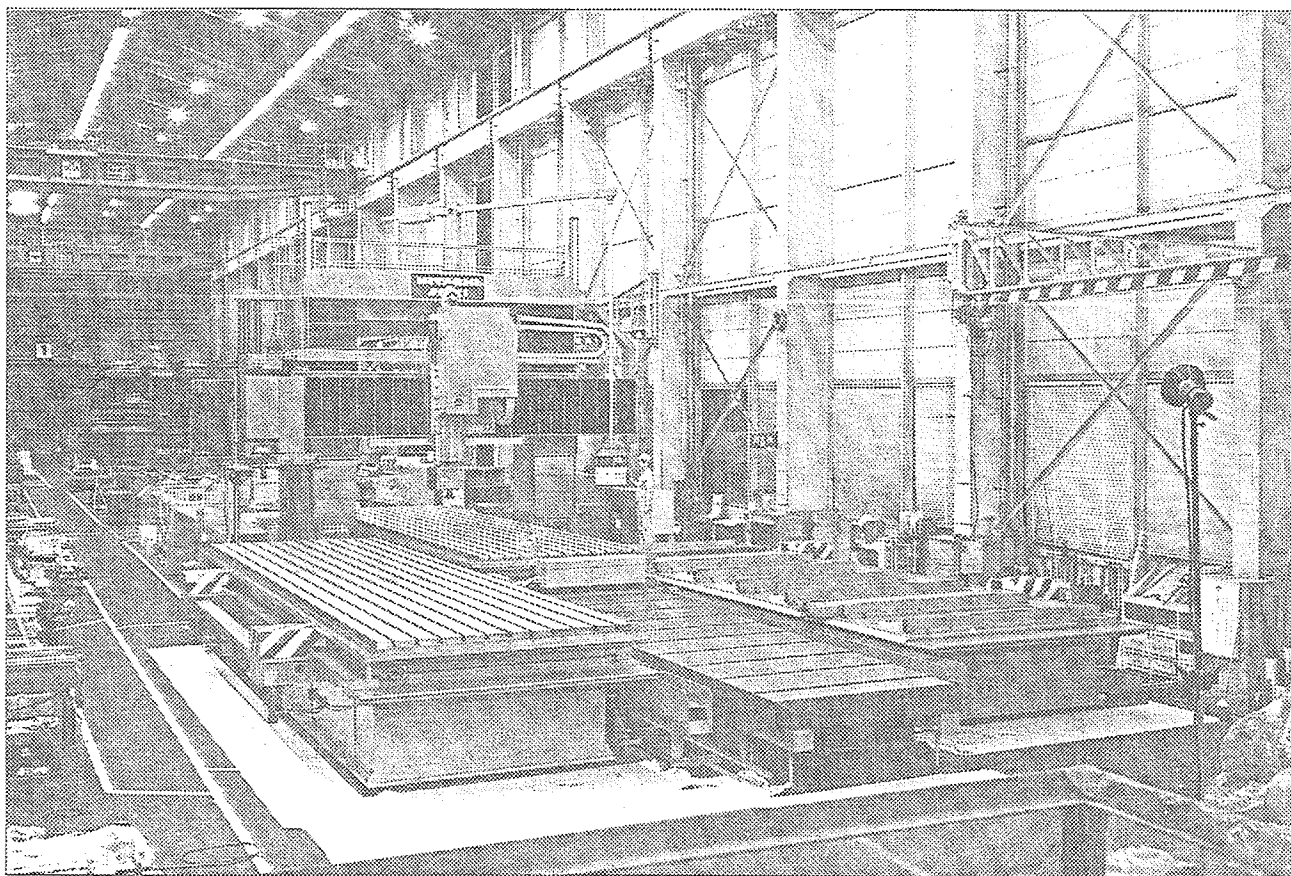
Large-size 5-Surface Gantry Type Machining Center, Model VE 32, Courtesy of Hitachi Seiki Co., Ltd.

Fig. 34 — 'Gantry' Style Milling Machine   Ref. [39]

Z Axis

Y Axis

Spindle Motor

Side Frame

X Axis

Base Structure
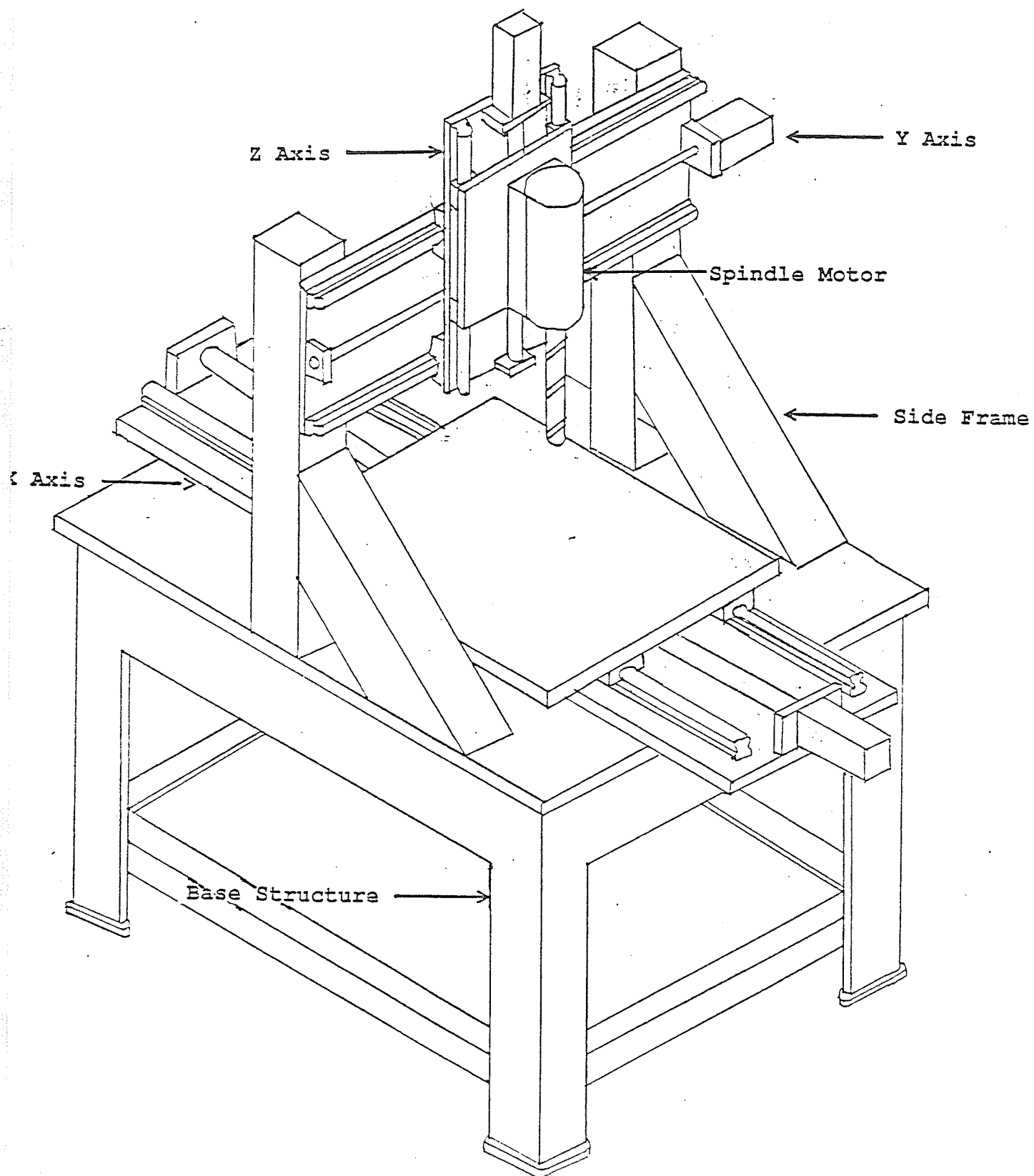
Fig. 35 - Three Axis Router Components
(as built for Otto Bock Ltd.)

60
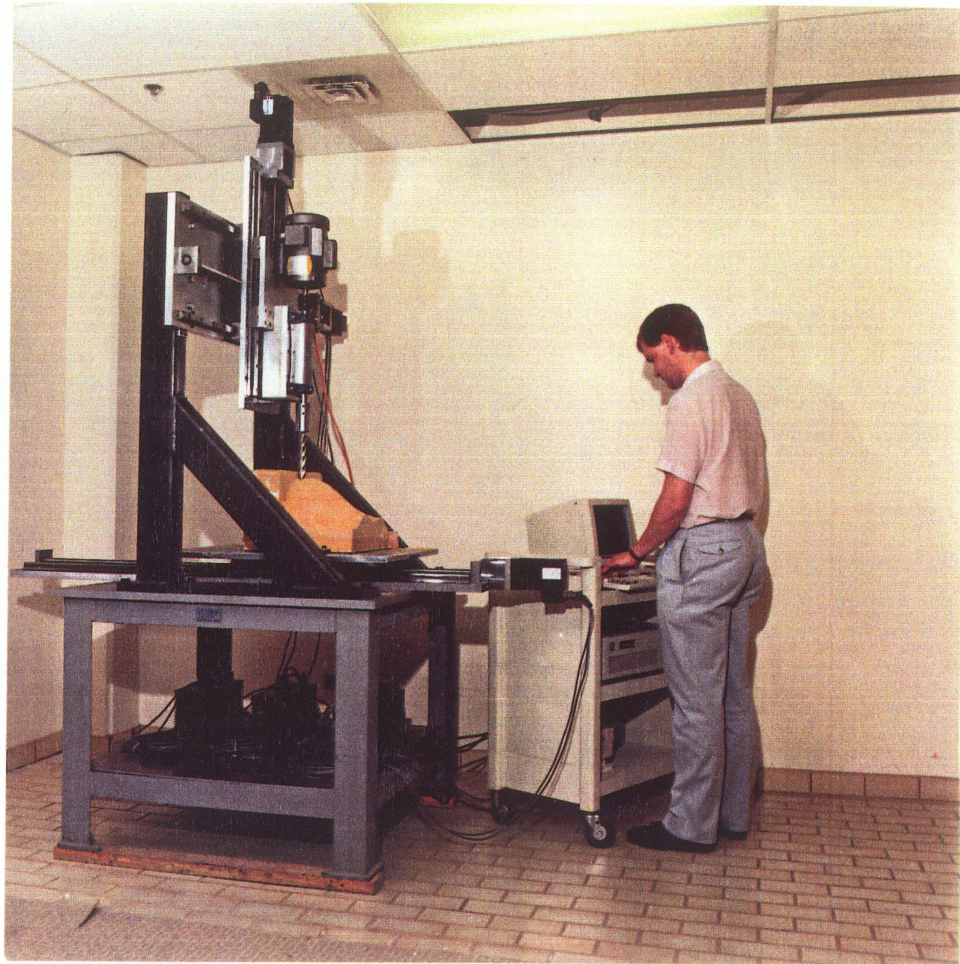
Fig. 36 - Author Operating Three Axis Router
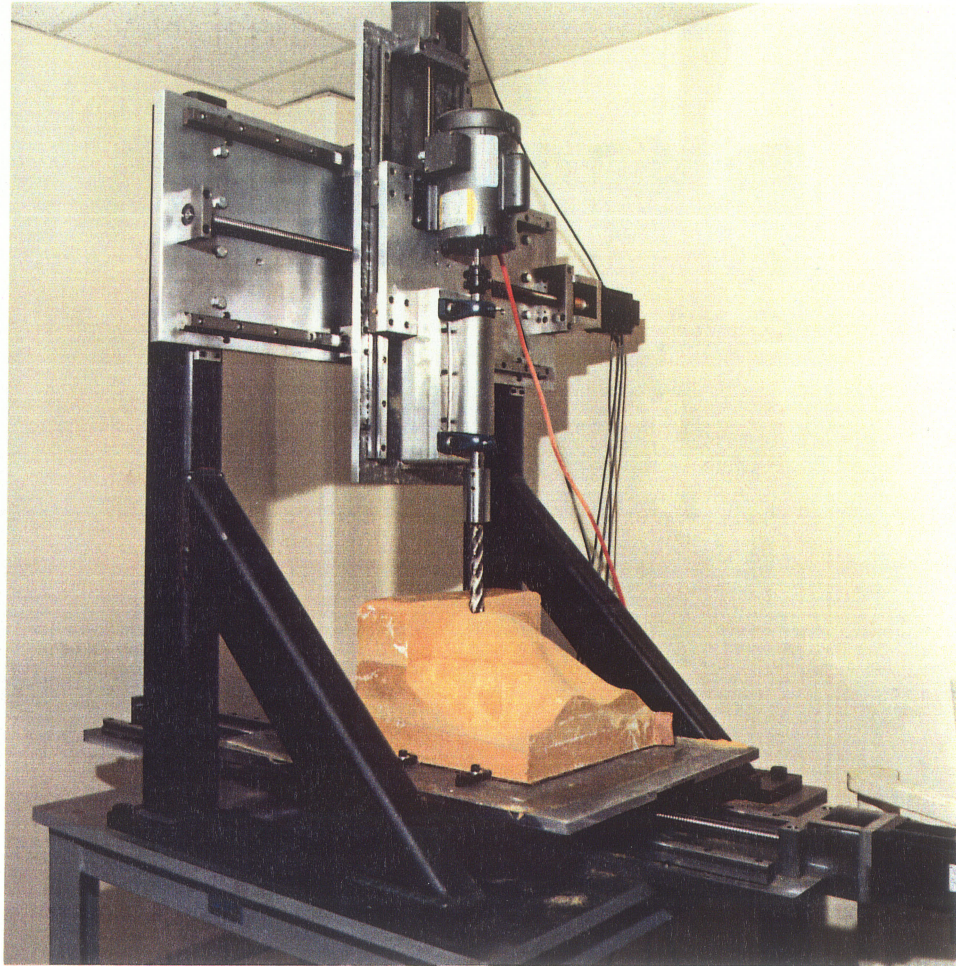
Fig. 37 - Foam Piece Mounted in Router
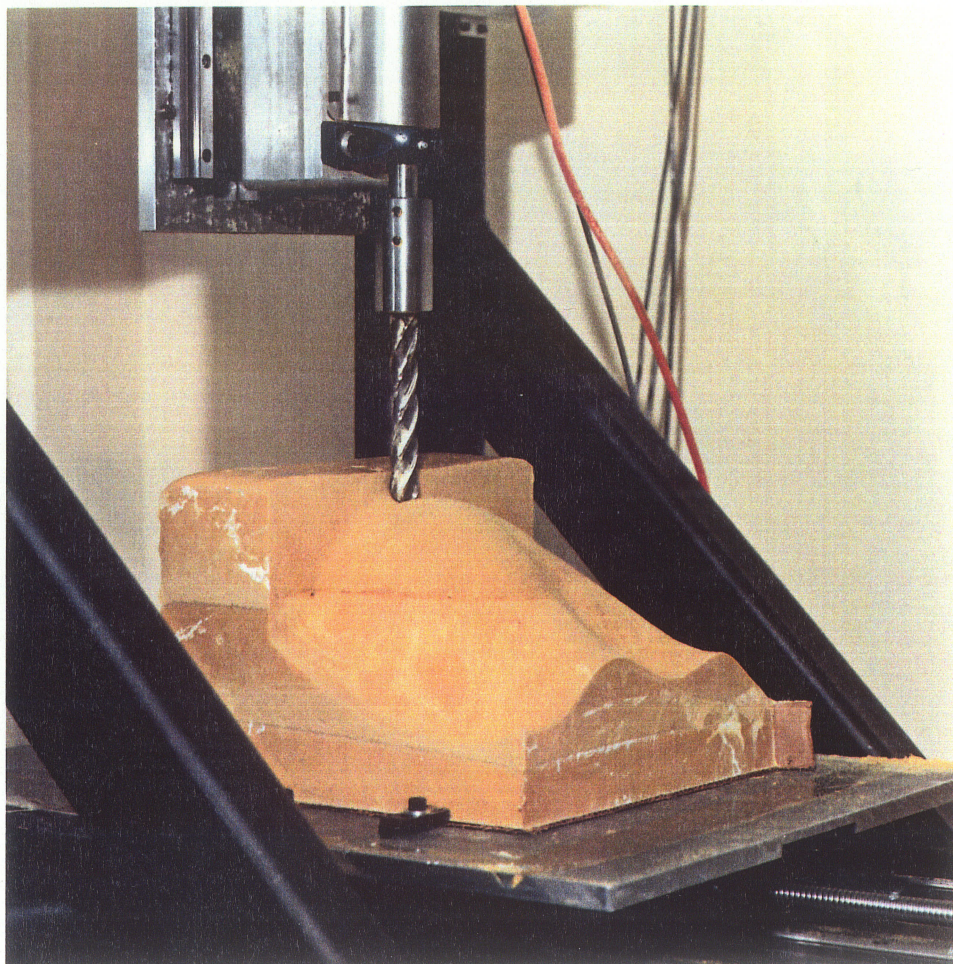
Fig. 38 - Foam Piece Being Carved

4.2.2 Y Axis

The Y axis is the movement of the carriage, carrying the Z axis and router head assembly along the top of the gantry. The Y axis carriage table is mounted on recirculating ball bushings which run on hardened linear ways mounted on an aluminum plate. The aluminum plate is mounted to the side frames. The carriage is driven by a recirculating ball screw mounted underneath the carriage. The ball screw is driven by a brushless AC servo/motor system powered by a servo amplifier. The movement has end of travel limit switches and a home switch.

4.2.3 Z Axis

The Z axis is the vertical movement of the routing head. An aluminum carriage carries a constant speed spindle motor with a holding device for a routing tool. The carriage is mounted on recirculating ball bushings which run on linear ways mounted on the Y axis carriage. The movement is achieved through a ball screw mounted underneath the carriage and driven by a brushless AC servo motor/resolver system powered by a servo amplifier. The movement has end of travel limit switches and a home switch.

4.2.4 Machine Structure

The machine base structure is a welded structural steel

frame with a 3/4" blanchard ground table top. Bolt holes are located in the table top for the mounting of the X axis assembly and the side frames. The side frames are hollow structural steel tubing welded together and secured with bolts to the machine base structure. The Y axis and Z axis are manufactured from aluminum plate material. The work clamping table is manufactured from aluminum plate with provision for the securing of the foam work pieces.

4.2.5 Control System

The three axis router is controlled by a Compumotor PC23 indexer board mounted in an AT style computer. The PC23 indexer board is a microprocessor based three axis controller. It occupies four addresses on the I/O bus which do not conflict with other devices in the PC such as disk drives, serial card or graphics adaptors. The PC23 can control three axes of motor/drives that accept pulse and direction input. The PC23 uses a sixteen bit processor to control the three motor axes. Acceleration, velocity and position commands are passed over the PC bus to the indexer board. Additional functions allow for the monitoring of limit switches, home switches and trigger inputs. The PC23 indexer is connected to the three motor/drives through an optically isolated adaptor box. The adaptor box is powered by a separate 5 Volt

power supply. The limit switches, home switches and motor/drives are connected to the adaptor box. The Compumotor PC23 operation manual [36] details the specification and operation of the PC23 indexer board.

The motor/drive system for each axis consists of a brushless servo motor, brushless resolver feedback and a microprocessor based closed loop drive amplifier. The motor/drive system accept step and direction inputs from the indexer. The microprocessor in the drive unit monitors the pulse input from the indexer and compares it to the resolver feedback. The microprocessor subtracts the actual position of the motor to calculate the positional error. The positional error is put into an equation with the previous positional errors and commands to the amplifier to calculate the current levels to drive the motor. The resolver position is read every 512 microseconds. The high sampling rate allows for a control system with a very fast response. This fast response provides very accurate positional and velocity control of the servo motor. The Compumotor KS-Series operation manual [37] details the specifications and operation of the motor/drive system. Figure [39] outlines the three axis router motion control system.
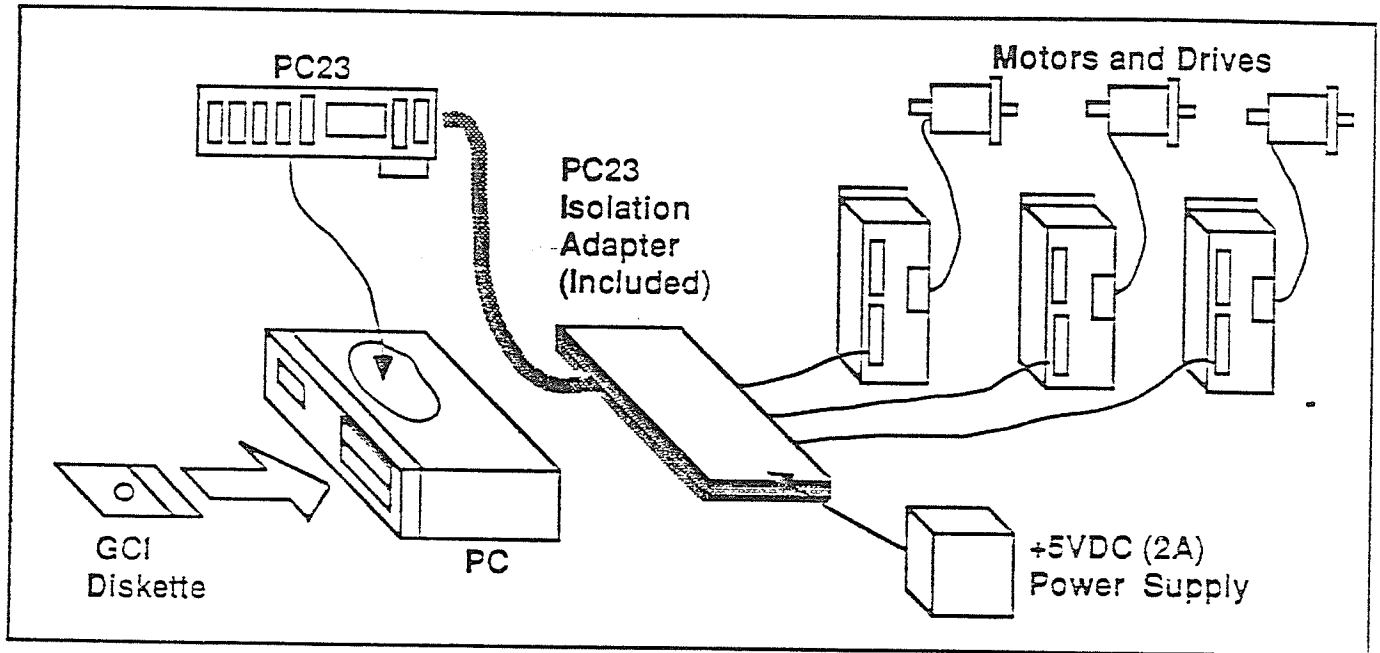
Fig. 39 - Router Control System, Ref. [38]

4.2.6 <u>Three Axis Router Software Development</u>

As stated earlier the PC23 occupies four addresses in the PC's I/O bus. Two of these addresses are not used as they are duplicates of the others. PC23 motion control commands and responses are transferred via the Input Data Buffer (I.D.B.) and the Output Data Buffer (O.D.B.) at the PC23 base address. Control commands and status information are passed by the Control Byte (C.B.) and the Status Byte (S.B.) one address above the base address of the PC23. The Output Data Buffer (O.D.B.) and the Status Byte (S.B.) are read only registers. The Input Data Buffer (I.D.B.) and Control Byte (C.B.) are write only registers. The PC23 indexer commands are strings of ASCII characters which are passed to and read from the PC23 indexer one character at a time by an application program. The 'C' programming language was selected for the development of the Three Axis Router Software. The 'C' language was selected because of the many functions with I/O and string handling capabilities. Two programs were developed by the author for the control of the Three Axis Router.

The first program is a preprocessor which allows for the conversion of tool path files created through the Supersue software package to commands which are compatible with the PC23 indexer. The source code of the "Convrt" program is

contained in Appendix A. The program used to operate the Three Axis Router is called "Pcontour". It allows for the command strings created by the "Convrt" preprocessor program to be downloaded to the PC23 indexer. Appendix A contains the source code of the "Pcontour" program.

5.1   Introduction

Five plaster casts were selected to be used for the testing of the prototype system. The casts were digitized; a surface was generated from the digitized data and a tool path was generated to carve the resulting molds on our Three Axis Router.   The plaster casts selected for the testing of the system were typical of plaster casts produced through the manual manufacturing technique.   Figures [1-15] of Appendix D shows the plaster casts, the "Plot3d" output of the surfaces produced from the "Truepers" program and the casts produced by the Three Axis Router.   The times required for digitizing, surface modelling and mold manufacture are recorded in Table 1 - Proposed System Test Summary.

5.2   Digitizing

The plaster casts surfaces were digitized randomly with a spacing of 1/4 inch between points.   The times recorded for digitizing ranged from 30 minutes to 45 minutes.   The times recorded for digitizing are basically a function of the surface area that must be digitized.   The cast "brear" required the longest time period for digitizing; it was also the surface which covered the largest surface area.

70

5.3 Surface Modelling

The digitized surface data was input into the "Truepers" surface fitting program. Very good results were obtained by first generating a surface using a half inch grid spacing and then inputting this resulting surface data into a second pass of "Truepers" using a quarter inch grid spacing. The times required for surface modelling ranged from 29 minutes to 40 minutes, consistent with increases in cast size. The cast "brear" required the longest time for surface modelling. Surface modelling was performed on an Intel 80386 chip based computer.

5.4 Tool Path Generation

The output of the "Truepers" program was used as input into the "Supersue" tool path generation program. A 6.00", long, .750" diameter ball end mill was selected for the machining of the mold surfaces. The "Convrt" program was used to convert the cutter location data generated through the "Supersue" program to a format readable by the PC23 indexer contained in the Three Axis Router. The time required to generate the toolpath files is contained within the mold machining time of Table 1 - Proposed System Test Summary.

5.5 Mold Manufacture

The casts were machined from a rigid foam material commonly used by Otto Bock. The properties of the rigid foam are similar to the properties of wood. Areas which required a greater than six inch depth of cut were roughed out manually with the Three Axis Router. The "Pcontour" program was used for the carving of the molds from data which was generated by the "Convrt" program. The feedrate of the Three Axis Router was set at approximately 12 inches/minute in the X-Y plane. This feedrate is well below the capability of the Three Axis Router, but was selected for the testing of the system.

5.6 Discussion of Prototype System Testing

The molds manufactured by using our prototype system were very close to the casts that were digitized. One characteristic common to all the molds manufactured by our prototype system was the surface waviness in areas of high slope. Areas of the molds which with little slope change were smooth. The waviness of the molds surfaces was not noticeable until the actual mold was produced. It was difficult to notice the occurrence of the waviness from the "Plot3d" program output. A possible cause for the waviness or resulting surface inaccuracies in areas of high slope are the

limitations of the "Truepers" surface fitting program. The "Truepers" program generates a single valued surface $Z(X,Y)$ defined over a rectangular grid in X and Y. In these areas of high slope a large surface area is being defined by relatively few data points. A different surface fitting technique would probably give better results. One possible technique would be to fit splines through digitized points on a desired surface and then fit a spline surface through the data points. This technique is shown in figures [40]-[41].

The times recorded for digitizing, surface modelling/tool path generation were satisfactory. The times recorded for the manufacture of the molds on the Three Axis Router was relatively long. As shown in Table 2 the times for mold manufacture and roughing ranged from 80 minutes to 175 minutes. However while the Three Axis Router is carving out the mold surface, no person is required to monitor the operation. A person is required however for manually roughing out the areas of greater than six inches of depth of cut. It should be noted however that the Three Axis Router was not running at the maximum potential feed rate during these tests.

5.7 <u>Comparison of the Manual System to the Proposed System</u>

Comparing the manual system to the proposed system there are some obvious time savings to consider in favour of the
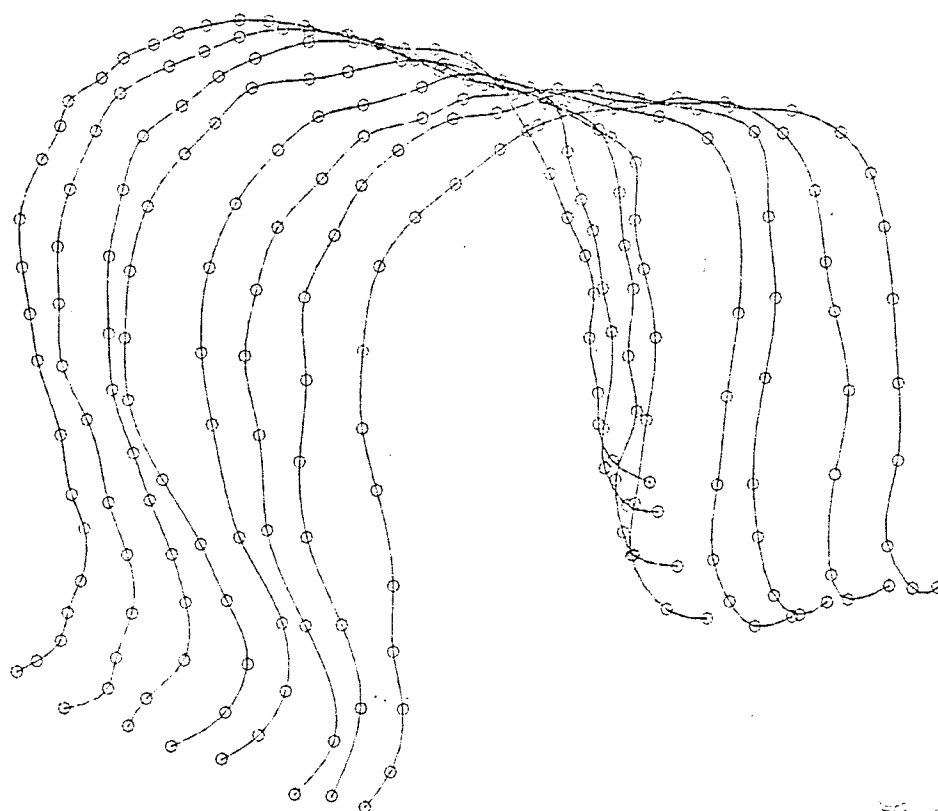
Fig. 40 - Splines of Digitized Data
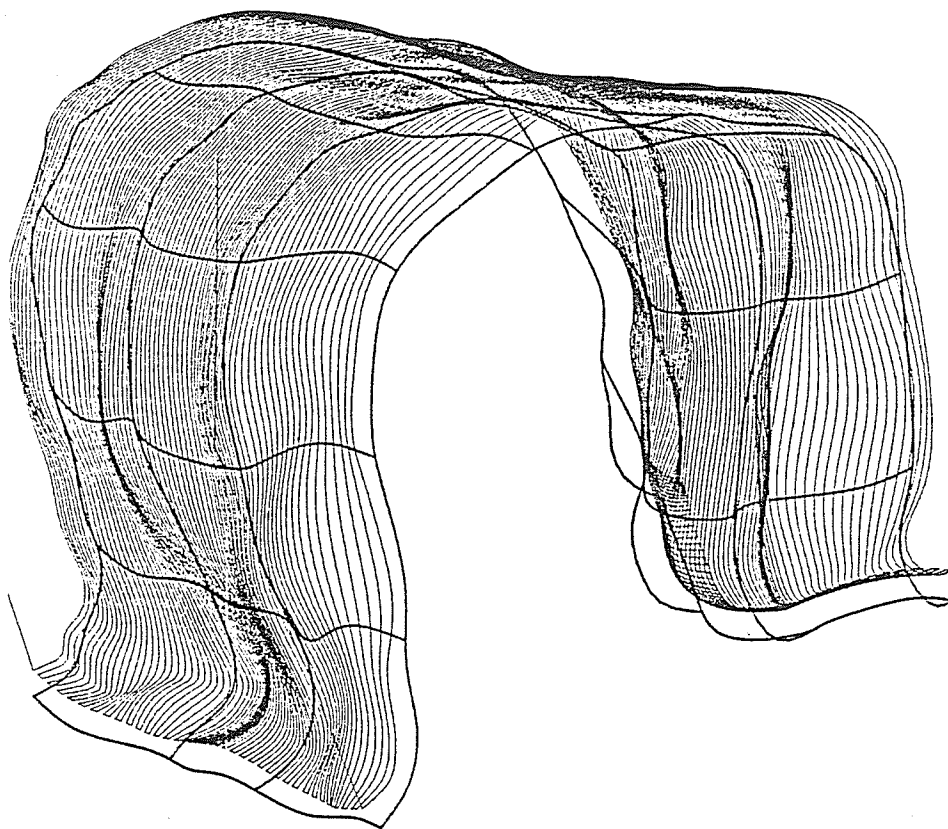
Fig. 41 - Spline Surface Fit to Spline Data

proposed system. The fitting operation and cushion manufacture are the same time estimates for both systems. The fitting operation is estimated at one hour and the cushion manufacture is two hours for the production of two cushions used in a seating system.

The cast/mold production for the manual system is based on the total estimated (16 hours) production time of a complete seating system minus the fitting and cushion manufacture times. The cast/mold production times of our proposed system are based on the sum of the total times contained in Table 1 for the casts "lisab" and "lisar" which are the trunk and back casts of a seating system. Table 2 compares the production times for the manual and proposed system. The cast/mold production time for the proposed system is approximately half the time estimated for the manual system. This is a very significant time saving. Considering that the Three Axis Router is producing the actual mold, there is a very significant labour saving in that the machine may run unattended. In this example the actual direct labour for producing a seating system would be approximately 6.5 hours after subtracting the mold machining time on the Three Axis Router. The total cost of cushions can therefore be reduced

Table 1

Propose System Test-Summary

Cast	back	brear	lisab	lisar	rear
Cast Length (x in.)	15.50	20.00	20.00	14.75	15.75
Cast Width (y in.)	13.75	17.00	15.00	14.75	15.75
Num. Points	1012	1754	1051	571	963
Digitizing (min.)	30	45	30	30	30
Surface Modelling (min.)	29	40	30	30	30
Machine Set Up	15	15	15	15	15
Mold Roughing (min.)	30	60	30	30	0
Mold Machining (min.)	77	115	110	80	80
TOTAL Prod. Time (min.)	(181)	(275)	(225)	(185)	(155)

Table 2

Comparison of Manual System to Proposed System

	Manual Technique	Proposed Technique
Fitting Operation (hr.)	1	1
Digitizing Operation (hr.)	0	1
Cast/Mold Production (hr.)	13	5.75
Cushion Manufacture (hr.)	2	2
Total Production time (hr.)	16	9.75

Table 3

Manual Technique-Cost Breakdown

Therapist Labour	14 Hrs. @ 70.00/hr	980.00
Material		20.00
Shipping (for casts and cushions)		100.00
Production of Cushions (O.B.O. Central Fab.)		<u>500.00</u>
	Total ---->$1600.00	

Table 4

Proposed Technique-Cost Breakdown

Therapist Labour	2 Hrs. @ 70.00/hr	140.00
Material		20.00
Shipping (for cushions)		50.00
Data Transmission of Digitized Data		20.00
O.B.O Central Fab. Direct Labour (1)		75.00
Machine Cost (2)		80.00
Production of Cushions (O.B.O. Central Fab.)		<u>500.00</u>
	Total ---->$ 885.00	

(1) Direct Labour = (Surface Modelling + Router Setup + Mold
                    Roughing) X Shop Rate

    Direct Labour = 2.5 hrs. X $30.00/hr

(2) Machine Cost = <u>(Router + Computer + Software Cost)</u>
                   (Life of Machine X Num. Systems/year)

    Machine Cost = $60,000.00/(5 yrs. X 150 systems/yr.)

78

Table 5   Comparison of Technique Cycle Time

Manual Technique

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Fitting Operation							
Cast/Mold Production							
Ship to OBO. Central Fab.							
Cushion Manufacture							
Ship Cushion to Therapist							

Proposed Technique

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Fitting Operation							
Digitizing Operation							
Data Transmission							
Cast/Mold Production							
Cushion Manufacture							
Ship to Therapist							

79

significantly as it shown in Tables 3 and 4. The cost of

cushions produced manually would be $1600.00, this includes

$500.00 for the cost of Otto Bock Central Fab. to produce the

cushions from the casts supplied. This price is based on the

current prices quoted by therapists in the Winnipeg area as

outlined in Table 3. The estimated cost of the cushions

produced by the proposed system is $885.00 as shown in Table

4. This estimated cost is approximately 55% the cost of a

system produced by the manual technique. Table 5 compares the

cycle time between the two manufacturing techniques. The

proposed technique is approximately 1/2 the time required to

deliver a system using the manual technique. The main time

saving is that no plaster cast need be transported to the Otto

Bock Central Fabrication facility. The obvious advantages of

not sending a plaster cast are reduced cycle time, the

prevention of cast loss and damage . The cost saving and

reduced cycle time shown by the proposed system clearly

demonstrates the potential of the proposed system.

The manufacturing system developed in this thesis offers the promise of a lower cost seating system. The cycle time of the proposed system is approximately 1/2 that of the manual technique. Our alternative system offers the promise of being easier to use than the present manufacturing technique. The cost of a completed seating system using the proposed technique is approximately 55% of the cost of a system using the manual technique. Overall, with a lower cost seating system more people could have access to the product, which would raise their quality of life.

The system developed in this thesis does have its limitations. Presently only a single valued surfaces (i.e. no undercuts) have been digitized, modelled and carved. Only a small number of plaster casts have been tested; the use of the fitting chair with the three dimensional digitizer has not been tested. These limitations must be overcome before the system could be used as an alternative to the present manufacturing technique.   Listed on the following page are a number of recommendations outlining future work that should occur:

<u>Digitizing</u>- The 3 dimensional digitizer should be tested with the fitting chair. Micro-computer based software should be developed for the digitizing of undercut surfaces, with features which allow for surface viewing from a user defined angle with the ability for surface modification.

<u>Tool Path Generation</u>- Tool path generation software packages and techniques should be investigated for the machining of undercut surfaces.

<u>Surface Reproduction</u>- Software should be developed for the automatic roughing for the removal of material greater than six inches in depth. The A possibility of adding a fourth axis to the router should be investigated for the machining of undercut surfaces.

Otto Bock Orthopedic Industry of Canada considers the thesis work to be of great value. More work based on the thesis is to occur in the future. One of the very satisfactory results of this thesis is that it has shown the potential of university/industry cooperation. The result have proven useful to the sponsoring company -by the development of a promising new production method with additional technology transfer spin-offs to other corporate areas; to

82

the University -by developing its expertise and visibility in this advanced technology area, and to the Msc. student who learned a great deal and in fact was later hired by the sponsoring Company to continue the development of this project.

VII PRESENT STATUS

The author has been employed with Otto Bock Orthopedics Industry of Canada Ltd. since April, 1989. His current position is Project Leader with the priority for the implementation of the custom seating system as outlined in the preceding thesis. The status of the project to October, 1989 is:

Digitizing- Currently micro-computer based software is being developed for the digitizing of undercut surfaces. The software's features allow for viewing with shaded rendering from any viewpoint. Surface modification features are to be added in early 1990.

Digitizing/Fitting Chair- Currently the 3D digitizer is being used with fitting chair for a geriatric seating study. The techniques for digitizing are being developed. The results of this study will be used for a future product line of Otto Bock Orhthopedic Industry of Canada Ltd.

Toolpath Generation- A number of micro-computer based CAM programs are being investigated for the machining of undercut surfaces. The investigation has been invaluable in finding

84

information related to three dimensional CAD/CAM packages that have potentially other uses in the Otto Bock organization.

Digitizing Techniques- Currently the author is involved with the testing of a digitizing technique based on stereo vision. The company is working in cooperation with the National Research Canada at the Canadian Institute of Industrial Technology in Winnipeg. The digitizing technique based on stereo vision is being investigated for its promise to provide a speed enhancement over the magnetic field digitizing technique.

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IX. APPENDIX A:

Computer Source Code

```
$STORAGE:2
$NOFLOATCALLS
C*********************************************************************
C    Routine Name :   SPACE                                          *
C    Last Revised :   87/03/20                                       *
C    Sub Version  :   1.00                                           *
C    File Name    :   SPAC8.FOR                                      *
C    Sys Version  :   1.00                                           *
C    Author(s)    :   W. McAdam                                      *
C                                                                    *
C*********************************************************************
C    Purpose:   Test  for importing data from 3SPACE DIGITIZER      |
C                                                                    |
C    Subroutines Called:                                            |
C      PUTCOM  MOUSES  GETCOM(EXTERNAL)                             |
C                                                                    |
C--------------------------------------------------------------------|
C

       PROGRAM SPACE
C
       INTEGER IPORT,N,ND,OUT,OPTION,NN,NP
       INTEGER LNGTH,ILGTH,M1,M2,M3,M4,BLGTH,PITCH
       REAL XP,YP,ZP,X,Y,Z,XMAX,YMAX
       CHARACTER INSTR*26,OUTSTR*38,SNSTR*55,STAT*4,SEND*51
       CHARACTER FILNAM*12,NAME*12,EXT*4
       CHARACTER*1 TEST,PRO,RET
       EXTERNAL MOUSES
C
       CALL CLRSCN

C
C-------------------------------------------------------------------
C     SCREEN HEADER                                                |
C-------------------------------------------------------------------
C
C
       CALL HEADSP
       CALL CLRSCN
C
C-------------------------------------------------------------------
C     SET IPORT = COM2                                             |
C-------------------------------------------------------------------
C
       IPORT=1
C
C-------------------------------------------------------------------
C     CHECK STATUS OF DIGITIZER                                    |
C     TEST TO SEE IF TIP CALCULATIONS ARE ENABLED                  |
C-------------------------------------------------------------------
C
       CALL STATUS
C
C-------------------------------------------------------------------
C     SET DIGITIZER OUTPUT TO CARTESIAN COORDINATES                |
C-------------------------------------------------------------------
C
       OUTSTR='O2,1'
       LNGTH=5
       CALL PUTCOM(IPORT,OUTSTR,LNGTH,1,IERR)
```

```fortran
      RETURN
      END
C--------------------------------------------------------------------
C      THIS SUBROUTINE ENABLES TIP CALCULATIONS IF NECESSARY        |
C--------------------------------------------------------------------
      SUBROUTINE STATUS
      CHARACTER TEST*1,STAT*4,SEND*51,OUTSTR*38,SNSTR*55,NAME*8
      INTEGER IPORT,LNGTH,ILNGTH
      IPORT=1
      OUTSTR='S'
      LNGTH=1
      SNSTR=' '
      CALL PUTCOM(IPORT,OUTSTR,LNGTH,0,IERR)
      CALL GETCOM(IPORT,SNSTR,ILNGTH,55,IERR)
      READ(SNSTR,100)STAT,TEST,SEND
  100 FORMAT(A4,A1,A51)
      IF (TEST .EQ. '2' .OR. TEST .EQ. 'S' .OR. TEST .EQ. '0')THEN
         OUTSTR='tYt'
         LNGTH=3
         CALL PUTCOM(IPORT,OUTSTR,LNGTH,0,IERR)
      END IF
      RETURN
      END
C--------------------------------------------------------------------
C      THIS SUBROUTINE PRINTS OUT THE MAIN MENU                     |
C--------------------------------------------------------------------
      SUBROUTINE MENU
      CALL CLRSCN
      WRITE(*,'(1X,A1,A5)')CHAR(27),'[7;1f'
      WRITE(*,100)
      WRITE(*,101)
      WRITE(*,102)
      WRITE(*,103)
      WRITE(*,104)
      WRITE(*,105)
      WRITE(*,106)
      WRITE(*,107)
      WRITE(*,108)
      WRITE(*,109)
      WRITE(*,110)
      WRITE(*,111)
C
  100 FORMAT(25X,'┌',27('─'),'┐')
  101 FORMAT(25X,'|',27(' '),'|')
  102 FORMAT(25X,'|',9X,'MAIN MENU',9X,'|')
  103 FORMAT(25X,'|',27(' '),'|')
  104 FORMAT(25X,'|',4X,'F1 -DATA ACQUISITION',3X,'|')
  105 FORMAT(25X,'|',4X,'F2 -RETURN TO D.A.',5X,'|')
  106 FORMAT(25X,'|',4X,'F3 -HELP',15X,'|')
  107 FORMAT(25X,'|',4X,'F4 -EXIT TO DOS',8X,'|')
  108 FORMAT(25X,'|',27(' '),'|')
  109 FORMAT(25X,'|',27(' '),'|')
  110 FORMAT(25X,'|',27(' '),'|')
  111 FORMAT(25X,'└',27('─'),'─')
C
      RETURN
      END
C
C--------------------------------------------------------------------
```

```fortran
          IF(MOPT .EQ. 1)THEN
              CALL DELPNT(NN,ND,NP,N)
          ELSE IF(MOPT .EQ. 2)THEN
              GOTO 100
          END IF
        END IF
        GOTO 200
     ELSE IF(OPTION .EQ. 3)THEN
        GOTO 100
     ELSE IF(OPTION .EQ. 4)THEN
        GOTO 400
     ELSE IF(OPTION .NE. 1 .OR. OPTION .NE. 2 .OR. OPTION .NE. 3
    *.OR. OPTION .NE. 4 )THEN
        GOTO 100
     END IF
400  CALL DATASD(ND,N,OUT,X,Y,Z)
     WRITE(*,'(1X,A1,A3)')CHAR(27),'[0m'
     CALL CLRSCN
     CALL RUNKEY
     CALL CLRSCN
     STOP
     END


C
C-----------------------------------------------------------------------
C     THIS ROUTINE PRINTS "SPACE" ON THE SCREEN1.                      |
C-----------------------------------------------------------------------
C
     SUBROUTINE HEADSP
     CHARACTER*1 RET
C
     WRITE(*,'(1X,A1,A5)')CHAR(27),'[5;1f'
     WRITE(*,10)CHAR(27),'[33m',CHAR(27),'[0m'
     WRITE(*,20)CHAR(27),'[33m',CHAR(27),'[0m'
     WRITE(*,30)CHAR(27),'[33m',CHAR(27),'[0m'
     WRITE(*,40)CHAR(27),'[33m',CHAR(27),'[0m'
     WRITE(*,50)CHAR(27),'[33m',CHAR(27),'[0m'
C
10   FORMAT(34X,A1,A4,'                         ',A1,A3)
20   FORMAT(34X,A1,A4,'                         ',A1,A3)
30   FORMAT(34X,A1,A4,'                         ',A1,A3)
40   FORMAT(34X,A1,A4,'                         ',A1,A3)
50   FORMAT(34X,A1,A4,'                         ',A1,A3)
C
     WRITE(*,'(1X,A1,A6)')CHAR(27),'[14;1f'
     WRITE(*,100)CHAR(27),'[34m',CHAR(27),'[0m'
100  FORMAT(38X,A1,A4,'VERSION 1.00',A1,A3)
     WRITE(*,'(1X,A1,A6)')CHAR(27),'[16;1f'
     WRITE(*,200)CHAR(27),'[34m',CHAR(27),'[0m'
200  FORMAT(33X,A1,A4,'UNIVERSITY OF MANITOBA',A1,A3)
     WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
     WRITE(*,300)CHAR(27),'[34m',CHAR(27),'[0m'
300  FORMAT(29X,A1,A4,'DEPT. OF MECHANICAL ENGINEERING',A1,A3)
     WRITE(*,'(1X,A1,A6)')CHAR(27),'[22;1f'
     WRITE(*,400)CHAR(27),'[31;5;47m',CHAR(27),'[0m'
400  FORMAT(33X,A1,A9,'PRESS RETURN TO CONTINUE',A1,A3\)
     READ(*,500)RET
500  FORMAT(A1)
```

```
C
C-------------------------------------------------------------------
C      DEFINE MEASUREMENT PLANE   POSITIVE X,Y,Z                    |
C-------------------------------------------------------------------
C
       OUTSTR='H1,0,0,-1'
       LNGTH=9
       CALL PUTCOM(IPORT,OUTSTR,LNGTH,1,IERR)
C
       OUTSTR='A1,0,0,0,-64.48,0,0,0,-64.48,0'
       LNGTH=30
       CALL PUTCOM(IPORT,OUTSTR,LNGTH,1,IERR)
C
C-------------------------------------------------------------------
C      MAIN MENU SELECTION                                          |
C                                                                   |
C-------------------------------------------------------------------
C
  100   CALL MENU
        CALL OPT(OPTION)
        IF (OPTION .EQ. 1)THEN
           CALL INITL(XMAX,YMAX,NAME)
           N=0
           NN=0
           ND=0
           OUT=0
           X=0.0
           Y=0.0
           Z=0.0
        END IF
        IF (OPTION .EQ. 1 .OR. OPTION .EQ. 2)THEN
           CALL TPHDR
           CALL INFO(XMAX,YMAX,NAME)
           CALL FILL(NN)
           M1=0
           CALL MOUSES(M1,M2,M3,M4)
  200      CALL CHECK(MOPT)
           IF (MOPT .EQ. 1)THEN
C
C-------------------------------------------------------------------
C      GET  DATA POINTS                                             |
C-------------------------------------------------------------------
C
              CALL DATASD(ND,N,OUT,X,Y,Z)
              ND=0
              CALL GETDAT(IPORT,XP,YP,ZP)
              CALL CHKLIM(XMAX,YMAX,XP,YP,ZP,OUT,NN)
              IF(OUT .EQ. 0)THEN
                 CALL CONVRT(XP,YP,ZP,X,Y,Z,XMAX,YMAX,NN)
                 N=N+1
                 NP=0
              END IF
           END IF
           IF (MOPT .EQ. 2)THEN
              WRITE(*,'(1X,A1,A6)')CHAR(27),'[16;1f'
              WRITE(*,210)
  210         FORMAT(10X,'|',20X,'L=DELETE LAST POINT',1X,'R=MAIN MENU',15
     *        X,'|')
              CALL CHECK(MOPT)
```

93

```fortran
C      INITIALIZATION PROCEDURE
C-----------------------------------------------------------------------      |
       SUBROUTINE INITL(XMAX,YMAX,NAME)
       CHARACTER FILNAM*12,NAME*12,EXT*4
       REAL XMAX,YMAX
       CALL CLRSCN
       WRITE(*,'(1X,A1,A5)')CHAR(27),'[7;1f'
       WRITE(*,100)
       WRITE(*,101)
       WRITE(*,102)
       WRITE(*,103)
       WRITE(*,104)
       WRITE(*,104)
       WRITE(*,105)
       WRITE(*,106)
       WRITE(*,107)
       WRITE(*,108)
       WRITE(*,108)
       WRITE(*,109)
C
 100   FORMAT(25X,'Γ',27('−'),'⌐')
 101   FORMAT(25X,'|',27(' '),'|')
 102   FORMAT(25X,'|',6X,'DATA AQUISITION',6X,'|')
 103   FORMAT(25X,'|',12X,'MENU',11X,'|')
 104   FORMAT(25X,'|',27(' '),'|')
 105   FORMAT(25X,'|',1X,'ENTER: -OUTPUT DATA FILE',2X,'|')
 106   FORMAT(25X,'|',8X,'-XMAX [INCHES]',5X,'|')
 107   FORMAT(25X,'|',8X,'-YMAX [INCHES]',5X,'|')
 108   FORMAT(25X,'|',27(' '),'|')
 109   FORMAT(25X,'L',27('—'),'⌐')
C
       WRITE(*,*)' '
       WRITE(*,*)' '
       WRITE(*,112)
 112   FORMAT(27X,' OUTPUT FILE>'\)
       READ(*,113)NAME
 113   FORMAT(A12)
       WRITE(FILNAM,114)NAME
 114   FORMAT(A12)
       OPEN(3,FILE=FILNAM,STATUS='NEW')
       WRITE(*,115)
 115   FORMAT(35X,'XMAX>'\)
       READ(*,117)XMAX
C
       WRITE(*,116)
 116   FORMAT(35X,'YMAX>'\)
       READ(*,117)YMAX
C
 117   FORMAT(F4.1)
       RETURN
       END
C
C-----------------------------------------------------------------------
C      THIS SUBROUTINE SELECTS WHICH OPTION WAS SELECTED                      |
C-----------------------------------------------------------------------
C
       SUBROUTINE OPT(OPTION)
       INTEGER OPTION
       CALL FUNKEY
```

```
      WRITE(*,*)' '
      WRITE(*,100)
 100  FORMAT(33X,'ENTER OPTION>'\)
      READ(*,110)OPTION
 110  FORMAT(I1)
      RETURN
      END
C
C------------------------------------------------------------------
C     THIS SUBROUTINE PRINTS "L=POINT   R=OPTIONS"                 |
C------------------------------------------------------------------
      SUBROUTINE LPRO
      WRITE(*,'(1X,A1,A6)')CHAR(27),'[16;1f'
      WRITE(*,100)
 100  FORMAT(10X,'|',25X,'L=POINT',4X,'R=OPTIONS',21X,'|')
      WRITE(*,'(1X,A1,A3)')CHAR(27),'[1D'
      RETURN
      END
C
C------------------------------------------------------------------
C     THIS SUBROUTINE CHECKS THE STATUS OF THE MOUSE AND PROVIDES THE |
C     FOUR POSSIBLE CASES                                           |
C------------------------------------------------------------------
C
      SUBROUTINE CHECK(MOPT)
      INTEGER M1,M2,M3,M4
      INTEGER MOPT
      MOPT=0
 10   M1=5
      M2=0
      CALL MOUSES(M1,M2,M3,M4)
      IF (M2 .GT. 0 )THEN
         MOPT=1
      ELSE
         M1=5
         M2=1
         CALL MOUSES(M1,M2,M3,M4)
         IF(M2 .GT. 0)THEN
            MOPT=2
         ELSE
            GOTO 10
         END IF
      END IF
      RETURN
      END
C
C------------------------------------------------------------------
C     THIS SUBROUTINE CHECKS TO SEE IF A POINT IS WRITTEN TO DISK  |
C------------------------------------------------------------------
      SUBROUTINE DATASD(ND,N,OUT,X,Y,Z)
      INTEGER ND,N,OUT
      REAL X,Y,Z
      IF (ND .EQ. 0 .AND. N .GT. 0 .AND. OUT .NE. 1)THEN
         WRITE(3,100)X,Y,Z
 100     FORMAT(F7.2,1X,F7.2,1XF7.2)
      END IF
      ND=0
      RETURN
      END
```

```
C
C--------------------------------------------------------------------------
C     THIS SUBROUTINE ACCESSES THE DIGITIZER FOR A POINT                  |
C--------------------------------------------------------------------------
C
      SUBROUTINE GETDAT(IPORT,XP,YP,ZP)
      INTEGER IPORT,LNGTH,ILNGTH
      CHARACTER OUTSTR*1,INSTR*26,RECORD*4
      OUTSTR='P'
      LNGTH=1
      INSTR=' '
      ILNGTH=26
      CALL PUTCOM(IPORT,OUTSTR,LNGTH,0,IERR)
      CALL GETCOM(IPORT,INSTR,ILNGTH,26,IERR)
      READ(INSTR,100)RECORD,XP,YP,ZP
 100  FORMAT(A4,F7.2,F7.2,F7.2)
      RETURN
      END


C
C--------------------------------------------------------------------------
C     THIS SUBROUTINE CHECKS TO SEE IF THE DIGITIZED POINT IS WITHIN      |
C     LIMITS XMAX,YMAX.  IF IT IS OUTSIDE OF THE LIMITS NO POINT IS       |
C     TAKEN AND A WARNING BEEP IS SOUND.                                  |
C--------------------------------------------------------------------------
C
      SUBROUTINE CHKLIM(XMAX,YMAX,XP,YP,ZP,OUT,NN)
      REAL XMAX,YMAX,XP,YP,ZP
      INTEGER OUT,PITCH,BLGTH,NN
      BLGTH=400
      PITCH=80
      OUT=0
      IF(ABS(XP) .GT. XMAX/2.0 .OR. ABS(YP) .GT. YMAX/2.0)THEN
          CALL LPRO
          WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
          WRITE(*,100)NN,CHAR(27),'[31;5;47m',CHAR(27),'[0m'
 100      FORMAT(10X,'|',5X,'N=',I4,4X,A1,A9,'NO POINT TAKEN>OUTSIDE SUR'
     *    'FACE LIMITS',A1,A3,14X,'|')
          OUT=1
          WRITE(*,'(1X,A1,A3)')CHAR(27),'[1D'
          CALL BEEP(BLGTH,PITCH)
      END IF
      RETURN
      END
C
C--------------------------------------------------------------------------
C     THE DATA SENT FROM THE DIGITIZER IS CONVERTED TO A USEABLE          |
C     FORMAT BY THIS LOOP.  ANY POINTS FALLING OUTSIDE XMAX AND           |
C     YMAX ARE OMMITED.                                                   |
C--------------------------------------------------------------------------
C
      SUBROUTINE CONVRT(XP,YP,ZP,X,Y,Z,XMAX,YMAX,NN)
      REAL XP,YP,ZP,X,Y,Z,XMAX,YMAX
      INTEGER NN
      IF(XP .GT. 0.0 .AND. YP .GT. 0.0)THEN
          X=XMAX/2.0 - XP
          Y=YMAX/2.0 - YP
          Z=ZP
      ELSE IF(XP .GT. 0.0 .AND. YP .LT. 0.0)THEN
```

```fortran
            X=XMAX/2.0 - XP
            Y=YMAX/2.0 + ABS(YP)
            Z=ZP
         ELSE IF (XP .LT. 0.0 .AND. YP .LT. 0.0)THEN
            X=XMAX/2.0 + ABS(XP)
            Y=YMAX/2.0 + ABS(YP)
            Z=ZP
         ELSE IF (XP .LT. 0.0 .AND. YP .GT. 0.0)THEN
            X=XMAX/2.0 + ABS(XP)
            Y=YMAX/2.0 - (YP)
            Z=ZP
         ELSE IF(XP .EQ. 0.0 .AND. YP .GT. 0.0)THEN
            X=XMAX/2.0
            Y=YMAX/2.0 - YP
            Z=ZP
         ELSE IF(XP .EQ. 0.0 .AND. YP .LT. 0.0)THEN
            X=XMAX/2.0
            Y=YMAX/2.0 + ABS(YP)
            Z=ZP
         ELSE IF(XP .GT. 0.0 .AND. YP .EQ. 0.0)THEN
            X=XMAX/2.0 - XP
            Y=YMAX/2.0
            Z=ZP
         ELSE IF(XP .LT. 0.0 .AND. YP .EQ. 0.0)THEN
            X=XMAX/2.0 - XP
            Y=YMAX/2.0
            Z=ZP
         ELSE IF(XP .EQ. 0.0 .AND. YP .EQ. 0.0)THEN
            X=XMAX/2.0
            Y=YMAX/2.0
            Z=ZP
         END IF
         NN=NN+1
         CALL LPRO
         WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
         WRITE(*,100)NN,X,Y,Z
  100    FORMAT(10X,'|',5X,'N=',I4,10X,'X=',F7.2,1X,'Y=',F7.2,1X,'Z=',F7.2,
     *16X,'|')
         WRITE(*,'(1X,A1,A3)')CHAR(27),'[1D'
C
         RETURN
         END
C
C-------------------------------------------------------------------------
C     THIS SUBROUTINE PRODUCES THE TOP BORDER OF THE DATA ACQUISITION  |
C     FILE                                                             |
C-------------------------------------------------------------------------
C
         SUBROUTINE TPHDR
         CALL CLRSCN
         WRITE(*,'(1X,A1,A5)')CHAR(27),'[7;1f'
         WRITE(*,100)
         WRITE(*,200)
  100    FORMAT(10X,'⌐',66('⎺'),'⌐')
  200    FORMAT(10X,'|',66(' '),'|')
         RETURN
         END
C
C-------------------------------------------------------------------------
```

```fortran
C     THIS SUBROUTINE PRINTS THE OUTPUT FILE NAME AND XMAX, YMAX        |
C     ON THE HEADER                                                     |
C------------------------------------------------------------------------
C
      SUBROUTINE INFO(XMAX,YMAX,NAME)
      REAL XMAX,YMAX
      CHARACTER*12 NAME
      WRITE(*,100)CHAR(27),'[30;47m',NAME,CHAR(27),'[0m'
      WRITE(*,200)CHAR(27),'[30;47m',XMAX,CHAR(27),'[0m'
      WRITE(*,300)CHAR(27),'[30;47m',YMAX,CHAR(27),'[0m'
 100  FORMAT(10X,'|',20X,A1,A7,'OUTPUT FILE NAME>',A12,A1,A3,17X,'|')
 200  FORMAT(10X,'|',23X,A1,A7,' XMAX> ',F4.1,' INCHES',A1,A3,25X,'|')
 300  FORMAT(10X,'|',23X,A1,A7,' YMAX> ',F4.1,' INCHES',A1,A3,25X,'|')
      CALL BPHDR
      RETURN
      END
C
C------------------------------------------------------------------------
C     THIS SUBROUTINE CLEARS THE SCREEN                                 |
C------------------------------------------------------------------------
      SUBROUTINE CLRSCN
      WRITE(*,'(1X,A1,A3)')CHAR(27),'[2J'
      RETURN
      END

C------------------------------------------------------------------------
C     THIS SUBROUTINE PRINTS THE BOTTOM OF THE TOP HEADER               |
C------------------------------------------------------------------------
      SUBROUTINE BPHDR
      WRITE(*,100)
      WRITE(*,200)
 100  FORMAT(10X,'|',66(' '),'|')
 200  FORMAT(10X,'L',66('-'),'J')
      RETURN
      END
C
C------------------------------------------------------------------------
C     THIS SUBROUTINE PRINTS THE BOTTOM HEADER                          |
C------------------------------------------------------------------------
      SUBROUTINE TALHDR
      WRITE(*,100)
      WRITE(*,200)
 100  FORMAT(10X,'|',66(' '),'|')
 200  FORMAT(10X,'L',66(' '),'J')
      RETURN
      END
C
C------------------------------------------------------------------------
C     THIS ROUTINE DEFINES THE REST OF THE DATA ACQUISITION FRAME       |
C------------------------------------------------------------------------
      SUBROUTINE FILL(NN)
      INTEGER NN
      WRITE(*,'(1X,A1,A6)')CHAR(27),'[14;1f'
      WRITE(*,100)
      WRITE(*,100)
 100  FORMAT(10X,'|',66X,'|')
      CALL LPRO
      WRITE(*,'(1X,A1,A6)')CHAR(27),'[17;1f'
      WRITE (*,100)
```

```fortran
      WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
      WRITE (*,200)NN
 200  FORMAT(10X,' ',5X,'N=',I4,55X,' ')
      WRITE(*,'(1X,A1,A6)')CHAR(27),'[19;1f'
      CALL TALHDR
      RETURN
      END
C
C---------------------------------------------------------------------
C     THIS SUBROUTINE CONTROLS THE DELETION OF A POINT WHICH WAS      |
C     SELECTED BY THE DIGITIZER OPERATOR                              |
C---------------------------------------------------------------------
      SUBROUTINE DELPNT(NN,ND,NP,N)
      INTEGER NN,ND,NP,BLGTH,PITCH,N
      BLGTH=400
      PITCH=70
      ND=1
      NN=NN-1
      IF (N .EQ. 0)THEN
         WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
         WRITE(*,100)CHAR(27),'[31;5;47m',CHAR(27),'[0m'
 100     FORMAT(10X,'|',5X,'N=',',    0',15X,A1,A9,'NO POINT TO DELETE',A1
     *   ,A3,22X,'|')
         NN=NN+1
         CALL BEEP(BLGTH,PITCH)
         CALL LPRO
      END IF
      IF (NP .EQ. 1 .AND. N .GT. 0 )THEN
         NN=NN+1
         CALL LPRO
         WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
         WRITE(*,200)NN,CHAR(27),'[31;5;47m',CHAR(27),'[0m'
 200     FORMAT(10X,'|',5X,'N=',I4,13X,A1,A9,'POINT ALREADY DELETED',A1
     *   ,A3,21X,'|')
         CALL BEEP(BLGTH,PITCH)
      ELSE IF(NP .EQ. 0 .AND. N .GT. 0)THEN
         CALL LPRO
         WRITE(*,'(1X,A1,A6)')CHAR(27),'[18;1f'
         WRITE(*,300)NN
 300     FORMAT(10X,'|',5X,'N=',I4,15X,'DATA POINT DELETED',22X,'|')
         NP=1
      END IF
      RETURN
      END
C
C---------------------------------------------------------------------
C     THIS SUBROUTINE ASSIGNS VALUES TO THE FUNCTION KEYS            |
C     (ONLY FUNCTION KEYS F1,F2,F3,F4 HAVE BEEN ASSIGNED            |
C---------------------------------------------------------------------
C
      SUBROUTINE FUNKEY
      WRITE(*,'(1X,A1,A13)')CHAR(27),'[0;59;"1";13p'
      WRITE(*,'(1X,A1,A13)')CHAR(27),'[0;60;"2";13p'
      WRITE(*,'(1X,A1,A13)')CHAR(27),'[0;61;"3";13p'
      WRITE(*,'(1X,A1,A13)')CHAR(27),'[0;62;"4";13p'
      RETURN
      END

C
```

```
C
C-------------------------------------------------------------------------
C     THIS SUBROUTINE DISENGAGES VALUES ASSIGNED TO THE FUNCTION KEYS   |
C     (ONLY FUNCTION KEYS F1,F2,F3,F4 HAVE BEEN DISENGAGED              |
C-------------------------------------------------------------------------
C
      SUBROUTINE RUNKEY
      WRITE(*,'(1X,A1,A11)')CHAR(27),'[0;59;0;59p'
      WRITE(*,'(1X,A1,A11)')CHAR(27),'[0;60;0;60p'
      WRITE(*,'(1X,A1,A11)')CHAR(27),'[0;61;0;61p'
      WRITE(*,'(1X,A1,A11)')CHAR(27),'[0;62;0;62p'
      RETURN
      END

C
```

```c
/*-----------------------------------------------------------*/
/*  Program Name: convrt.c                                   */
/*  Version      : 1.00                                      */
/*  File Name    : convrt.c                                  */
/*  Author       : W. McAdam                                 */
/*-----------------------------------------------------------*/
/*  Purpose: To change the tool path file generated through  */
/*           the Supersue tool path program to strings that  */
/*           can be read by the PC23 indexer board.          */
/*                                                           */
/*-----------------------------------------------------------*/

#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <fcntl.h>

#define mill_para 25400.00

main()
{
        int check;
        unsigned int i,j,k,lp;
        unsigned int lpendi,lpendj,lpendk,lpcnti,lpcntj,lpcntk;
        FILE *input, *output;
        float tmp[3];
        float deli,delj,delk,seg;
        float strti,strtj,strtk,fnshi,fnshj,fnshk;
        char namei[81];
        char nameo[81];

        lp=50;
        seg=50.0;
        check=1;

        printf("Enter File Name For Input---->");
        gets(namei);
        printf("Enter File Name For Output--->");
        gets(nameo);

        input=fopen(namei,"r");
        output=fopen(nameo,"w");

        fscanf(input,"%f %f %f",&tmp[0],&tmp[1],&tmp[2]);

        strti=tmp[0];
        strtj=tmp[1];
        strtk=tmp[2];

        while (feof(input)==0){
                fscanf(input,"%f %f %f",&tmp[0],&tmp[1],&tmp[2]);

                fnshi=tmp[0];
                fnshj=tmp[1];
                fnshk=tmp[2];
                deli=fnshi-strti;
                delj=fnshj-strtj;
                delk=fnshk-strtk;
```

```
            if (deli >= 0.0){
                   lpcnti=lp + 0x7F00;
                   lpendi=0x7F80;
                   i=ceil(deli*mill_para/seg);
            }
            else
            {
                   lpcnti=lp + 0xFF00;
                   lpendi=0xFF80;
                   i=ceil(fabs(deli*mill_para/seg)) + 0x8000;
            }

            if (delj >=0.0){
                   lpcntj=lp + 0xFF00;
                   lpendj=0xFF80;
                   j=ceil(delj*mill_para/seg)+0x8000;
            }
            else
            {
                   lpcntj=lp + 0x7F00;
                   lpendj=0x7F80;
                   j=ceil(fabs(delj*mill_para/seg));
            }
            if (delk >=0.0){
                   lpcntk=lp +0x7F00;
                   lpendk=0x7F80;
                   k=ceil(delk*mill_para/seg);
                   if (check == 0)
                          fprint (output,"SD00000000000 SD00000000000
                                  SD00000000000 \n");
                   check=1;
            }
            else
            {
                   lpcntk=lp + 0xFF00;
                   lpendk=0xFF80;

                   k=ceil(fabs(delk*mill_para/seg))+0x8000;
                   if (check == 1)
                          fprintf(output,"SD000000000000 SD000000000000
                                  SD000000000000 \n");
                   check=0;
            }
            fprintf(output,"SD%04X%04X%04X SD%04X%04X%04X SD%04X%04X%04X \n"
                   ,lpcnti,lpcntj,lpcntk,i,j,k,lpendi,lpendj,lpendk);

            strti=fnshi;
            strtj=fnshj;
            strtk=fnshk;

      }
      fclose(input);
      fclose(output);
}^Z
```

```c
/*-----------------------------------------------------*/
/*    Program Name : pcontour.c                         */
/*    Version      : 1.00                               */
/*    File Name    : prep1.c                            */
/*    Author       : W. McAdam                          */
/*-----------------------------------------------------*/
/*    Purpose: To test the three axis router            */
/*                                                      */
/*-----------------------------------------------------*/

#include <stdio.h>

#define FAIL 0x20
#define MAXINT 32000
#define START_M 0x7f
#define INTCLR 0x20
#define RESTART 0x17
#define POSITIVE 0x8000
#define ALDONE 0x7
#define STOP 0x64
#define START 0x40
#define CB 0x60
#define CB1 0x61
#define IDB_M 0x10
#define IDB 0x70
#define IDB1 0x71
#define ODB 0x8
#define ACK 0xe0
#define BFULL 0x80
#define RETURN 0xd
#define MAXLIN 47

int address = 0x300;

main()
{
        FILE *input;
        char namei[81];
        char testst[MAXLIN];
        char *setup, *start, *exit;

        setup="1Q2 2Q2 3Q2 MSL111 1TD25 2TD25 3TD25";
        start="MSS";
        exit="1Q0 2Q0 3Q0";
        FILE *input;

        initialize();
        writestr(setup);

        printf("\n\n\n\n");
        printf("--------------PCONTOUR-------------\n");
        printf("\n\n\n\n");
        printf("   PROGRAM FOR TESTING THE CONTOURING\n");
        printf("   FEATURES OF THE THREE AXIS ROUTER\n");
        printf("\n\n\n\n");

        printf("   Enter File Name----->");
        gets(namei);
        input=fopen(namei,"r");
```

```c
        printf("\n\n\n");
        printf(" HIt Any Key To Exit The Program ");

        while (feof(input)==0){
                fgets(testst,MAXLIN,input);
                writestr(testst);

                if (testst[18] !='0' || testst[19] !='0' ||
                        testst[20] !='0'){
                        writestr(start);

                loop: byte=inportb(address+1);
                        stop=kbhit();
                        if (stop != 0) goto endcon;
                        if (byte & 2) goto loop;
                        writestr(exit);
                        writestr(setup);
                }
  endcon:
        close(input);
        printf(" Exiting Program");
        writestr(exit);
 }


/*INITIALIZE*/

initialize ()
{
        int i = 0;
        outportb(address+1, STOP);
        while (!((inportb(address+1)) & FAIL));
        outportb(address+1, START);
        outportb(address+1, CB);
        while(((inportb(address+1) & START_M) !=RESTART) && (i++ != MAXINT));
        if (i >= MAXINT)
                { printf ("Invalid address\n");
                  exit(); }
        outportb(address+1,INTCLR);
        outportb(address+1,CB);
        return;
}

/*WRITCHAR*/

writechar(alpha)
char alpha;
{
        while (!(inportb(address+1) & IDB_M));
        outportb(address, alpha);
        outportb(address+1, IDB);
        while (inportb(address+1) & IDB_M);
        outportb(address+1, CB);
        while (!(inportb(address+1) & IDB_M));
        return;

}
```

```
/*WRITESTR*/

writestr (s)
char *s;
{
      while (*s)
            writechar (*s++);
      return;
}


/*readchar*/

readchar()
{
      char alpha=0;
      while (!(inportb(address+1) & ODB));
      alpha = inportb(address);
      outportb (address+1,ACK);
      while ((inportb(address+1) & ODB));
      outportb (address+1, CB);
      return(alpha);
}


/*readstr*/

readstr(s)
char *s;
{
      while ((*s++ = readchar()) != 13);
      *s = '\o';
      return;
}

initialize ()
{
      int i = 0;
      outportb(address+1, STOP);
      while (!((inportb(address+1)) & FAIL));
      outportb(address+1, START);
      outportb(address+1, CB);
      while(((inportb(address+1) & START_M) !=RESTART) && (i++ != MAXINT));
      if (i >= MAXINT)
            { printf ("Invalid address\n");
              exit(); }
      outportb(address+1,INTCLR);
      outportb(address+1,CB);
      return;
}

/*WRITCHAR*/

writechar(alpha)
char alpha;
{
      while (!(inportb(address+1) & IDB_M));
      outportb(address, alpha);
      outportb(address+1, IDB);
      while (inportb(address+1) & IDB_M);
      outportb(address+1, CB);
```

```c
        while (!(inportb(address+1) & IDB_M));
        return;

}

/*WRITESTR*/

writestr (s)
char *s;
{
        while (*s)
                writechar (*s++);
        return;
}

/*readchar*/

readchar()
{
        char alpha=0;
        while (!(inportb(address+1) & ODB));
        alpha = inportb(address);
        outportb (address+1,ACK);
        while ((inportb(address+1) & ODB));
        outportb (address+1, CB);
        return(alpha);
}

/*readstr*/

readstr(s)
char *s;
{
        while ((*s++ = readchar()) != 13);
        *s = '\o';
        return;
}
^Z
```

X. APPENDIX B:

3Space Isotrak Accuracy Tests

3Space Isotrak Accuracy Tests

File: gridb1.pc
Origin: -23.44,-9.40,1.90
Vector Distance from Origin to Source: 25.32"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR
X	Y	Z	X	Y	Z	X	Y	Z	D
0.00	0.00	0.00	-0.01	-0.03	0.00	-0.01	-0.03	0.00	0.03
1.00	0.00	0.00	1.04	-0.05	0.04	0.04	-0.05	0.04	0.08
2.00	0.00	0.00	2.06	-0.04	-0.02	0.06	-0.04	-0.02	0.07
3.00	0.00	0.00	3.06	-0.07	0.05	0.06	-0.07	0.05	0.10
4.00	0.00	0.00	4.05	-0.06	0.06	0.05	-0.06	0.06	0.10
5.00	0.00	0.00	5.03	-0.02	-0.09	0.03	-0.02	-0.09	0.10
6.00	0.00	0.00	6.04	-0.04	0.07	0.04	-0.04	0.07	0.09
7.00	0.00	0.00	7.03	-0.05	0.03	0.03	-0.05	0.03	0.07
8.00	0.00	0.00	8.07	-0.09	0.05	0.07	-0.09	0.05	0.12
9.00	0.00	0.00	9.07	-0.06	0.00	0.07	-0.06	0.00	0.09
10.00	0.00	0.00	10.11	-0.04	0.02	0.11	-0.04	0.02	0.12
11.00	0.00	0.00	11.11	-0.04	0.01	0.11	-0.04	0.01	0.12
12.00	0.00	0.00	12.11	0.00	0.03	0.11	0.00	0.03	0.11
13.00	0.00	0.00	13.10	0.00	0.02	0.10	0.00	0.02	0.10
14.00	0.00	0.00	14.12	0.00	0.02	0.12	0.00	0.02	0.12
15.00	0.00	0.00	15.12	0.00	-0.01	0.12	0.00	-0.01	0.12
0.00	1.00	0.00	0.05	0.95	0.06	0.05	-0.05	0.06	0.09
1.00	1.00	0.00	1.05	0.92	0.05	0.05	-0.08	0.05	0.11
2.00	1.00	0.00	2.05	0.97	0.07	0.05	-0.03	0.07	0.09
3.00	1.00	0.00	3.03	0.96	0.06	0.03	-0.04	0.06	0.08
4.00	1.00	0.00	3.99	0.99	-0.02	-0.01	-0.01	-0.02	0.02
5.00	1.00	0.00	4.98	0.96	-0.12	-0.02	-0.04	-0.12	0.13
6.00	1.00	0.00	6.04	0.95	0.03	0.04	-0.05	0.03	0.07
7.00	1.00	0.00	7.02	0.95	0.02	0.02	-0.05	0.02	0.06
8.00	1.00	0.00	8.08	0.95	0.02	0.08	-0.05	0.02	0.10
9.00	1.00	0.00	9.14	0.92	0.05	0.14	-0.08	0.05	0.17
10.00	1.00	0.00	10.10	0.98	0.04	0.10	-0.02	0.04	0.11
11.00	1.00	0.00	11.12	0.98	0.04	0.12	-0.02	0.04	0.13
12.00	1.00	0.00	12.12	0.99	0.03	0.12	-0.01	0.03	0.12
13.00	1.00	0.00	13.14	0.96	0.02	0.14	-0.04	0.02	0.15
14.00	1.00	0.00	14.14	0.98	0.00	0.14	-0.02	0.00	0.14
15.00	1.00	0.00	15.11	0.97	0.01	0.11	-0.03	0.01	0.11
0.00	2.00	0.00	0.03	1.92	0.04	0.03	-0.08	0.04	0.09
1.00	2.00	0.00	1.05	1.96	0.04	0.05	-0.04	0.04	0.08
2.00	2.00	0.00	2.04	1.92	0.02	0.04	-0.08	0.02	0.09
3.00	2.00	0.00	3.04	1.96	0.04	0.04	-0.04	0.04	0.07
4.00	2.00	0.00	4.03	1.97	0.06	0.03	-0.03	0.06	0.07
5.00	2.00	0.00	5.03	1.97	0.04	0.03	-0.03	0.04	0.06
6.00	2.00	0.00	6.03	1.96	0.03	0.03	-0.04	0.03	0.06
7.00	2.00	0.00	7.04	1.96	-0.06	0.04	-0.04	-0.06	0.08
8.00	2.00	0.00	8.07	1.96	0.00	0.07	-0.04	0.00	0.08
9.00	2.00	0.00	9.09	1.99	0.06	0.09	-0.01	0.06	0.11
10.00	2.00	0.00	10.12	1.99	0.02	0.12	-0.01	0.02	0.12
11.00	2.00	0.00	11.11	2.00	0.04	0.11	0.00	0.04	0.12
12.00	2.00	0.00	12.12	2.00	0.02	0.12	0.00	0.02	0.12
13.00	2.00	0.00	13.13	1.99	0.01	0.13	-0.01	0.01	0.13
14.00	2.00	0.00	14.12	2.00	0.00	0.12	0.00	0.00	0.12
15.00	2.00	0.00	15.13	2.02	0.00	0.13	0.02	0.00	0.13

0.00	3.00	0.00	0.04	2.94	0.00	0.04	-0.06	0.00	0.07
1.00	3.00	0.00	1.03	2.93	0.01	0.03	-0.07	0.01	0.08
2.00	3.00	0.00	2.02	2.96	0.04	0.02	-0.04	0.04	0.06
3.00	3.00	0.00	3.02	2.94	0.04	0.02	-0.06	0.04	0.07
4.00	3.00	0.00	3.99	2.96	-0.08	-0.01	-0.04	-0.08	0.09
5.00	3.00	0.00	5.02	2.94	-0.03	0.02	-0.06	-0.03	0.07
6.00	3.00	0.00	6.02	2.96	0.06	0.02	-0.04	0.06	0.07
7.00	3.00	0.00	7.02	2.96	-0.10	0.02	-0.04	-0.10	0.11
8.00	3.00	0.00	8.11	2.96	0.09	0.11	-0.04	0.09	0.15
9.00	3.00	0.00	9.08	2.97	0.07	0.08	-0.03	0.07	0.11
10.00	3.00	0.00	10.14	2.97	0.07	0.14	-0.03	0.07	0.16
11.00	3.00	0.00	11.12	2.97	0.04	0.12	-0.03	0.04	0.13
12.00	3.00	0.00	12.11	2.98	0.01	0.11	-0.02	0.01	0.11
13.00	3.00	0.00	13.06	2.97	-0.16	0.06	-0.03	-0.16	0.17
14.00	3.00	0.00	14.09	2.96	0.07	0.09	-0.04	0.07	0.12
15.00	3.00	0.00	15.13	2.99	0.00	0.13	-0.01	0.00	0.13
0.00	4.00	0.00	0.06	3.92	0.00	0.06	-0.08	0.00	0.10
1.00	4.00	0.00	1.03	3.95	0.02	0.03	-0.05	0.02	0.06
2.00	4.00	0.00	2.02	3.93	0.03	0.02	-0.07	0.03	0.08
3.00	4.00	0.00	2.99	3.96	-0.11	-0.01	-0.04	-0.11	0.12
4.00	4.00	0.00	4.02	3.99	0.01	0.02	-0.01	0.01	0.02
5.00	4.00	0.00	5.06	3.93	-0.03	0.06	-0.07	-0.03	0.10
6.00	4.00	0.00	6.01	3.97	0.07	0.01	-0.03	0.07	0.08
7.00	4.00	0.00	7.03	4.01	-0.04	0.03	0.01	-0.04	0.05
8.00	4.00	0.00	8.08	4.00	0.06	0.08	0.00	0.06	0.10
9.00	4.00	0.00	9.09	3.97	0.04	0.09	-0.03	0.04	0.10
10.00	4.00	0.00	10.11	3.99	0.06	0.11	-0.01	0.06	0.13
11.00	4.00	0.00	11.09	3.99	0.03	0.09	-0.01	0.03	0.10
12.00	4.00	0.00	12.13	3.98	0.03	0.13	-0.02	0.03	0.13
13.00	4.00	0.00	13.11	3.99	0.03	0.11	-0.01	0.03	0.11
14.00	4.00	0.00	14.12	4.01	0.02	0.12	0.01	0.02	0.12
15.00	4.00	0.00	15.11	4.01	0.00	0.11	0.01	0.00	0.11
0.00	5.00	0.00	0.03	4.93	0.00	0.03	-0.07	0.00	0.08
1.00	5.00	0.00	1.04	4.92	-0.01	0.04	-0.08	-0.01	0.09
2.00	5.00	0.00	2.00	4.94	-0.02	0.00	-0.06	-0.02	0.06
3.00	5.00	0.00	3.02	4.93	-0.15	0.02	-0.07	-0.15	0.17
4.00	5.00	0.00	4.03	4.92	0.06	0.03	-0.08	0.06	0.10
5.00	5.00	0.00	5.00	4.97	0.00	0.00	-0.03	0.00	0.03
6.00	5.00	0.00	6.06	4.93	-0.02	0.06	-0.07	-0.02	0.09
7.00	5.00	0.00	7.05	4.95	0.04	0.05	-0.05	0.04	0.08
8.00	5.00	0.00	8.06	4.94	0.06	0.06	-0.06	0.06	0.10
9.00	5.00	0.00	9.08	4.94	0.06	0.08	-0.06	0.06	0.12
10.00	5.00	0.00	10.08	4.99	0.07	0.08	-0.01	0.07	0.11
11.00	5.00	0.00	11.11	5.00	0.04	0.11	0.00	0.04	0.12
12.00	5.00	0.00	12.08	5.00	0.05	0.08	0.00	0.05	0.09
13.00	5.00	0.00	13.07	5.01	0.00	0.07	0.01	0.00	0.07
14.00	5.00	0.00	14.09	5.00	-0.01	0.09	0.00	-0.01	0.09
15.00	5.00	0.00	15.11	5.02	-0.03	0.11	0.02	-0.03	0.12
0.00	6.00	0.00	0.02	5.93	-0.03	0.02	-0.07	-0.03	0.08
1.00	6.00	0.00	1.04	5.89	-0.03	0.04	-0.11	-0.03	0.12
2.00	6.00	0.00	2.00	5.95	-0.01	0.00	-0.05	-0.01	0.05
3.00	6.00	0.00	2.99	5.97	-0.11	-0.01	-0.03	-0.11	0.11
4.00	6.00	0.00	4.03	5.91	0.03	0.03	-0.09	0.03	0.10
5.00	6.00	0.00	5.03	5.91	0.01	0.03	-0.09	0.01	0.10
6.00	6.00	0.00	6.02	5.97	0.04	0.02	-0.03	0.04	0.05
7.00	6.00	0.00	7.08	5.94	0.04	0.08	-0.06	0.04	0.11
8.00	6.00	0.00	8.06	5.92	0.06	0.06	-0.08	0.06	0.12
9.00	6.00	0.00	9.07	5.96	0.08	0.07	-0.04	0.08	0.11
10.00	6.00	0.00	10.08	5.95	0.05	0.08	-0.05	0.05	0.11

11.00	6.00	0.00	11.08	5.96	0.04	0.08	-0.04	0.04	0.10
12.00	6.00	0.00	12.03	5.95	-0.17	0.03	-0.05	-0.17	0.18
13.00	6.00	0.00	13.07	5.95	0.02	0.07	-0.05	0.02	0.09
14.00	6.00	0.00	14.08	5.96	0.00	0.08	-0.04	0.00	0.09
15.00	6.00	0.00	15.10	5.97	-0.04	0.10	-0.03	-0.04	0.11
0.00	7.00	0.00	0.03	6.92	-0.04	0.03	-0.08	-0.04	0.09
1.00	7.00	0.00	1.03	6.94	-0.03	0.03	-0.06	-0.03	0.07
2.00	7.00	0.00	2.02	6.94	0.01	0.02	-0.06	0.01	0.06
3.00	7.00	0.00	3.01	6.94	0.05	0.01	-0.06	0.05	0.08
4.00	7.00	0.00	4.01	6.99	0.04	0.01	-0.01	0.04	0.04
5.00	7.00	0.00	5.01	6.98	0.02	0.01	-0.02	0.02	0.03
6.00	7.00	0.00	6.03	6.94	0.02	0.03	-0.06	0.02	0.07
7.00	7.00	0.00	7.06	6.96	0.07	0.06	-0.04	0.07	0.10
8.00	7.00	0.00	8.08	6.93	0.05	0.08	-0.07	0.05	0.12
9.00	7.00	0.00	9.07	6.94	0.03	0.07	-0.06	0.03	0.10
10.00	7.00	0.00	10.06	6.92	0.04	0.06	-0.08	0.04	0.11
11.00	7.00	0.00	11.06	6.97	0.02	0.06	-0.03	0.02	0.07
12.00	7.00	0.00	12.06	6.98	0.08	0.06	-0.02	0.08	0.10
13.00	7.00	0.00	13.04	6.97	0.00	0.04	-0.03	0.00	0.05
14.00	7.00	0.00	14.08	6.99	-0.02	0.08	-0.01	-0.02	0.08
15.00	7.00	0.00	15.08	6.96	-0.02	0.08	-0.04	-0.02	0.09
0.00	8.00	0.00	0.02	7.92	-0.03	0.02	-0.08	-0.03	0.09
1.00	8.00	0.00	1.02	7.94	-0.05	0.02	-0.06	-0.05	0.08
2.00	8.00	0.00	1.96	7.97	-0.12	-0.04	-0.03	-0.12	0.13
3.00	8.00	0.00	2.98	7.96	-0.12	-0.02	-0.04	-0.12	0.13
4.00	8.00	0.00	3.99	7.94	-0.01	-0.01	-0.06	-0.01	0.06
5.00	8.00	0.00	5.03	7.92	0.00	0.03	-0.08	0.00	0.09
6.00	8.00	0.00	6.04	7.94	0.01	0.04	-0.06	0.01	0.07
7.00	8.00	0.00	7.08	7.95	0.03	0.08	-0.05	0.03	0.10
8.00	8.00	0.00	8.05	7.96	0.07	0.05	-0.04	0.07	0.09
9.00	8.00	0.00	9.06	7.97	0.03	0.06	-0.03	0.03	0.07
10.00	8.00	0.00	10.05	7.99	0.03	0.05	-0.01	0.03	0.06
11.00	8.00	0.00	11.05	7.98	0.01	0.05	-0.02	0.01	0.05
12.00	8.00	0.00	12.03	8.00	-0.01	0.03	0.00	-0.01	0.03
13.00	8.00	0.00	13.06	8.00	0.00	0.06	0.00	0.00	0.06
14.00	8.00	0.00	14.07	7.99	-0.02	0.07	-0.01	-0.02	0.07
15.00	8.00	0.00	15.03	8.03	-0.03	0.03	0.03	-0.03	0.05

*-Error greater than .25"

3Space Isotrak Accuracy Tests

File: gridb3.pc
Origin: -23.44,-9.40,1.90
Vector Distance from Origin to Source: 25.32"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR
X	Y	Z	X	Y	Z	X	Y	Z	D
0.00	0.00	0.00	-0.04	0.04	-0.05	-0.04	0.04	-0.05	0.08
1.00	0.00	0.00	1.01	0.05	0.04	0.01	0.05	0.04	0.06
2.00	0.00	0.00	2.01	0.04	0.05	0.01	0.04	0.05	0.06
3.00	0.00	0.00	3.03	0.03	0.06	0.03	0.03	0.06	0.07
4.00	0.00	0.00	4.03	0.02	0.05	0.03	0.02	0.05	0.06
5.00	0.00	0.00	5.01	0.02	-0.08	0.01	0.02	-0.08	0.08
6.00	0.00	0.00	6.03	-0.03	0.00	0.03	-0.03	0.00	0.04
7.00	0.00	0.00	7.02	-0.01	0.02	0.02	-0.01	0.02	0.03
8.00	0.00	0.00	8.08	-0.01	0.02	0.08	-0.01	0.02	0.08
9.00	0.00	0.00	9.05	-0.03	-0.01	0.05	-0.03	-0.01	0.06
10.00	0.00	0.00	10.12	-0.04	0.02	0.12	-0.04	0.02	0.13
11.00	0.00	0.00	11.10	0.04	0.05	0.10	0.04	0.05	0.12
12.00	0.00	0.00	12.13	0.02	0.05	0.13	0.02	0.05	0.14
13.00	0.00	0.00	13.12	0.00	0.03	0.12	0.00	0.03	0.12
14.00	0.00	0.00	14.13	0.01	0.01	0.13	0.01	0.01	0.13
15.00	0.00	0.00	15.13	-0.04	-0.14	0.13	-0.04	-0.14	0.20
0.00	1.00	0.00	-0.04	1.06	-0.02	-0.04	0.06	-0.02	0.07
1.00	1.00	0.00	1.00	1.03	0.04	0.00	0.03	0.04	0.05
2.00	1.00	0.00	2.01	1.03	0.08	0.01	0.03	0.08	0.09
3.00	1.00	0.00	3.04	1.02	0.03	0.04	0.02	0.03	0.05
4.00	1.00	0.00	3.97	1.05	-0.06	-0.03	0.05	-0.06	0.08
5.00	1.00	0.00	4.96	1.03	-0.14	-0.04	0.03	-0.14	0.15
6.00	1.00	0.00	5.99	1.01	-0.01	-0.01	0.01	-0.01	0.02
7.00	1.00	0.00	7.01	0.99	0.00	0.01	-0.01	0.00	0.01
8.00	1.00	0.00	8.06	0.98	0.01	0.06	-0.02	0.01	0.06
9.00	1.00	0.00	9.11	1.00	0.05	0.11	0.00	0.05	0.12
10.00	1.00	0.00	10.12	1.01	0.04	0.12	0.01	0.04	0.13
11.00	1.00	0.00	11.11	1.00	0.06	0.11	0.00	0.06	0.13
12.00	1.00	0.00	12.15	0.98	0.04	0.15	-0.02	0.04	0.16
13.00	1.00	0.00	13.15	0.98	0.05	0.15	-0.02	0.05	0.16
14.00	1.00	0.00	14.12	0.98	0.01	0.12	-0.02	0.01	0.12
15.00	1.00	0.00	15.11	0.99	0.04	0.11	-0.01	0.04	0.12
0.00	2.00	0.00	0.01	2.04	0.04	0.01	0.04	0.04	0.06
1.00	2.00	0.00	0.99	2.03	0.06	-0.01	0.03	0.06	0.07
2.00	2.00	0.00	2.03	2.01	0.05	0.03	0.01	0.05	0.06
3.00	2.00	0.00	3.04	1.99	0.04	0.04	-0.01	0.04	0.06
4.00	2.00	0.00	4.03	2.01	0.05	0.03	0.01	0.05	0.06
5.00	2.00	0.00	5.04	1.99	0.06	0.04	-0.01	0.06	0.07
6.00	2.00	0.00	6.02	2.01	0.06	0.02	0.01	0.06	0.06
7.00	2.00	0.00	7.07	1.98	0.03	0.07	-0.02	0.03	0.08
8.00	2.00	0.00	8.05	2.00	0.05	0.05	0.00	0.05	0.07
9.00	2.00	0.00	9.07	1.99	0.06	0.07	-0.01	0.06	0.09
10.00	2.00	0.00	10.09	2.02	0.05	0.09	0.02	0.05	0.10
11.00	2.00	0.00	11.08	2.05	0.07	0.08	0.05	0.07	0.12
12.00	2.00	0.00	12.11	2.02	0.05	0.11	0.02	0.05	0.12
13.00	2.00	0.00	13.11	2.02	0.04	0.11	0.02	0.04	0.12
14.00	2.00	0.00	14.11	2.01	0.05	0.11	0.01	0.05	0.12
15.00	2.00	0.00	15.12	2.03	0.02	0.12	0.03	0.02	0.13

0.00	3.00	0.00	0.03	2.99	0.07	0.03	-0.01	0.07	0.08
1.00	3.00	0.00	1.02	2.99	0.09	0.02	-0.01	0.09	0.09
2.00	3.00	0.00	1.99	2.99	0.07	-0.01	-0.01	0.07	0.07
3.00	3.00	0.00	2.98	3.02	0.08	-0.02	0.02	0.08	0.08
4.00	3.00	0.00	4.00	3.02	0.07	0.00	0.02	0.07	0.07
5.00	3.00	0.00	5.02	2.97	0.05	0.02	-0.03	0.05	0.06
6.00	3.00	0.00	5.98	3.00	0.05	-0.02	0.00	0.05	0.05
7.00	3.00	0.00	6.98	3.00	-0.07	-0.02	0.00	-0.07	0.07
8.00	3.00	0.00	8.03	3.00	0.03	0.03	0.00	0.03	0.04
9.00	3.00	0.00	9.02	3.02	0.07	0.02	0.02	0.07	0.08
10.00	3.00	0.00	10.07	3.00	0.07	0.07	0.00	0.07	0.10
11.00	3.00	0.00	11.09	2.98	0.04	0.09	-0.02	0.04	0.10
12.00	3.00	0.00	12.09	3.03	0.04	0.09	0.03	0.04	0.10
13.00	3.00	0.00	13.08	3.01	0.04	0.08	0.01	0.04	0.09
14.00	3.00	0.00	14.07	3.01	0.03	0.07	0.01	0.03	0.08
15.00	3.00	0.00	15.07	3.01	0.01	0.07	0.01	0.01	0.07
0.00	4.00	0.00	0.01	3.97	0.05	0.01	-0.03	0.05	0.06
1.00	4.00	0.00	1.01	3.98	0.06	0.01	-0.02	0.06	0.06
2.00	4.00	0.00	1.99	4.01	0.06	-0.01	0.01	0.06	0.06
3.00	4.00	0.00	2.96	4.01	-0.12	-0.04	0.01	-0.12	0.13
4.00	4.00	0.00	3.95	4.05	-0.04	-0.05	0.05	-0.04	0.08
5.00	4.00	0.00	5.00	3.99	0.02	0.00	-0.01	0.02	0.02
6.00	4.00	0.00	5.98	4.01	0.05	-0.02	0.01	0.05	0.05
7.00	4.00	0.00	6.98	4.03	-0.06	-0.02	0.03	-0.06	0.07
8.00	4.00	0.00	8.07	4.01	0.06	0.07	0.01	0.06	0.09
9.00	4.00	0.00	9.07	4.01	0.06	0.07	0.01	0.06	0.09
10.00	4.00	0.00	10.06	4.02	0.06	0.06	0.02	0.06	0.09
11.00	4.00	0.00	11.09	4.03	0.05	0.09	0.03	0.05	0.11
12.00	4.00	0.00	12.10	4.05	0.04	0.10	0.05	0.04	0.12
13.00	4.00	0.00	13.07	4.03	0.00	0.07	0.03	0.00	0.08
14.00	4.00	0.00	14.09	4.00	0.02	0.09	0.00	0.02	0.09
15.00	4.00	0.00	15.11	4.04	-0.02	0.11	0.04	-0.02	0.12
0.00	5.00	0.00	0.03	5.00	0.05	0.03	0.00	0.05	0.06
1.00	5.00	0.00	1.02	5.01	0.03	0.02	0.01	0.03	0.04
2.00	5.00	0.00	2.00	4.98	0.06	0.00	-0.02	0.06	0.06
3.00	5.00	0.00	2.98	5.03	-0.08	-0.02	0.03	-0.08	0.09
4.00	5.00	0.00	4.01	5.04	0.11	0.01	0.04	0.11	0.12
5.00	5.00	0.00	4.99	5.03	0.03	-0.01	0.03	0.03	0.04
6.00	5.00	0.00	6.01	5.03	-0.07	0.01	0.03	-0.07	0.08
7.00	5.00	0.00	7.03	5.02	0.10	0.03	0.02	0.10	0.11
8.00	5.00	0.00	8.06	5.03	0.08	0.06	0.03	0.08	0.10
9.00	5.00	0.00	9.06	5.05	0.07	0.06	0.05	0.07	0.10
10.00	5.00	0.00	10.07	5.03	0.05	0.07	0.03	0.05	0.09
11.00	5.00	0.00	11.08	5.06	0.06	0.08	0.06	0.06	0.12
12.00	5.00	0.00	12.07	5.05	0.04	0.07	0.05	0.04	0.09
13.00	5.00	0.00	13.11	5.06	0.03	0.11	0.06	0.03	0.13
14.00	5.00	0.00	14.09	5.07	0.02	0.09	0.07	0.02	0.12
15.00	5.00	0.00	15.09	5.07	-0.01	0.09	0.07	-0.01	0.11
0.00	6.00	0.00	0.04	6.02	-0.03	0.04	0.02	-0.03	0.05
1.00	6.00	0.00	1.00	6.00	0.03	0.00	0.00	0.03	0.03
2.00	6.00	0.00	1.99	6.02	0.08	-0.01	0.02	0.08	0.08
3.00	6.00	0.00	2.96	6.03	-0.11	-0.04	0.03	-0.11	0.12
4.00	6.00	0.00	4.01	6.00	0.02	0.01	0.00	0.02	0.02
5.00	6.00	0.00	5.00	6.02	0.03	0.00	0.02	0.03	0.04
6.00	6.00	0.00	5.99	6.02	-0.11	-0.01	0.02	-0.11	0.11
7.00	6.00	0.00	7.05	6.04	0.05	0.05	0.04	0.05	0.08
8.00	6.00	0.00	8.07	6.01	0.10	0.07	0.01	0.10	0.12
9.00	6.00	0.00	9.05	6.01	0.05	0.05	0.01	0.05	0.07
10.00	6.00	0.00	10.06	6.04	0.08	0.06	0.04	0.08	0.11

11.00	6.00	0.00	11.09	6.01	0.05	0.09	0.01	0.05	0.10
12.00	6.00	0.00	12.07	6.02	0.08	0.07	0.02	0.08	0.11
13.00	6.00	0.00	13.10	6.00	0.03	0.10	0.00	0.03	0.10
14.00	6.00	0.00	14.08	6.00	0.00	0.08	0.00	0.00	0.08
15.00	6.00	0.00	15.10	6.02	-0.02	0.10	0.02	-0.02	0.10
0.00	7.00	0.00	0.01	7.01	0.00	0.01	0.01	0.00	0.01
1.00	7.00	0.00	1.02	7.01	0.05	0.02	0.01	0.05	0.05
2.00	7.00	0.00	2.01	7.01	0.05	0.01	0.01	0.05	0.05
3.00	7.00	0.00	3.01	7.03	-0.04	0.01	0.03	-0.04	0.05
4.00	7.00	0.00	3.98	7.07	0.02	-0.02	0.07	0.02	0.08
5.00	7.00	0.00	4.99	7.04	0.02	-0.01	0.04	0.02	0.05
6.00	7.00	0.00	6.02	7.03	-0.01	0.02	0.03	-0.01	0.04
7.00	7.00	0.00	7.03	7.08	0.05	0.03	0.08	0.05	0.10
8.00	7.00	0.00	8.07	7.02	0.05	0.07	0.02	0.05	0.09
9.00	7.00	0.00	9.06	7.06	0.09	0.06	0.06	0.09	0.12
10.00	7.00	0.00	10.05	7.04	0.04	0.05	0.04	0.04	0.08
11.00	7.00	0.00	11.08	7.03	0.04	0.08	0.03	0.04	0.09
12.00	7.00	0.00	12.07	7.02	0.05	0.07	0.02	0.05	0.09
13.00	7.00	0.00	13.06	7.04	-0.02	0.06	0.04	-0.02	0.07
14.00	7.00	0.00	14.07	7.04	-0.02	0.07	0.04	-0.02	0.08
15.00	7.00	0.00	15.07	7.01	-0.05	0.07	0.01	-0.05	0.09
0.00	8.00	0.00	0.00	8.03	0.01	0.00	0.03	0.01	0.03
1.00	8.00	0.00	1.02	8.07	0.05	0.02	0.07	0.05	0.09
2.00	8.00	0.00	2.01	8.04	0.06	0.01	0.04	0.06	0.07
3.00	8.00	0.00	3.00	8.06	0.08	0.00	0.06	0.08	0.10
4.00	8.00	0.00	4.00	8.06	0.07	0.00	0.06	0.07	0.09
5.00	8.00	0.00	4.97	8.03	-0.06	-0.03	0.03	-0.06	0.07
6.00	8.00	0.00	6.03	8.02	0.02	0.03	0.02	0.02	0.04
7.00	8.00	0.00	7.06	8.01	0.04	0.06	0.01	0.04	0.07
8.00	8.00	0.00	8.06	8.04	0.04	0.06	0.04	0.04	0.08
9.00	8.00	0.00	9.07	8.03	0.07	0.07	0.03	0.07	0.10
10.00	8.00	0.00	10.06	8.04	0.05	0.06	0.04	0.05	0.09
11.00	8.00	0.00	11.07	8.05	0.02	0.07	0.05	0.02	0.09
12.00	8.00	0.00	12.04	8.03	0.01	0.04	0.03	0.01	0.05
13.00	8.00	0.00	13.06	8.05	-0.01	0.06	0.05	-0.01	0.08
14.00	8.00	0.00	14.09	8.04	-0.02	0.09	0.04	-0.02	0.10
15.00	8.00	0.00	15.06	8.03	-0.05	0.06	0.03	-0.05	0.08

*-Error greater than .25"

3Space Isotrak Accuracy Tests

File: grid141.pc
Origin: -23.5,-8.50,14.35
Vector Distance from Origin to Source: 28.81"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR
X	Y	Z	X	Y	Z	X	Y	Z	D
0.00	0.00	0.00	0.03	0.00	0.05	0.03	0.00	0.05	0.06
1.00	0.00	0.00	1.01	0.02	0.06	0.01	0.02	0.06	0.06
2.00	0.00	0.00	2.03	0.01	0.10	0.03	0.01	0.10	0.10
3.00	0.00	0.00	2.96	-0.05	-0.06	-0.04	-0.05	-0.06	0.09
4.00	0.00	0.00	3.95	-0.04	-0.05	-0.05	-0.04	-0.05	0.08
5.00	0.00	0.00	5.07	0.00	0.03	0.07	0.00	0.03	0.08
6.00	0.00	0.00	6.07	-0.02	0.04	0.07	-0.02	0.04	0.08
7.00	0.00	0.00	7.07	-0.02	0.06	0.07	-0.02	0.06	0.09
8.00	0.00	0.00	8.06	-0.01	0.02	0.06	-0.01	0.02	0.06
9.00	0.00	0.00	9.05	0.01	0.01	0.05	0.01	0.01	0.05
10.00	0.00	0.00	10.08	0.00	0.02	0.08	0.00	0.02	0.08
11.00	0.00	0.00	11.10	0.00	0.03	0.10	0.00	0.03	0.10
12.00	0.00	0.00	12.10	0.00	0.03	0.10	0.00	0.03	0.10
13.00	0.00	0.00	13.10	0.00	0.02	0.10	0.00	0.02	0.10
14.00	0.00	0.00	14.12	0.01	0.03	0.12	0.01	0.03	0.12
15.00	0.00	0.00	15.11	0.01	-0.01	0.11	0.01	-0.01	0.11
0.00	1.00	0.00	0.06	1.07	0.16	0.06	0.07	0.16	0.18
1.00	1.00	0.00	0.94	1.00	0.01	-0.06	0.00	0.01	0.06
2.00	1.00	0.00	2.02	1.00	0.11	0.02	0.00	0.11	0.11
3.00	1.00	0.00	2.99	0.97	-0.01	-0.01	-0.03	-0.01	0.03
4.00	1.00	0.00	3.97	0.98	0.01	-0.03	-0.02	0.01	0.04
5.00	1.00	0.00	5.08	0.99	0.09	0.08	-0.01	0.09	0.12
6.00	1.00	0.00	6.07	1.00	0.08	0.07	0.00	0.08	0.11
7.00	1.00	0.00	7.07	1.02	0.09	0.07	0.02	0.09	0.12
8.00	1.00	0.00	8.09	1.03	0.08	0.09	0.03	0.08	0.12
9.00	1.00	0.00	9.11	1.00	0.08	0.11	0.00	0.08	0.14
10.00	1.00	0.00	10.11	1.02	0.09	0.11	0.02	0.09	0.14
11.00	1.00	0.00	11.16	1.04	0.11	0.16	0.04	0.11	0.20
12.00	1.00	0.00	12.14	1.06	0.10	0.14	0.06	0.10	0.18
13.00	1.00	0.00	13.13	1.05	0.09	0.13	0.05	0.09	0.17
14.00	1.00	0.00	14.12	1.02	0.04	0.12	0.02	0.04	0.13
15.00	1.00	0.00	15.13	1.08	0.06	0.13	0.08	0.06	0.16
0.00	2.00	0.00	0.05	2.07	0.17	0.05	0.07	0.17	0.19
1.00	2.00	0.00	0.97	2.00	0.07	-0.03	0.00	0.07	0.08
2.00	2.00	0.00	1.95	1.98	0.00	-0.05	-0.02	0.00	0.05
3.00	2.00	0.00	2.95	2.00	0.01	-0.05	0.00	0.01	0.05
4.00	2.00	0.00	3.93	1.99	0.02	-0.07	-0.01	0.02	0.07
5.00	2.00	0.00	5.06	2.00	0.11	0.06	0.00	0.11	0.13
6.00	2.00	0.00	6.04	1.99	0.11	0.04	-0.01	0.11	0.12
7.00	2.00	0.00	7.04	2.01	0.10	0.04	0.01	0.10	0.11
8.00	2.00	0.00	8.08	2.02	0.11	0.08	0.02	0.11	0.14
9.00	2.00	0.00	9.08	2.02	0.11	0.08	0.02	0.11	0.14
10.00	2.00	0.00	10.07	2.01	0.09	0.07	0.01	0.09	0.11
11.00	2.00	0.00	11.11	2.04	0.10	0.11	0.04	0.10	0.15
12.00	2.00	0.00	12.09	2.04	0.10	0.09	0.04	0.10	0.14
13.00	2.00	0.00	13.11	2.08	0.11	0.11	0.08	0.11	0.17
14.00	2.00	0.00	14.11	2.09	0.10	0.11	0.09	0.10	0.17
15.00	2.00	0.00	15.12	2.10	0.02	0.12	0.10	0.02	0.16

0.00	3.00	0.00	0.01	3.00	0.09	0.01	0.00	0.09	0.09
1.00	3.00	0.00	1.02	3.02	0.16	0.02	0.02	0.16	0.16
2.00	3.00	0.00	1.94	3.01	0.02	-0.06	0.01	0.02	0.06
3.00	3.00	0.00	2.92	3.00	0.02	-0.08	0.00	0.02	0.08
4.00	3.00	0.00	4.02	3.03	0.12	0.02	0.03	0.12	0.13
5.00	3.00	0.00	5.05	3.00	0.14	0.05	0.00	0.14	0.15
6.00	3.00	0.00	6.02	3.03	0.14	0.02	0.03	0.14	0.14
7.00	3.00	0.00	7.06	3.01	0.15	0.06	0.01	0.15	0.16
8.00	3.00	0.00	8.07	3.01	0.16	0.07	0.01	0.16	0.17
9.00	3.00	0.00	9.03	3.03	0.12	0.03	0.03	0.12	0.13
10.00	3.00	0.00	10.08	3.04	0.16	0.08	0.04	0.16	0.18
11.00	3.00	0.00	11.11	3.10	0.17	0.11	0.10	0.17	0.23
12.00	3.00	0.00	12.10	3.03	0.11	0.10	0.03	0.11	0.15
13.00	3.00	0.00	13.12	3.07	0.14	0.12	0.07	0.14	0.20
14.00	3.00	0.00	14.12	3.06	0.11	0.12	0.06	0.11	0.17
15.00	3.00	0.00	15.17	3.09	0.10	0.17	0.09	0.10	0.22
0.00	4.00	0.00	0.06	3.99	0.17	0.06	-0.01	0.17	0.18
1.00	4.00	0.00	0.92	3.99	-0.01	-0.08	-0.01	-0.01	0.08
2.00	4.00	0.00	1.91	3.97	-0.02	-0.09	-0.03	-0.02	0.10
3.00	4.00	0.00	2.91	3.99	0.05	-0.09	-0.01	0.05	0.10
4.00	4.00	0.00	4.02	4.00	0.15	0.02	0.00	0.15	0.15
5.00	4.00	0.00	5.02	4.06	0.17	0.02	0.06	0.17	0.18
6.00	4.00	0.00	6.06	4.01	0.19	0.06	0.01	0.19	0.20
7.00	4.00	0.00	7.00	4.02	0.13	0.00	0.02	0.13	0.13
8.00	4.00	0.00	8.06	4.04	0.18	0.06	0.04	0.18	0.19
9.00	4.00	0.00	9.03	4.02	0.15	0.03	0.02	0.15	0.15
10.00	4.00	0.00	10.06	4.07	0.16	0.06	0.07	0.16	0.18
11.00	4.00	0.00	11.08	4.07	0.15	0.08	0.07	0.15	0.18
12.00	4.00	0.00	12.08	4.07	0.15	0.08	0.07	0.15	0.18
13.00	4.00	0.00	13.06	4.10	0.13	0.06	0.10	0.13	0.17
14.00	4.00	0.00	14.09	4.11	0.09	0.09	0.11	0.09	0.17
15.00	4.00	0.00	15.20	4.20	0.12	0.20	0.20	0.12	0.31	*
0.00	5.00	0.00	0.05	4.99	0.21	0.05	-0.01	0.21	0.22
1.00	5.00	0.00	0.90	4.94	-0.02	-0.10	-0.06	-0.02	0.12
2.00	5.00	0.00	1.89	4.99	0.06	-0.11	-0.01	0.06	0.13
3.00	5.00	0.00	2.85	5.00	0.02	-0.15	0.00	0.02	0.15
4.00	5.00	0.00	4.01	5.02	0.18	0.01	0.02	0.18	0.18
5.00	5.00	0.00	4.98	5.02	0.17	-0.02	0.02	0.17	0.17
6.00	5.00	0.00	6.01	5.00	0.17	0.01	0.00	0.17	0.17
7.00	5.00	0.00	7.00	5.05	0.17	0.00	0.05	0.17	0.18
8.00	5.00	0.00	8.04	5.03	0.19	0.04	0.03	0.19	0.20
9.00	5.00	0.00	9.00	5.05	0.16	0.00	0.05	0.16	0.17
10.00	5.00	0.00	10.07	5.08	0.20	0.07	0.08	0.20	0.23
11.00	5.00	0.00	11.06	5.05	0.19	0.06	0.05	0.19	0.21
12.00	5.00	0.00	12.08	5.11	0.19	0.08	0.11	0.19	0.23
13.00	5.00	0.00	13.13	5.12	0.19	0.13	0.12	0.19	0.26	*
14.00	5.00	0.00	14.09	5.14	0.11	0.09	0.14	0.11	0.20
15.00	5.00	0.00	15.07	5.13	0.09	0.07	0.13	0.09	0.17
0.00	6.00	0.00	-0.02	6.00	0.16	-0.02	0.00	0.16	0.16
1.00	6.00	0.00	0.89	5.99	0.03	-0.11	-0.01	0.03	0.11
2.00	6.00	0.00	1.89	6.00	0.07	-0.11	0.00	0.07	0.13
3.00	6.00	0.00	2.86	6.00	0.05	-0.14	0.00	0.05	0.15
4.00	6.00	0.00	4.00	6.02	0.20	0.00	0.02	0.20	0.20
5.00	6.00	0.00	4.98	6.02	0.18	-0.02	0.02	0.18	0.18
6.00	6.00	0.00	5.98	6.03	0.17	-0.02	0.03	0.17	0.17
7.00	6.00	0.00	6.98	6.03	0.19	-0.02	0.03	0.19	0.19
8.00	6.00	0.00	7.96	6.02	0.16	-0.04	0.02	0.16	0.17
9.00	6.00	0.00	9.01	6.02	0.19	0.01	0.02	0.19	0.19
10.00	6.00	0.00	10.05	6.04	0.22	0.05	0.04	0.22	0.23

11.00	6.00	0.00	11.06	6.06	0.21	0.06	0.06	0.21	0.23
12.00	6.00	0.00	12.06	6.05	0.20	0.06	0.05	0.20	0.21
13.00	6.00	0.00	13.10	6.03	0.15	0.10	0.03	0.15	0.18
14.00	6.00	0.00	14.09	6.07	0.14	0.09	0.07	0.14	0.18
15.00	6.00	0.00	15.10	6.05	0.12	0.10	0.05	0.12	0.16
0.00	7.00	0.00	-0.07	7.05	0.10	-0.07	0.05	0.10	0.13
1.00	7.00	0.00	0.90	7.00	0.04	-0.10	0.00	0.04	0.11
2.00	7.00	0.00	1.90	7.00	0.09	-0.10	0.00	0.09	0.13
3.00	7.00	0.00	2.87	7.02	0.09	-0.13	0.02	0.09	0.16
4.00	7.00	0.00	4.00	7.02	0.20	0.00	0.02	0.20	0.20
5.00	7.00	0.00	4.99	7.06	0.20	-0.01	0.06	0.20	0.21
6.00	7.00	0.00	6.02	7.05	0.22	0.02	0.05	0.22	0.23
7.00	7.00	0.00	7.00	7.04	0.22	0.00	0.04	0.22	0.22
8.00	7.00	0.00	8.01	7.03	0.23	0.01	0.03	0.23	0.23
9.00	7.00	0.00	9.02	7.04	0.22	0.02	0.04	0.22	0.22
10.00	7.00	0.00	10.08	7.05	0.25	0.08	0.05	0.25	0.27	*
11.00	7.00	0.00	11.02	7.05	0.19	0.02	0.05	0.19	0.20
12.00	7.00	0.00	12.09	7.06	0.22	0.09	0.06	0.22	0.25
13.00	7.00	0.00	13.11	7.07	0.16	0.11	0.07	0.16	0.21
14.00	7.00	0.00	14.10	7.12	0.15	0.10	0.12	0.15	0.22
15.00	7.00	0.00	15.20	7.15	0.17	0.20	0.15	0.17	0.30	*
0.00	8.00	0.00	-0.01	8.04	0.21	-0.01	0.04	0.21	0.21
1.00	8.00	0.00	0.90	8.03	0.08	-0.10	0.03	0.08	0.13
2.00	8.00	0.00	1.87	8.05	0.08	-0.13	0.05	0.08	0.16
3.00	8.00	0.00	3.02	8.00	0.22	0.02	0.00	0.22	0.22
4.00	8.00	0.00	3.98	8.01	0.21	-0.02	0.01	0.21	0.21
5.00	8.00	0.00	4.98	8.02	0.21	-0.02	0.02	0.21	0.21
6.00	8.00	0.00	5.98	8.07	0.20	-0.02	0.07	0.20	0.21
7.00	8.00	0.00	6.99	8.04	0.21	-0.01	0.04	0.21	0.21
8.00	8.00	0.00	8.00	8.06	0.21	0.00	0.06	0.21	0.22
9.00	8.00	0.00	9.04	8.08	0.24	0.04	0.08	0.24	0.26	*
10.00	8.00	0.00	9.98	8.07	0.21	-0.02	0.07	0.21	0.22
11.00	8.00	0.00	11.01	8.07	0.20	0.01	0.07	0.20	0.21
12.00	8.00	0.00	12.00	8.09	0.19	0.00	0.09	0.19	0.21
13.00	8.00	0.00	13.13	8.09	0.21	0.13	0.09	0.21	0.26	*
14.00	8.00	0.00	14.14	8.12	0.17	0.14	0.12	0.17	0.25	*
15.00	8.00	0.00	15.04	8.11	0.10	0.04	0.11	0.10	0.15

*-Error greater than .25"

3Space Isotrak Accuracy Tests

File: grid143.pc
Origin: -23.50,-8.50,14.35
Vector Distance from Origin to Source: 28.81"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR
X	Y	Z	X	Y	Z	X	Y	Z	D
0.00	0.00	0.00	-0.08	0.01	-0.07	-0.08	0.01	-0.07	0.11
1.00	0.00	0.00	0.88	-0.01	-0.16	-0.12	-0.01	-0.16	0.20
2.00	0.00	0.00	1.88	-0.05	-0.14	-0.12	-0.05	-0.14	0.19
3.00	0.00	0.00	2.89	-0.03	-0.15	-0.11	-0.03	-0.15	0.19
4.00	0.00	0.00	3.98	0.00	-0.04	-0.02	0.00	-0.04	0.04
5.00	0.00	0.00	5.00	-0.01	-0.05	0.00	-0.01	-0.05	0.05
6.00	0.00	0.00	5.96	0.01	-0.06	-0.04	0.01	-0.06	0.07
7.00	0.00	0.00	6.99	0.02	-0.05	-0.01	0.02	-0.05	0.05
8.00	0.00	0.00	8.03	-0.03	-0.03	0.03	-0.03	-0.03	0.05
9.00	0.00	0.00	9.01	-0.06	-0.08	0.01	-0.06	-0.08	0.10
10.00	0.00	0.00	9.99	-0.04	-0.07	-0.01	-0.04	-0.07	0.08
11.00	0.00	0.00	11.01	-0.03	-0.07	0.01	-0.03	-0.07	0.08
12.00	0.00	0.00	12.07	-0.01	-0.03	0.07	-0.01	-0.03	0.08
13.00	0.00	0.00	13.04	-0.05	-0.07	0.04	-0.05	-0.07	0.09
14.00	0.00	0.00	14.04	-0.03	-0.06	0.04	-0.03	-0.06	0.08
15.00	0.00	0.00	15.08	-0.01	-0.09	0.08	-0.01	-0.09	0.12
0.00	1.00	0.00	-0.08	0.96	-0.14	-0.08	-0.04	-0.14	0.17
1.00	1.00	0.00	0.90	0.95	-0.11	-0.10	-0.05	-0.11	0.16
2.00	1.00	0.00	1.85	0.91	-0.13	-0.15	-0.09	-0.13	0.22
3.00	1.00	0.00	2.99	0.97	-0.04	-0.01	-0.03	-0.04	0.05
4.00	1.00	0.00	3.99	0.94	-0.03	-0.01	-0.06	-0.03	0.07
5.00	1.00	0.00	4.97	0.98	-0.03	-0.03	-0.02	-0.03	0.05
6.00	1.00	0.00	5.99	1.00	0.00	-0.01	0.00	0.00	0.01
7.00	1.00	0.00	6.96	0.96	-0.05	-0.04	-0.04	-0.05	0.08
8.00	1.00	0.00	8.00	0.95	-0.01	0.00	-0.05	-0.01	0.05
9.00	1.00	0.00	8.95	0.96	-0.05	-0.05	-0.04	-0.05	0.08
10.00	1.00	0.00	10.02	1.00	0.01	0.02	0.00	0.01	0.02
11.00	1.00	0.00	10.99	0.97	-0.03	-0.01	-0.03	-0.03	0.04
12.00	1.00	0.00	12.05	0.98	-0.01	0.05	-0.02	-0.01	0.05
13.00	1.00	0.00	13.02	0.98	-0.01	0.02	-0.02	-0.01	0.03
14.00	1.00	0.00	14.12	1.05	-0.02	0.12	0.05	-0.02	0.13
15.00	1.00	0.00	15.07	1.00	-0.07	0.07	0.00	-0.07	0.10
0.00	2.00	0.00	-0.10	1.99	-0.15	-0.10	-0.01	-0.15	0.18
1.00	2.00	0.00	0.87	1.96	-0.10	-0.13	-0.04	-0.10	0.17
2.00	2.00	0.00	1.86	1.98	-0.10	-0.14	-0.02	-0.10	0.17
3.00	2.00	0.00	2.97	1.99	-0.01	-0.03	-0.01	-0.01	0.03
4.00	2.00	0.00	3.98	1.99	0.02	-0.02	-0.01	0.02	0.03
5.00	2.00	0.00	4.95	1.99	0.01	-0.05	-0.01	0.01	0.05
6.00	2.00	0.00	5.95	1.98	-0.01	-0.05	-0.02	-0.01	0.05
7.00	2.00	0.00	7.00	2.01	0.03	0.00	0.01	0.03	0.03
8.00	2.00	0.00	7.98	2.00	0.01	-0.02	0.00	0.01	0.02
9.00	2.00	0.00	9.01	1.97	0.02	0.01	-0.03	0.02	0.04
10.00	2.00	0.00	10.02	2.03	0.06	0.02	0.03	0.06	0.07
11.00	2.00	0.00	11.01	2.00	0.01	0.01	0.00	0.01	0.01
12.00	2.00	0.00	12.00	2.02	0.00	0.00	0.02	0.00	0.02
13.00	2.00	0.00	13.05	2.06	0.04	0.05	0.06	0.04	0.09
14.00	2.00	0.00	14.11	2.09	0.03	0.11	0.09	0.03	0.15
15.00	2.00	0.00	15.07	2.01	-0.04	0.07	0.01	-0.04	0.08

0.00	3.00	0.00	-0.09	3.06	-0.11	-0.09	0.06	-0.11	0.15
1.00	3.00	0.00	0.88	3.00	-0.06	-0.12	0.00	-0.06	0.13
2.00	3.00	0.00	1.85	3.00	-0.07	-0.15	0.00	-0.07	0.17
3.00	3.00	0.00	3.00	3.01	0.05	0.00	0.01	0.05	0.05
4.00	3.00	0.00	3.94	3.04	0.04	-0.06	0.04	0.04	0.08
5.00	3.00	0.00	4.97	3.01	0.03	-0.03	0.01	0.03	0.04
6.00	3.00	0.00	5.94	3.03	0.05	-0.06	0.03	0.05	0.08
7.00	3.00	0.00	6.96	3.01	0.04	-0.04	0.01	0.04	0.06
8.00	3.00	0.00	7.96	3.02	0.02	-0.04	0.02	0.02	0.05
9.00	3.00	0.00	8.97	2.97	0.04	-0.03	-0.03	0.04	0.06
10.00	3.00	0.00	9.96	2.99	0.02	-0.04	-0.01	0.02	0.05
11.00	3.00	0.00	11.01	3.01	0.04	0.01	0.01	0.04	0.04
12.00	3.00	0.00	12.01	3.04	0.05	0.01	0.04	0.05	0.06
13.00	3.00	0.00	13.06	3.07	0.04	0.06	0.07	0.04	0.10
14.00	3.00	0.00	14.08	3.06	0.03	0.08	0.06	0.03	0.10
15.00	3.00	0.00	15.08	3.01	0.00	0.08	0.01	0.00	0.08
0.00	4.00	0.00	-0.12	4.04	-0.09	-0.12	0.04	-0.09	0.16
1.00	4.00	0.00	0.85	4.00	-0.08	-0.15	0.00	-0.08	0.17
2.00	4.00	0.00	1.97	3.99	0.05	-0.03	-0.01	0.05	0.06
3.00	4.00	0.00	2.94	4.03	0.04	-0.06	0.03	0.04	0.08
4.00	4.00	0.00	3.97	4.00	0.08	-0.03	0.00	0.08	0.09
5.00	4.00	0.00	4.99	4.04	0.07	-0.01	0.04	0.07	0.08
6.00	4.00	0.00	5.97	4.02	0.08	-0.03	0.02	0.08	0.09
7.00	4.00	0.00	6.94	4.01	0.06	-0.06	0.01	0.06	0.09
8.00	4.00	0.00	7.99	4.03	0.09	-0.01	0.03	0.09	0.10
9.00	4.00	0.00	8.99	4.03	0.11	-0.01	0.03	0.11	0.11
10.00	4.00	0.00	9.97	4.03	0.06	-0.03	0.03	0.06	0.07
11.00	4.00	0.00	11.00	4.02	0.07	0.00	0.02	0.07	0.07
12.00	4.00	0.00	12.04	4.08	0.04	0.04	0.08	0.04	0.10
13.00	4.00	0.00	13.05	4.07	0.05	0.05	0.07	0.05	0.10
14.00	4.00	0.00	14.02	4.07	0.02	0.02	0.07	0.02	0.08
15.00	4.00	0.00	15.07	4.05	-0.02	0.07	0.05	-0.02	0.09
0.00	5.00	0.00	-0.13	4.98	-0.08	-0.13	-0.02	-0.08	0.15
1.00	5.00	0.00	0.84	4.98	-0.06	-0.16	-0.02	-0.06	0.17
2.00	5.00	0.00	1.98	4.99	0.09	-0.02	-0.01	0.09	0.09
3.00	5.00	0.00	2.94	4.99	0.08	-0.06	-0.01	0.08	0.10
4.00	5.00	0.00	3.96	4.97	0.08	-0.04	-0.03	0.08	0.09
5.00	5.00	0.00	4.91	4.99	0.06	-0.09	-0.01	0.06	0.11
6.00	5.00	0.00	5.91	5.00	0.08	-0.09	0.00	0.08	0.12
7.00	5.00	0.00	6.96	5.04	0.12	-0.04	0.04	0.12	0.13
8.00	5.00	0.00	8.01	5.05	0.15	0.01	0.05	0.15	0.16
9.00	5.00	0.00	9.03	5.04	0.15	0.03	0.04	0.15	0.16
10.00	5.00	0.00	9.97	5.00	0.11	-0.03	0.00	0.11	0.11
11.00	5.00	0.00	10.98	5.04	0.10	-0.02	0.04	0.10	0.11
12.00	5.00	0.00	12.06	5.07	0.08	0.06	0.07	0.08	0.12
13.00	5.00	0.00	13.00	5.04	0.04	0.00	0.04	0.04	0.06
14.00	5.00	0.00	14.03	5.05	0.03	0.03	0.05	0.03	0.07
15.00	5.00	0.00	15.03	5.03	-0.01	0.03	0.03	-0.01	0.04
0.00	6.00	0.00	-0.12	6.00	-0.05	-0.12	0.00	-0.05	0.13
1.00	6.00	0.00	0.87	5.99	-0.03	-0.13	-0.01	-0.03	0.13
2.00	6.00	0.00	1.97	5.99	0.10	-0.03	-0.01	0.10	0.10
3.00	6.00	0.00	2.94	5.98	0.09	-0.06	-0.02	0.09	0.11
4.00	6.00	0.00	3.95	5.99	0.09	-0.05	-0.01	0.09	0.10
5.00	6.00	0.00	4.98	5.96	0.11	-0.02	-0.04	0.11	0.12
6.00	6.00	0.00	5.95	5.97	0.10	-0.05	-0.03	0.10	0.12
7.00	6.00	0.00	6.92	5.97	0.08	-0.08	-0.03	0.08	0.12
8.00	6.00	0.00	7.96	6.00	0.14	-0.04	0.00	0.14	0.15
9.00	6.00	0.00	8.92	5.97	0.11	-0.08	-0.03	0.11	0.14
10.00	6.00	0.00	9.99	6.01	0.13	-0.01	0.01	0.13	0.13

11.00	6.00	0.00	10.95	5.99	0.12	-0.05	-0.01	0.12	0.13
12.00	6.00	0.00	12.03	6.05	0.10	0.03	0.05	0.10	0.12
13.00	6.00	0.00	12.97	6.01	0.07	-0.03	0.01	0.07	0.08
14.00	6.00	0.00	13.98	6.02	0.01	-0.02	0.02	0.01	0.03
15.00	6.00	0.00	14.98	6.02	0.01	-0.02	0.02	0.01	0.03
0.00	7.00	0.00	-0.15	7.00	-0.07	-0.15	0.00	-0.07	0.17
1.00	7.00	0.00	0.85	7.00	-0.04	-0.15	0.00	-0.04	0.16
2.00	7.00	0.00	1.95	7.02	0.09	-0.05	0.02	0.09	0.10
3.00	7.00	0.00	2.97	6.98	0.13	-0.03	-0.02	0.13	0.13
4.00	7.00	0.00	3.96	7.04	0.11	-0.04	0.04	0.11	0.12
5.00	7.00	0.00	4.95	7.01	0.11	-0.05	0.01	0.11	0.12
6.00	7.00	0.00	5.92	7.02	0.12	-0.08	0.02	0.12	0.15
7.00	7.00	0.00	6.92	7.04	0.11	-0.08	0.04	0.11	0.14
8.00	7.00	0.00	7.95	7.01	0.13	-0.05	0.01	0.13	0.14
9.00	7.00	0.00	8.90	7.00	0.10	-0.10	0.00	0.10	0.14
10.00	7.00	0.00	9.97	7.00	0.14	-0.03	0.00	0.14	0.14
11.00	7.00	0.00	10.96	6.98	0.12	-0.04	-0.02	0.12	0.13
12.00	7.00	0.00	11.98	6.99	0.10	-0.02	-0.01	0.10	0.10
13.00	7.00	0.00	12.99	7.02	0.07	-0.01	0.02	0.07	0.07
14.00	7.00	0.00	13.98	7.06	0.04	-0.02	0.06	0.04	0.07
15.00	7.00	0.00	14.98	7.05	0.03	-0.02	0.05	0.03	0.06
0.00	8.00	0.00	-0.11	8.00	-0.01	-0.11	0.00	-0.01	0.11
1.00	8.00	0.00	0.86	7.99	-0.01	-0.14	-0.01	-0.01	0.14
2.00	8.00	0.00	1.95	8.01	0.09	-0.05	0.01	0.09	0.10
3.00	8.00	0.00	2.94	8.01	0.12	-0.06	0.01	0.12	0.13
4.00	8.00	0.00	3.95	8.04	0.12	-0.05	0.04	0.12	0.14
5.00	8.00	0.00	4.91	7.99	0.11	-0.09	-0.01	0.11	0.14
6.00	8.00	0.00	5.90	8.01	0.11	-0.10	0.01	0.11	0.15
7.00	8.00	0.00	6.89	8.01	0.11	-0.11	0.01	0.11	0.16
8.00	8.00	0.00	7.93	8.03	0.15	-0.07	0.03	0.15	0.17
9.00	8.00	0.00	8.92	7.98	0.13	-0.08	-0.02	0.13	0.15
10.00	8.00	0.00	9.90	8.04	0.13	-0.10	0.04	0.13	0.17
11.00	8.00	0.00	10.94	8.03	0.13	-0.06	0.03	0.13	0.15
12.00	8.00	0.00	11.93	8.06	0.09	-0.07	0.06	0.09	0.13
13.00	8.00	0.00	13.00	8.04	0.09	0.00	0.04	0.09	0.10
14.00	8.00	0.00	13.95	8.06	0.06	-0.05	0.06	0.06	0.10
15.00	8.00	0.00	14.97	8.08	0.04	-0.03	0.08	0.04	0.09

*-Error greater than .25"

3Space Isotrak Accuracy Tests

File: grid221.pc
Origin: -23.00,-10.00,22.00
Vector Distance from Origin to Source: 33.36"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR	
X	Y	Z	X	Y	Z	X	Y	Z	D	
0.00	0.00	0.00	-0.06	-0.02	-0.05	-0.06	-0.02	-0.05	0.08	
1.00	0.00	0.00	0.99	-0.13	0.02	-0.01	-0.13	0.02	0.13	
2.00	0.00	0.00	2.00	-0.14	0.07	0.00	-0.14	0.07	0.16	
3.00	0.00	0.00	3.01	-0.12	0.06	0.01	-0.12	0.06	0.13	
4.00	0.00	0.00	4.02	-0.08	0.11	0.02	-0.08	0.11	0.14	
5.00	0.00	0.00	5.05	-0.10	0.11	0.05	-0.10	0.11	0.16	
6.00	0.00	0.00	6.13	-0.03	0.11	0.13	-0.03	0.11	0.17	
7.00	0.00	0.00	7.06	-0.09	0.06	0.06	-0.09	0.06	0.12	
8.00	0.00	0.00	8.03	-0.04	0.06	0.03	-0.04	0.06	0.08	
9.00	0.00	0.00	9.05	-0.04	0.07	0.05	-0.04	0.07	0.09	
10.00	0.00	0.00	10.20	0.02	0.10	0.20	0.02	0.10	0.22	
11.00	0.00	0.00	11.14	-0.07	0.09	0.14	0.07	0.09	0.18	
12.00	0.00	0.00	12.24	0.04	0.11	0.24	0.04	0.11	0.27	*
13.00	0.00	0.00	13.23	0.11	0.11	0.23	0.11	0.11	0.28	*
14.00	0.00	0.00	14.22	0.13	0.10	0.22	0.13	0.10	0.27	*
15.00	0.00	0.00	15.14	0.01	0.01	0.14	0.01	0.01	0.14	
0.00	1.00	0.00	0.05	0.90	0.04	0.05	-0.10	0.04	0.12	
1.00	1.00	0.00	0.93	0.93	0.03	-0.07	-0.07	0.03	0.10	
2.00	1.00	0.00	2.03	0.87	0.08	0.03	-0.13	0.08	0.16	
3.00	1.00	0.00	2.97	0.86	0.03	-0.03	-0.14	0.03	0.15	
4.00	1.00	0.00	3.98	0.93	0.08	-0.02	-0.07	0.08	0.11	
5.00	1.00	0.00	5.06	0.97	0.09	0.06	-0.03	0.09	0.11	
6.00	1.00	0.00	5.98	0.92	0.06	-0.02	-0.08	0.06	0.10	
7.00	1.00	0.00	6.99	0.92	0.05	-0.01	-0.08	0.05	0.09	
8.00	1.00	0.00	8.05	0.97	0.10	0.05	-0.03	0.10	0.12	
9.00	1.00	0.00	9.16	0.99	0.08	0.16	-0.01	0.08	0.18	
10.00	1.00	0.00	10.15	1.04	0.10	0.15	0.04	0.10	0.18	
11.00	1.00	0.00	11.18	1.06	0.10	0.18	0.06	0.10	0.21	
12.00	1.00	0.00	12.20	1.11	0.11	0.20	0.11	0.11	0.25	*
13.00	1.00	0.00	13.25	1.12	0.11	0.25	0.12	0.11	0.30	*
14.00	1.00	0.00	14.11	0.99	0.00	0.11	-0.01	0.00	0.11	
15.00	1.00	0.00	15.09	1.02	-0.01	0.09	0.02	-0.01	0.09	
0.00	2.00	0.00	-0.10	2.04	-0.05	-0.10	0.04	-0.05	0.12	
1.00	2.00	0.00	0.93	1.93	0.05	-0.07	-0.07	0.05	0.11	
2.00	2.00	0.00	1.98	1.85	0.07	-0.02	-0.15	0.07	0.17	
3.00	2.00	0.00	2.97	1.95	0.10	-0.03	-0.05	0.10	0.12	
4.00	2.00	0.00	4.04	1.93	0.13	0.04	-0.07	0.13	0.15	
5.00	2.00	0.00	5.00	1.92	0.03	0.00	-0.08	0.03	0.09	
6.00	2.00	0.00	5.99	1.98	0.08	-0.01	-0.02	0.08	0.08	
7.00	2.00	0.00	7.01	1.95	0.07	0.01	-0.05	0.07	0.09	
8.00	2.00	0.00	8.04	1.97	0.08	0.04	-0.03	0.08	0.09	
9.00	2.00	0.00	9.16	2.05	0.10	0.16	0.05	0.10	0.20	
10.00	2.00	0.00	10.14	2.04	0.10	0.14	0.04	0.10	0.18	
11.00	2.00	0.00	11.18	2.07	0.10	0.18	0.07	0.10	0.22	
12.00	2.00	0.00	12.21	2.10	0.11	0.21	0.10	0.11	0.26	*
13.00	2.00	0.00	13.09	2.01	0.00	0.09	0.01	0.00	0.09	
14.00	2.00	0.00	14.11	2.03	0.01	0.11	0.03	0.01	0.11	
15.00	2.00	0.00	15.12	2.06	0.00	0.12	0.06	0.00	0.13	

0.00	3.00	0.00	-0.08	2.90	-0.05	-0.08	-0.10	-0.05	0.14
1.00	3.00	0.00	0.97	2.88	0.02	-0.03	-0.12	0.02	0.13
2.00	3.00	0.00	1.91	2.90	0.02	-0.09	-0.10	0.02	0.14
3.00	3.00	0.00	2.95	2.97	0.09	-0.05	-0.03	0.09	0.11
4.00	3.00	0.00	4.02	2.95	0.06	0.02	-0.05	0.06	0.08
5.00	3.00	0.00	5.00	2.95	0.04	0.00	-0.05	0.04	0.06
6.00	3.00	0.00	5.94	2.93	0.06	-0.06	-0.07	0.06	0.11
7.00	3.00	0.00	6.91	2.91	0.03	-0.09	-0.09	0.03	0.13
8.00	3.00	0.00	8.10	2.98	0.09	0.10	-0.02	0.09	0.14
9.00	3.00	0.00	9.12	3.01	0.09	0.12	0.01	0.09	0.15
10.00	3.00	0.00	10.13	3.03	0.08	0.13	0.03	0.08	0.16
11.00	3.00	0.00	11.17	3.07	0.10	0.17	0.07	0.10	0.21
12.00	3.00	0.00	12.07	2.99	0.00	0.07	-0.01	0.00	0.07
13.00	3.00	0.00	13.06	3.00	-0.01	0.06	0.00	-0.01	0.06
14.00	3.00	0.00	14.11	3.05	0.01	0.11	0.05	0.01	0.12
15.00	3.00	0.00	15.11	3.01	-0.01	0.11	0.01	-0.01	0.11
0.00	4.00	0.00	-0.09	4.00	-0.01	-0.09	0.00	-0.01	0.09
1.00	4.00	0.00	1.02	3.99	0.10	0.02	-0.01	0.10	0.10
2.00	4.00	0.00	1.85	3.95	-0.02	-0.15	-0.05	-0.02	0.16
3.00	4.00	0.00	2.93	3.88	0.05	-0.07	-0.12	0.05	0.15
4.00	4.00	0.00	3.99	3.92	0.03	-0.01	-0.08	0.03	0.09
5.00	4.00	0.00	4.98	3.97	0.06	-0.02	-0.03	0.06	0.07
6.00	4.00	0.00	6.05	4.03	0.14	0.05	0.03	0.14	0.15
7.00	4.00	0.00	7.00	4.02	0.10	0.00	0.02	0.10	0.10
8.00	4.00	0.00	8.13	4.02	0.09	0.13	0.02	0.09	0.16
9.00	4.00	0.00	9.11	4.02	0.09	0.11	0.02	0.09	0.14
10.00	4.00	0.00	10.21	4.06	0.12	0.21	0.06	0.12	0.25
11.00	4.00	0.00	11.04	4.03	0.00	0.04	0.03	0.00	0.05
12.00	4.00	0.00	12.07	4.01	0.00	0.07	0.01	0.00	0.07
13.00	4.00	0.00	13.02	4.04	-0.01	0.02	0.04	-0.01	0.05
14.00	4.00	0.00	14.05	4.03	-0.02	0.05	0.03	-0.02	0.06
15.00	4.00	0.00	15.08	4.06	-0.05	0.08	0.06	-0.05	0.11
0.00	5.00	0.00	-0.06	4.92	-0.01	-0.06	-0.08	-0.01	0.10
1.00	5.00	0.00	0.92	4.93	0.00	-0.08	-0.07	0.00	0.11
2.00	5.00	0.00	1.91	4.93	0.02	-0.09	-0.07	0.02	0.12
3.00	5.00	0.00	2.88	4.99	0.07	-0.12	-0.01	0.07	0.14
4.00	5.00	0.00	3.95	4.96	0.04	-0.05	-0.04	0.04	0.08
5.00	5.00	0.00	5.05	5.01	0.10	0.05	0.01	0.10	0.11
6.00	5.00	0.00	5.98	4.97	0.07	-0.02	-0.03	0.07	0.08
7.00	5.00	0.00	6.98	4.97	0.06	-0.02	-0.03	0.06	0.07
8.00	5.00	0.00	8.12	5.02	0.12	0.12	0.02	0.12	0.17
9.00	5.00	0.00	9.13	5.05	0.11	0.13	0.05	0.11	0.18
10.00	5.00	0.00	10.21	5.05	0.12	0.21	0.05	0.12	0.25
11.00	5.00	0.00	11.02	5.00	0.00	0.02	0.00	0.00	0.02
12.00	5.00	0.00	12.01	4.97	-0.02	0.01	-0.03	-0.02	0.04
13.00	5.00	0.00	13.06	5.03	0.00	0.06	0.03	0.00	0.07
14.00	5.00	0.00	14.05	5.04	-0.04	0.05	0.04	-0.04	0.08
15.00	5.00	0.00	15.05	5.07	-0.06	0.05	0.07	-0.06	0.10
0.00	6.00	0.00	-0.03	5.97	-0.01	-0.03	-0.03	-0.01	0.04
1.00	6.00	0.00	0.85	6.11	0.01	-0.15	0.11	0.01	0.19
2.00	6.00	0.00	2.00	5.96	0.08	0.00	-0.04	0.08	0.09
3.00	6.00	0.00	2.89	6.09	0.06	-0.11	0.09	0.06	0.15
4.00	6.00	0.00	3.93	5.96	0.01	-0.07	-0.04	0.01	0.08
5.00	6.00	0.00	4.97	5.95	0.04	-0.03	-0.05	0.04	0.07
6.00	6.00	0.00	6.02	5.95	0.07	0.02	-0.05	0.07	0.09
7.00	6.00	0.00	7.03	5.99	0.04	0.03	-0.01	0.04	0.05
8.00	6.00	0.00	8.10	5.99	0.09	0.10	-0.01	0.09	0.13
9.00	6.00	0.00	9.12	6.03	0.09	0.12	0.03	0.09	0.15
10.00	6.00	0.00	9.99	5.97	-0.01	-0.01	-0.03	-0.01	0.03

11.00	6.00	0.00	11.03	5.96	-0.01	0.03	-0.04	-0.01	0.05
12.00	6.00	0.00	12.02	5.99	-0.02	0.02	-0.01	-0.02	0.03
13.00	6.00	0.00	12.91	5.97	-0.04	-0.09	-0.03	-0.04	0.10
14.00	6.00	0.00	14.09	5.99	-0.04	0.09	-0.01	-0.04	0.10
15.00	6.00	0.00	15.11	6.02	-0.03	0.11	0.02	-0.03	0.12
0.00	7.00	0.00	0.00	6.97	0.01	0.00	-0.03	0.01	0.03
1.00	7.00	0.00	0.92	6.86	-0.02	-0.08	-0.14	-0.02	0.16
2.00	7.00	0.00	1.90	6.98	0.01	-0.10	-0.02	0.01	0.10
3.00	7.00	0.00	3.01	6.99	0.05	0.01	-0.01	0.05	0.05
4.00	7.00	0.00	3.96	6.97	0.01	-0.04	-0.03	0.01	0.05
5.00	7.00	0.00	4.94	6.96	0.01	-0.06	-0.04	0.01	0.07
6.00	7.00	0.00	6.09	7.02	0.10	0.09	0.02	0.10	0.14
7.00	7.00	0.00	7.04	7.03	0.04	0.04	0.03	0.04	0.06
8.00	7.00	0.00	8.09	7.02	0.08	0.09	0.02	0.08	0.12
9.00	7.00	0.00	9.14	7.05	0.09	0.14	0.05	0.09	0.17
10.00	7.00	0.00	9.96	7.01	-0.01	-0.04	0.01	-0.01	0.04
11.00	7.00	0.00	11.03	6.98	-0.01	0.03	-0.02	-0.01	0.04
12.00	7.00	0.00	12.05	7.04	-0.01	0.05	0.04	-0.01	0.06
13.00	7.00	0.00	13.33	7.15	0.01	0.33	0.15	0.01	0.36	*
14.00	7.00	0.00	14.02	7.03	-0.06	0.02	0.03	-0.06	0.07
15.00	7.00	0.00	15.04	7.05	-0.09	0.04	0.05	-0.09	0.11
0.00	8.00	0.00	0.01	8.18	0.04	0.01	0.18	0.04	0.18
1.00	8.00	0.00	0.87	7.92	-0.08	-0.13	-0.08	-0.08	0.17
2.00	8.00	0.00	1.92	8.02	0.02	-0.08	0.02	0.02	0.08
3.00	8.00	0.00	2.95	7.98	0.00	-0.05	-0.02	0.00	0.05
4.00	8.00	0.00	3.97	7.95	0.00	-0.03	-0.05	0.00	0.06
5.00	8.00	0.00	5.00	8.02	0.03	0.00	0.02	0.03	0.04
6.00	8.00	0.00	5.93	8.00	-0.01	-0.07	0.00	-0.01	0.07
7.00	8.00	0.00	7.05	8.00	0.01	0.05	0.00	0.01	0.05
8.00	8.00	0.00	8.14	8.01	0.08	0.14	0.01	0.08	0.16
9.00	8.00	0.00	9.11	8.04	0.05	0.11	0.04	0.05	0.13
10.00	8.00	0.00	10.00	8.04	-0.04	0.00	0.04	-0.04	0.06
11.00	8.00	0.00	11.00	8.03	-0.05	0.00	0.03	-0.05	0.06
12.00	8.00	0.00	11.97	8.03	-0.05	-0.03	0.03	-0.05	0.07
13.00	8.00	0.00	12.97	8.05	-0.10	-0.03	0.05	-0.10	0.12
14.00	8.00	0.00	13.99	8.06	-0.09	-0.01	0.06	-0.09	0.11
15.00	8.00	0.00	14.95	8.07	-0.06	-0.05	0.07	-0.06	0.10

*-Error greater than .25"

3Space Isotrak Accuracy Tests

File: grid223.pc
Origin: -23.00,-10.00,22.00
Vector Distance from Origin to Source: 33.36"

----ACTUAL-----			----MEASURED---			---DIFFERENCE--			ERROR	
X	Y	Z	X	Y	Z	X	Y	Z	D	
0.00	0.00	0.00	0.04	-0.06	0.01	0.04	-0.06	0.01	0.07	
1.00	0.00	0.00	0.99	-0.04	0.05	-0.01	-0.04	0.05	0.06	
2.00	0.00	0.00	2.00	0.00	0.06	0.00	0.00	0.06	0.06	
3.00	0.00	0.00	3.06	-0.05	0.08	0.06	-0.05	0.08	0.11	
4.00	0.00	0.00	4.08	-0.05	0.10	0.08	-0.05	0.10	0.14	
5.00	0.00	0.00	5.08	-0.01	0.05	0.08	-0.01	0.05	0.09	
6.00	0.00	0.00	6.10	0.00	0.08	0.10	0.00	0.08	0.13	
7.00	0.00	0.00	7.06	-0.01	0.05	0.06	-0.01	0.05	0.08	
8.00	0.00	0.00	8.14	0.00	0.10	0.14	0.00	0.10	0.17	
9.00	0.00	0.00	9.23	0.04	0.08	0.23	0.04	0.08	0.25	
10.00	0.00	0.00	10.21	0.04	0.08	0.21	0.04	0.08	0.23	
11.00	0.00	0.00	11.25	0.06	0.10	0.25	0.06	0.10	0.28	*
12.00	0.00	0.00	12.25	0.12	0.10	0.25	0.12	0.10	0.29	*
13.00	0.00	0.00	13.17	0.01	-0.02	0.17	0.01	-0.02	0.17	
14.00	0.00	0.00	14.21	0.03	0.01	0.21	0.03	0.01	0.21	
15.00	0.00	0.00	15.15	0.01	-0.01	0.15	0.01	-0.01	0.15	
0.00	1.00	0.00	0.01	0.97	-0.01	0.01	-0.03	-0.01	0.03	
1.00	1.00	0.00	1.05	0.96	0.12	0.05	-0.04	0.12	0.14	
2.00	1.00	0.00	2.00	0.87	0.04	0.00	-0.13	0.04	0.14	
3.00	1.00	0.00	3.02	0.91	0.08	0.02	-0.09	0.08	0.12	
4.00	1.00	0.00	4.05	0.94	0.13	0.05	-0.06	0.13	0.15	
5.00	1.00	0.00	5.14	1.03	0.12	0.14	0.03	0.12	0.19	
6.00	1.00	0.00	6.06	0.95	0.08	0.06	-0.05	0.08	0.11	
7.00	1.00	0.00	7.06	0.98	0.09	0.06	-0.02	0.09	0.11	
8.00	1.00	0.00	8.06	0.93	0.06	0.06	-0.07	0.06	0.11	
9.00	1.00	0.00	9.23	1.06	0.12	0.23	0.06	0.12	0.27	*
10.00	1.00	0.00	10.23	1.07	0.13	0.23	0.07	0.13	0.27	*
11.00	1.00	0.00	11.26	1.11	0.13	0.26	0.11	0.13	0.31	*
12.00	1.00	0.00	12.25	1.07	0.10	0.25	0.07	0.10	0.28	*
13.00	1.00	0.00	13.13	1.03	0.00	0.13	0.03	0.00	0.13	
14.00	1.00	0.00	14.12	0.98	-0.02	0.12	-0.02	-0.02	0.12	
15.00	1.00	0.00	15.19	1.00	0.00	0.19	0.00	0.00	0.19	
0.00	2.00	0.00	0.04	1.94	0.04	0.04	-0.06	0.04	0.08	
1.00	2.00	0.00	1.00	1.98	0.07	0.00	-0.02	0.07	0.07	
2.00	2.00	0.00	1.98	1.94	0.07	-0.02	-0.06	0.07	0.09	
3.00	2.00	0.00	3.00	1.99	0.09	0.00	-0.01	0.09	0.09	
4.00	2.00	0.00	4.04	1.96	0.08	0.04	-0.04	0.08	0.10	
5.00	2.00	0.00	5.08	1.97	0.08	0.08	-0.03	0.08	0.12	
6.00	2.00	0.00	6.07	2.00	0.09	0.07	0.00	0.09	0.11	
7.00	2.00	0.00	6.97	1.96	0.05	-0.03	-0.04	0.05	0.07	
8.00	2.00	0.00	8.17	2.07	0.10	0.17	0.07	0.10	0.21	
9.00	2.00	0.00	9.22	2.07	0.12	0.22	0.07	0.12	0.26	*
10.00	2.00	0.00	10.15	2.10	0.11	0.15	0.10	0.11	0.21	
11.00	2.00	0.00	11.22	2.11	0.12	0.22	0.11	0.12	0.27	*
12.00	2.00	0.00	12.08	2.00	-0.01	0.08	0.00	-0.01	0.08	
13.00	2.00	0.00	13.11	2.03	0.00	0.11	0.03	0.00	0.11	
14.00	2.00	0.00	14.14	2.08	0.01	0.14	0.08	0.01	0.16	
15.00	2.00	0.00	15.18	2.05	0.00	0.18	0.05	0.00	0.19	

0.00	3.00	0.00	0.02	2.94	0.05	0.02	-0.06	0.05	0.08	
1.00	3.00	0.00	0.95	2.92	0.00	-0.05	-0.08	0.00	0.09	
2.00	3.00	0.00	2.02	2.98	0.09	0.02	-0.02	0.09	0.09	
3.00	3.00	0.00	2.93	2.92	0.07	-0.07	-0.08	0.07	0.13	
4.00	3.00	0.00	4.14	3.04	0.13	0.14	0.04	0.13	0.20	
5.00	3.00	0.00	5.00	2.98	0.07	0.00	-0.02	0.07	0.07	
6.00	3.00	0.00	6.03	2.97	0.08	0.03	-0.03	0.08	0.09	
7.00	3.00	0.00	6.99	2.99	0.09	-0.01	-0.01	0.09	0.09	
8.00	3.00	0.00	8.16	3.06	0.11	0.16	0.06	0.11	0.20	
9.00	3.00	0.00	9.19	3.09	0.13	0.19	0.09	0.13	0.25	
10.00	3.00	0.00	10.22	3.11	0.13	0.22	0.11	0.13	0.28	*
11.00	3.00	0.00	11.24	3.14	0.12	0.24	0.14	0.12	0.30	*
12.00	3.00	0.00	12.11	3.02	0.00	0.11	0.02	0.00	0.11	
13.00	3.00	0.00	13.16	3.01	0.02	0.16	0.01	0.02	0.16	
14.00	3.00	0.00	14.12	3.07	0.00	0.12	0.07	0.00	0.14	
15.00	3.00	0.00	15.15	3.02	-0.01	0.15	0.02	-0.01	0.15	
0.00	4.00	0.00	0.01	4.01	0.08	0.01	0.01	0.08	0.08	
1.00	4.00	0.00	1.01	4.01	0.08	0.01	0.01	0.08	0.08	
2.00	4.00	0.00	2.04	3.98	0.11	0.04	-0.02	0.11	0.12	
3.00	4.00	0.00	3.00	3.93	0.11	0.00	-0.07	0.11	0.13	
4.00	4.00	0.00	4.03	3.97	0.07	0.03	-0.03	0.07	0.08	
5.00	4.00	0.00	5.06	3.98	0.08	0.06	-0.02	0.08	0.10	
6.00	4.00	0.00	6.03	4.02	0.08	0.03	0.02	0.08	0.09	
7.00	4.00	0.00	7.10	4.03	0.08	0.10	0.03	0.08	0.13	
8.00	4.00	0.00	8.14	4.06	0.09	0.14	0.06	0.09	0.18	
9.00	4.00	0.00	9.20	4.12	0.14	0.20	0.12	0.14	0.27	*
10.00	4.00	0.00	10.21	4.09	0.13	0.21	0.09	0.13	0.26	*
11.00	4.00	0.00	11.11	4.04	0.03	0.11	0.04	0.03	0.12	
12.00	4.00	0.00	12.15	4.06	0.02	0.15	0.06	0.02	0.16	
13.00	4.00	0.00	13.08	4.06	0.00	0.08	0.06	0.00	0.10	
14.00	4.00	0.00	14.12	4.06	0.00	0.12	0.06	0.00	0.13	
15.00	4.00	0.00	15.10	4.03	-0.03	0.10	0.03	-0.03	0.11	
0.00	5.00	0.00	-0.01	5.00	0.01	-0.01	0.00	0.01	0.01	
1.00	5.00	0.00	0.99	4.98	0.08	-0.01	-0.02	0.08	0.08	
2.00	5.00	0.00	2.00	5.05	0.11	0.00	0.05	0.11	0.12	
3.00	5.00	0.00	2.99	4.96	0.10	-0.01	-0.04	0.10	0.11	
4.00	5.00	0.00	4.05	5.03	0.07	0.05	0.03	0.07	0.09	
5.00	5.00	0.00	4.98	5.02	0.04	-0.02	0.02	0.04	0.05	
6.00	5.00	0.00	6.01	5.03	0.09	0.01	0.03	0.09	0.10	
7.00	5.00	0.00	7.15	5.06	0.12	0.15	0.06	0.12	0.20	
8.00	5.00	0.00	8.16	5.08	0.13	0.16	0.08	0.13	0.22	
9.00	5.00	0.00	9.18	5.07	0.12	0.18	0.07	0.12	0.23	
10.00	5.00	0.00	10.21	5.11	0.13	0.21	0.11	0.13	0.27	*
11.00	5.00	0.00	11.12	5.07	0.05	0.12	0.07	0.05	0.15	
12.00	5.00	0.00	12.13	5.05	0.02	0.13	0.05	0.02	0.14	
13.00	5.00	0.00	13.12	5.09	0.00	0.12	0.09	0.00	0.15	
14.00	5.00	0.00	14.12	5.05	0.00	0.12	0.05	0.00	0.13	
15.00	5.00	0.00	15.16	5.07	-0.02	0.16	0.07	-0.02	0.18	
0.00	6.00	0.00	-0.01	6.05	0.03	-0.01	0.05	0.03	0.06	
1.00	6.00	0.00	1.00	5.99	0.10	0.00	-0.01	0.10	0.10	
2.00	6.00	0.00	1.97	6.05	0.09	-0.03	0.05	0.09	0.11	
3.00	6.00	0.00	3.01	6.01	0.06	0.01	0.01	0.06	0.06	
4.00	6.00	0.00	4.01	5.97	0.07	0.01	-0.03	0.07	0.08	
5.00	6.00	0.00	5.00	5.97	0.07	0.00	-0.03	0.07	0.08	
6.00	6.00	0.00	6.03	6.06	0.10	0.03	0.06	0.10	0.12	
7.00	6.00	0.00	7.11	6.03	0.12	0.11	0.03	0.12	0.17	
8.00	6.00	0.00	8.13	6.05	0.12	0.13	0.05	0.12	0.18	
9.00	6.00	0.00	9.19	6.10	0.14	0.19	0.10	0.14	0.26	*
10.00	6.00	0.00	10.23	6.08	0.13	0.23	0.08	0.13	0.28	*

11.00	6.00	0.00	11.11	6.03	0.04	0.11	0.03	0.04	0.12
12.00	6.00	0.00	12.08	6.03	0.02	0.08	0.03	0.02	0.09
13.00	6.00	0.00	13.07	6.05	0.00	0.07	0.05	0.00	0.09
14.00	6.00	0.00	14.14	5.98	-0.02	0.14	-0.02	-0.02	0.14
15.00	6.00	0.00	15.12	6.06	-0.02	0.12	0.06	-0.02	0.14
0.00	7.00	0.00	0.01	6.98	0.02	0.01	-0.02	0.02	0.03
1.00	7.00	0.00	0.98	7.03	0.05	-0.02	0.03	0.05	0.06
2.00	7.00	0.00	1.95	7.02	0.06	-0.05	0.02	0.06	0.08
3.00	7.00	0.00	3.04	7.05	0.07	0.04	0.05	0.07	0.09
4.00	7.00	0.00	4.13	7.06	0.13	0.13	0.06	0.13	0.19
5.00	7.00	0.00	4.97	7.03	0.05	-0.03	0.03	0.05	0.07
6.00	7.00	0.00	6.07	7.00	0.09	0.07	0.00	0.09	0.11
7.00	7.00	0.00	7.11	7.05	0.09	0.11	0.05	0.09	0.15
8.00	7.00	0.00	8.14	7.07	0.10	0.14	0.07	0.10	0.19
9.00	7.00	0.00	9.17	7.06	0.10	0.17	0.06	0.10	0.21
10.00	7.00	0.00	10.07	7.02	0.03	0.07	0.02	0.03	0.08
11.00	7.00	0.00	11.08	7.00	0.01	0.08	0.00	0.01	0.08
12.00	7.00	0.00	12.07	7.02	0.00	0.07	0.02	0.00	0.07
13.00	7.00	0.00	13.08	7.01	-0.04	0.08	0.01	-0.04	0.09
14.00	7.00	0.00	14.06	7.08	-0.05	0.06	0.08	-0.05	0.11
15.00	7.00	0.00	15.08	7.10	-0.05	0.08	0.10	-0.05	0.14
0.00	8.00	0.00	-0.02	8.11	0.02	-0.02	0.11	0.02	0.11
1.00	8.00	0.00	1.01	8.00	0.08	0.01	0.00	0.08	0.08
2.00	8.00	0.00	1.96	8.01	0.09	-0.04	0.01	0.09	0.10
3.00	8.00	0.00	3.10	8.06	0.12	0.10	0.06	0.12	0.17
4.00	8.00	0.00	4.05	8.02	0.11	0.05	0.02	0.11	0.12
5.00	8.00	0.00	4.96	8.02	0.03	-0.04	0.02	0.03	0.05
6.00	8.00	0.00	6.07	8.05	0.06	0.07	0.05	0.06	0.10
7.00	8.00	0.00	7.12	8.04	0.07	0.12	0.04	0.07	0.14
8.00	8.00	0.00	8.13	8.04	0.10	0.13	0.04	0.10	0.17
9.00	8.00	0.00	9.18	8.09	0.11	0.18	0.09	0.11	0.23
10.00	8.00	0.00	10.05	8.07	0.01	0.05	0.07	0.01	0.09
11.00	8.00	0.00	11.10	8.04	0.01	0.10	0.04	0.01	0.11
12.00	8.00	0.00	12.07	8.06	0.00	0.07	0.06	0.00	0.09
13.00	8.00	0.00	13.11	8.04	-0.04	0.11	0.04	-0.04	0.12
14.00	8.00	0.00	14.10	8.07	-0.05	0.10	0.07	-0.05	0.13
15.00	8.00	0.00	15.08	8.10	-0.07	0.08	0.10	-0.07	0.15

*-Error greater than .25"

XI. APPENDIX C:

Three Axis Router Specifications

(As built for this research project)

Three Axis Router Specifications

X Axis Travel: 48 inches.

Y Axis Travel: 29 inches.

Z Axis Travel: 18 inches.

Machine Dimensions: 72 inches(X) x 48 inches(Y) x 90 inches(Z)

Machine Weight: 1500 lbs.

Power Requirments: 120 VAC 1 phase

Linear Motion Components: -THK NSR25 TBA Ball Slides; THK BNT
                            -THK BNT 2005A Ball Screws

Control: Compumotor PC23 indexer board installed in an AT
       style computer.

Drives: Compumotor KS250 AC Brushless servomotors driven by
      digital servo amplifiers.

External Switches: End of travel limit switches and a home
  switch for each axis.

Machine Accuracy*: is a function of lead screw error,
               motor error and machine alignment.

    lead screw error = axial play + lead error

                        -axial play: .1 mm (maximun)
                        -lead error: +/- .21 mm/300 mm
                                screw length (maximun)

    motor error = +/- 18 arc min (.3 degrees)

    machine alignment = assumed to be minimal (has not been
                            measured)

    X axis error (max): +/- 0.037 inches

    Y axis error (max): +/- 0.024 inches

    Z axis error (max): +/- 0.017 inches

* Values used are from component specifications.

XII. APPENDIX D:

Testing of Prototype System
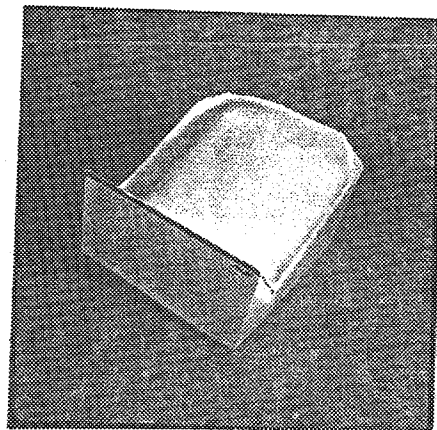
Fig. D.1 - Plaster Cast "back"

back121
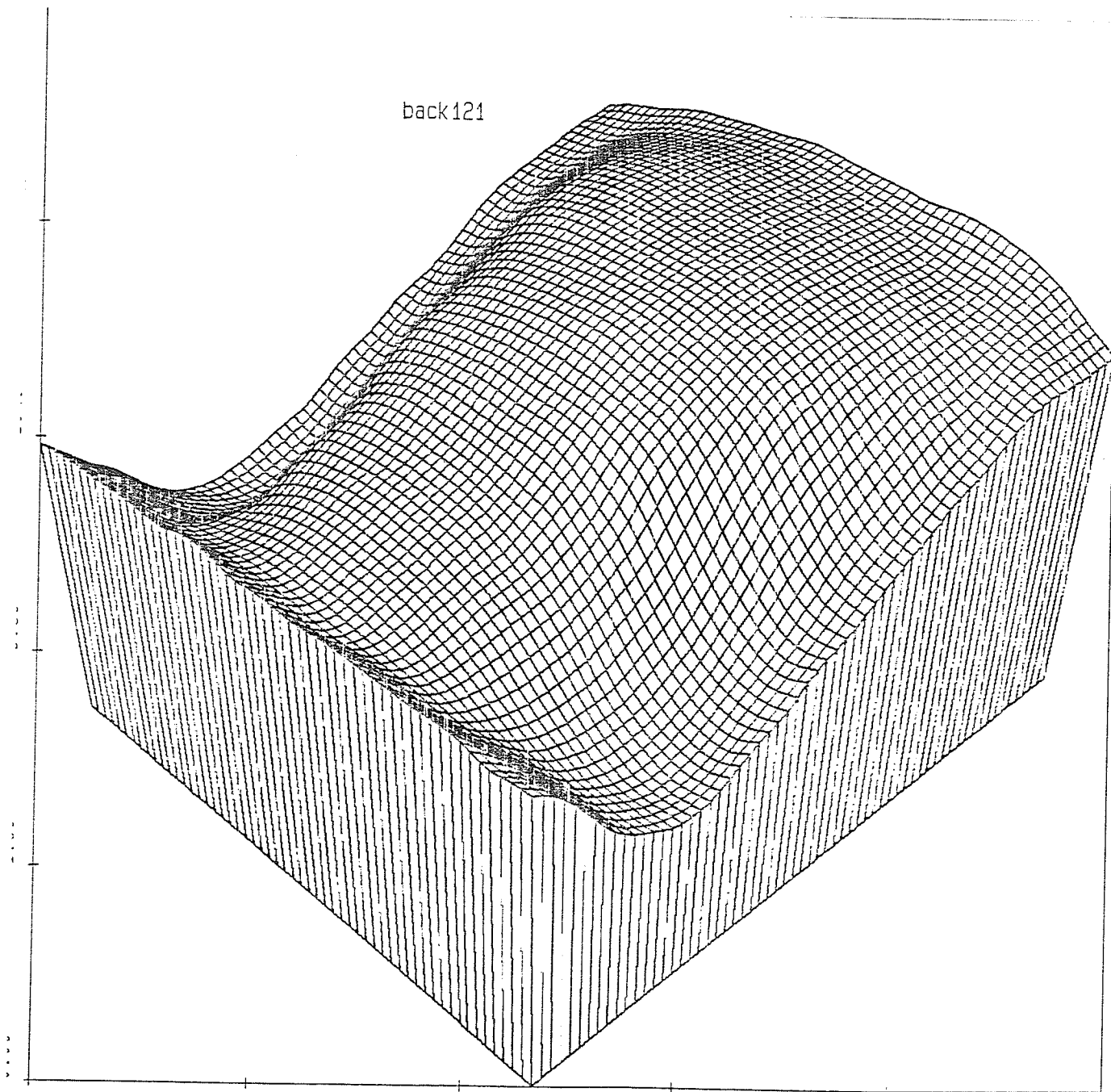
Fig. D.2 - Truepers Plot "back"

130

Fig. D.3 - Machined Cast "back"

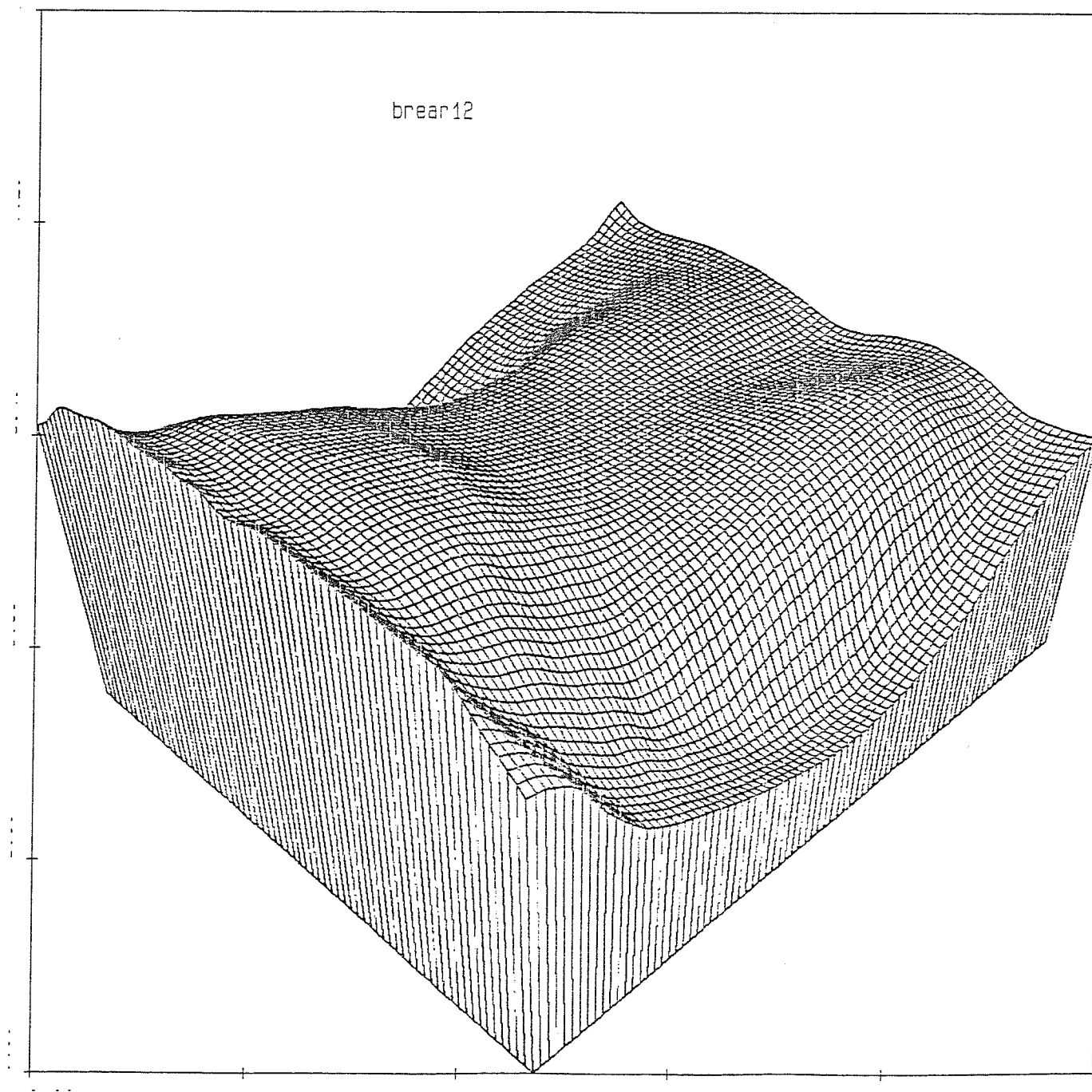Fig. D.4 - Plaster Cast "brear"

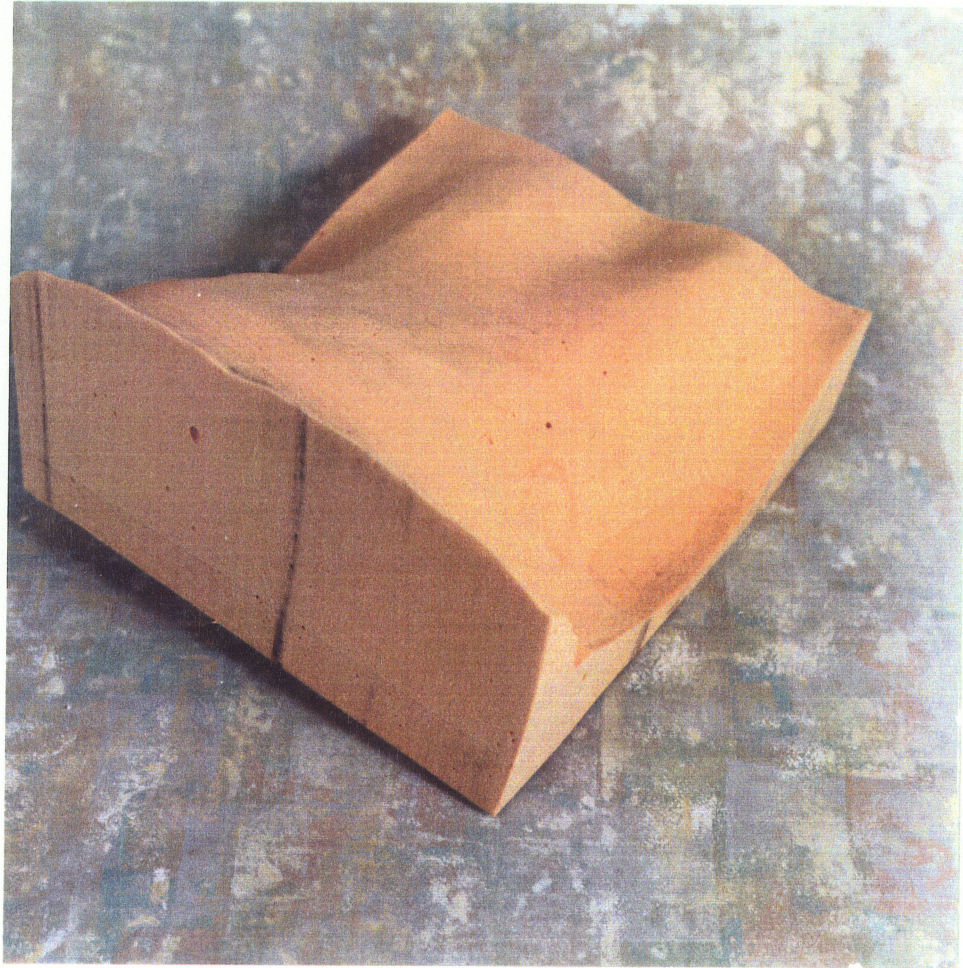brear12

Fig. D.5 - Truepers Plot "brear"

Fig. D.6 - Machined Cast "brear"
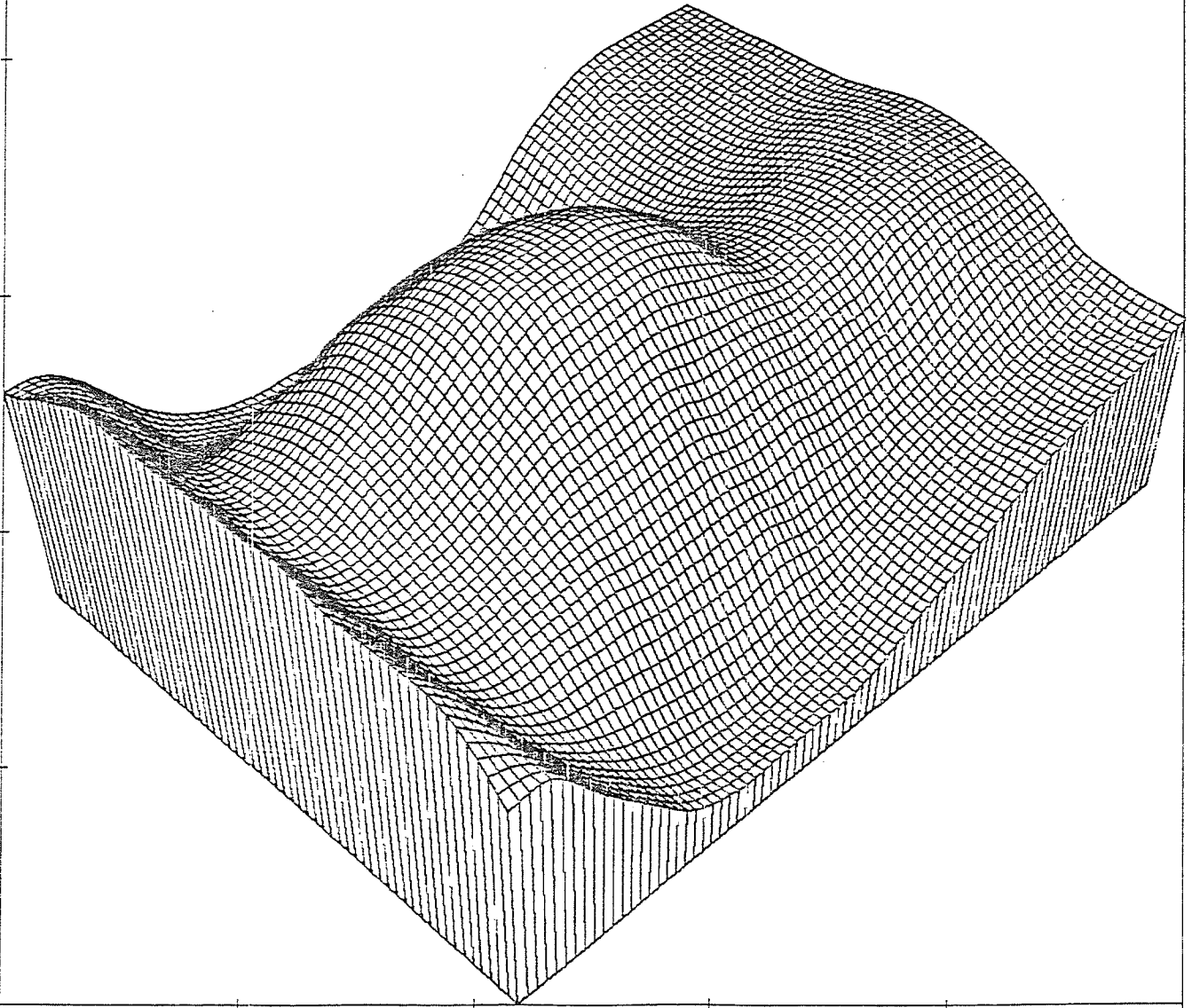
Fig. D.7 - Plaster Cast "lisab"

lisab21

Fig. D.8 - Truepers Plot "lisab"

Fig. D.9 - Machined Cast "lisab"
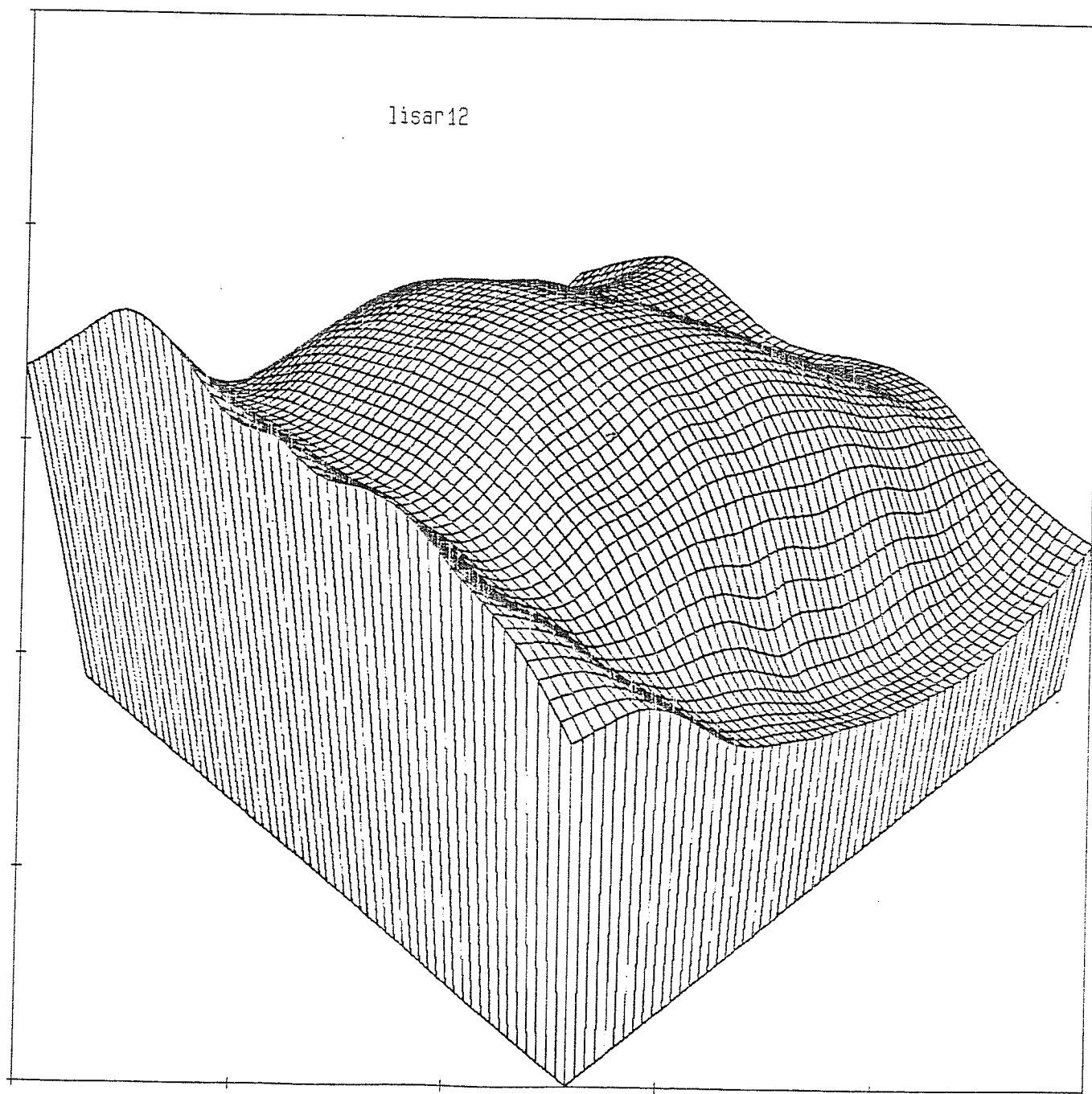
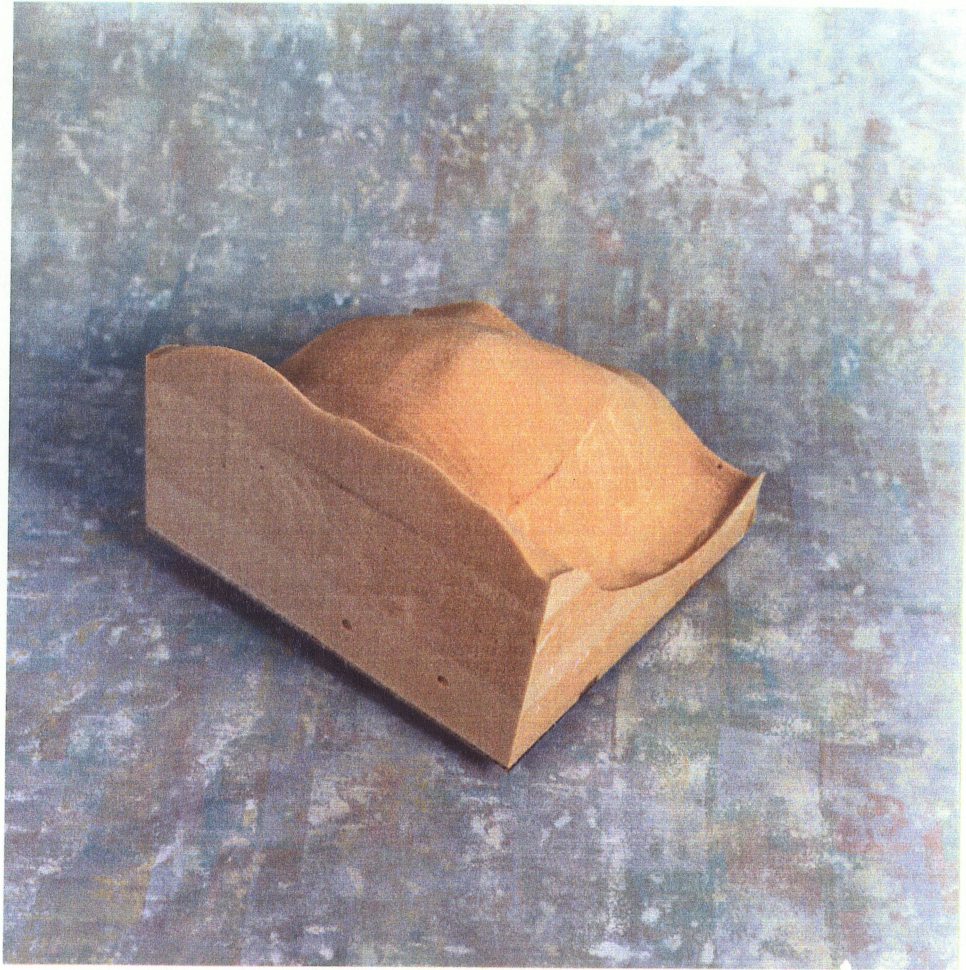Fig. D.10 - Plaster Cast "lisar"

lisar12

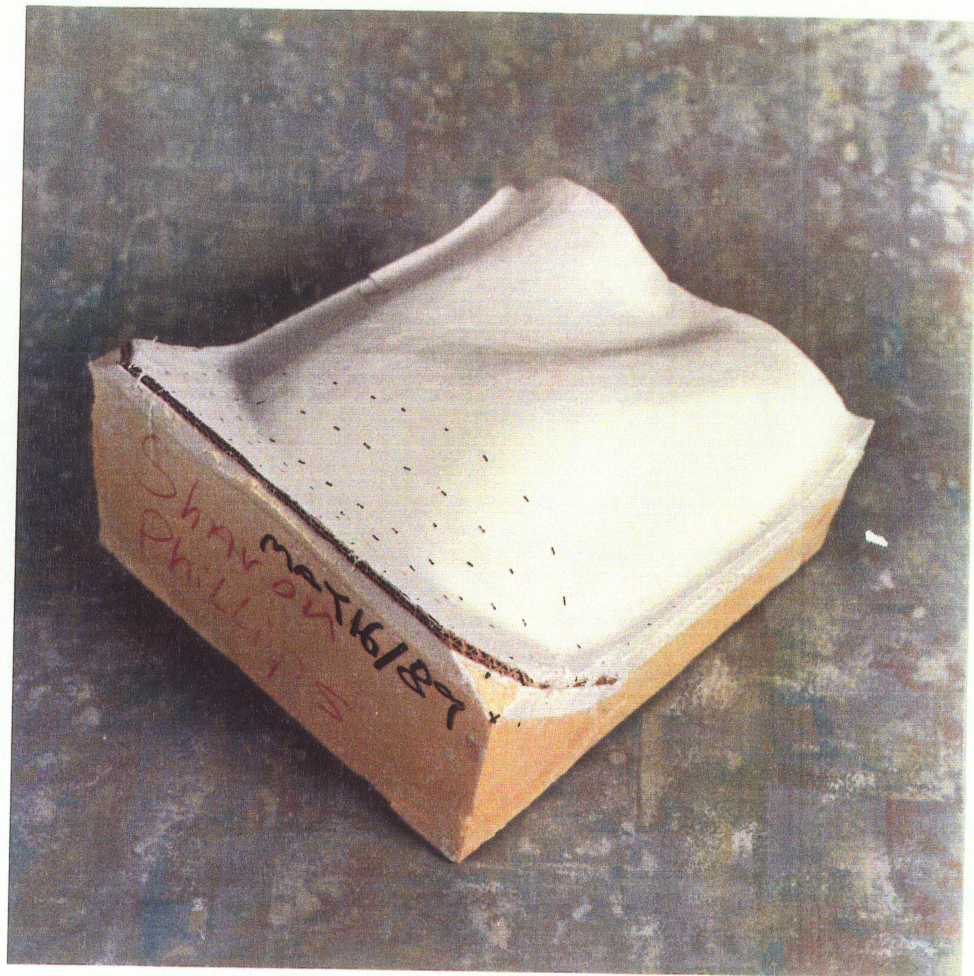Fig. D.11 - Truepers Plot "lisar"

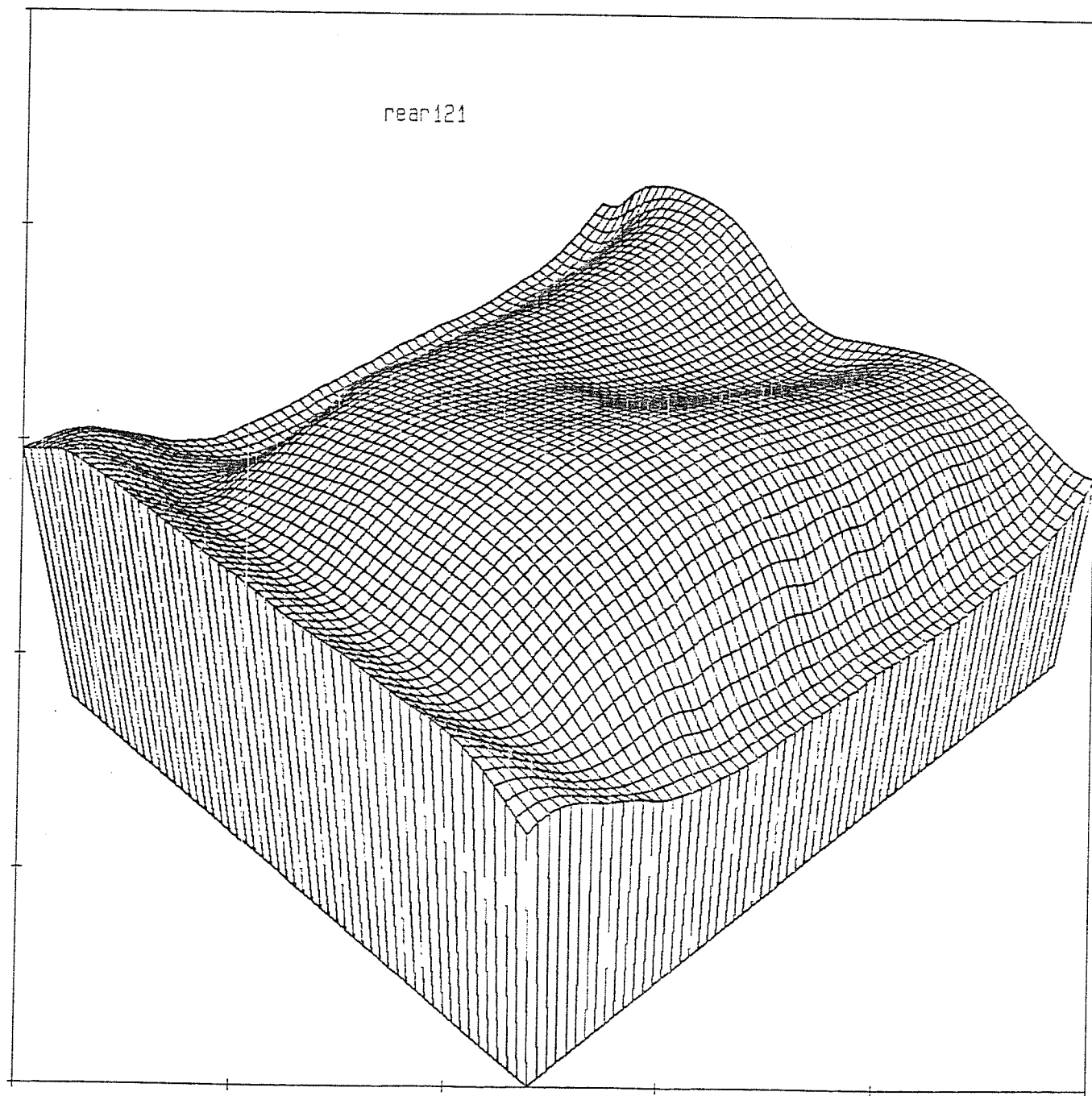Fig. D.12 - Machined Cast "lisar"

Fig. D.13 - Plaster Cast "rear"

rear121

Fig. D.14 - Truepers Plot "rear"

Fig. D.15 - Machined Cast "rear"