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RESEARCH  
PROGRAM  
PHASE I: PHOTOGRAMMETRIC DIMENSIONING  
OF DISTRIBUTIVE SYSTEMS MODELS

U.S. Department of Commerce  
Maritime Administration

in cooperation with  
Todd Pacific Shipyards Corporation

Transportation  
Research Institute

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| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                             |                                             |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                             |                                             |                                    |
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## FOREWORD

This is a report of only Phase I of the research project "Photogrammetric Dimensioning of Distributive Systems Models." It contains the researcher's acquired understanding and recommendations for Phase II. Its purpose is to solicit shipbuilders' comments.

The project is one of a number, in progress, being managed and cost shared by Todd Pacific Shipyards Corporation as part of the National Shipbuilding Research Program. The Program is a cooperative effort between the Maritime Administration's Office of Advanced Ship Development and the U.S. shipbuilding industry. The objective, described by the Ship Production Committee of the Society of Naval Architects and Marine Engineers, emphasizes productivity.

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OVERVIEW

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This project is a natural outgrowth of the Todd/MarAd sponsored project "Photogrammetry in Shipbuilding" which was very successfully concluded in 1976 with a report bearing the same title. In that earlier work it was demonstrated that photogrammetry can produce very reliable dimensions of an object from photographs. Five shipyards subsequently contracted for photogrammetric surveys of large structures, attesting to the productivity of the method.

One of the demonstrations conducted during the earlier project produced an accurate arrangement drawing of steam systems from photographs of a portion of a machinery space model. But, it was concluded that it would be more productive to produce dimensions from such models in digital rather than graphical form. In digital form the dimensional data could be readily manipulated for direct input to existing or developing computer-aided piping design programs. In substance, photogrammetry was seen as a logical link between design modeling of distributive systems and computer-aided piping design programs.

Design modeling, which is an alternative to traditional design processes in congested areas of ships, has been productively implemented by several foreign shipbuilders and most major U.S. designer/builders of petro-chemical plants and the like. Because the design takes form by way of building a very detailed scale model with only ship specifications and general diagrammatics as guides, there are (initially) no records of arrangements, dimensions, parts, etc. except those which are inherent in the model itself. The task, then, is to accurately extract this information from the model. Since shipbuilders are implementing computer-aided piping design programs,

these extracted data should be simultaneously formatted for direct input to such systems which, in turn, can produce joint maps, pipe detail drawings, fabrication instructions, bills of material, etc.

Presently this data extraction process is typically a manual one. There have been numerous attempts to mechanize the data extraction process, but only in one instance did any of these become implemented in a production environment. Photogrammetry is not presently used for this purpose, but properly applied, it is believed to have the potential for being the most productive of any of the possible data extraction processes.

Two conceptual photogrammetric systems which are believed to be best suited to the data extraction task are described in detail as are their relative merits. One system makes use of a stereoplotter mini-computer digitizer while the second utilizes a monocomparator mini-computer digitizer. Both digitizing systems use photographs from the same type of photogrammetric camera. The camera and either digitizing system can also be used for other shipyard dimensioning tasks .

It is recommended that Phase II of this project be implemented, wherein both conceptual digitizing systems can be evaluated. Concurrently, with the aid of a participating organization such as Offshore Power Systems, conceptual model building techniques which will aid the data extraction process can also be evaluated. Finally, data gathered from experimental digitizing efforts should be processed by the Newport News "RAPID" system to demonstrate, by way of output documents, end products resulting from the marriage of design modeling, photogrammetry and computer-aided piping design systems.

## TABLE OF CONTENTS

|                                                           | <u>Page</u> |
|-----------------------------------------------------------|-------------|
| OVERVIEW.....                                             | ii          |
| LIST OF ILLUSTRATIONS.....                                | vii         |
| LIST OF TABLES.....                                       | viii        |
| 1. INTRODUCTION.....                                      | 1           |
| 1.1 Background.....                                       | 2           |
| 1.2 Scope of the Current Project.....                     | 3           |
| 2. DESIGN MODELING . . . . .                              | 7           |
| 2.1 The Basic Concept. . . . .                            | 8           |
| 3. PHOTOGRAMMETRY . . . . .                               | 10          |
| 3.1 Basic Principles.. . . .                              | 11          |
| 3.1.1 Stereoscopic Perception . . . . .                   | 11          |
| 3.1.2 The Stereoplotter . . . . .                         | 12          |
| 3.1.3 The Analytical Approach. . . . .                    | 14          |
| 4. COMPUTER-AIDED PIPING DESIGN SYSTEMS . . . . .         | 19          |
| 4.1 Variations in Degree of Automation . . . . .          | 20          |
| 4.2 The Newport News RAPID System . . . . .               | 21          |
| 4.2.1 Reasons for Detailed Review . . . . .               | 21          |
| 4.2.2 RAPID Hardware . . . . .                            | 22          |
| 4.2.3 RAPID Capabilities . . . . .                        | 25          |
| 4.2.3.1 Input . . . . .                                   | 25          |
| 4.2.3.2 Data Processing . . . . .                         | 26          |
| 4.2.3.3 Output . . . . .                                  | 28          |
| 5. A REVIEW OF DIMENSIONING DESIGN MODELS . . . . .       | 32          |
| 5.1 The Need . . . . .                                    | 33          |
| 5.2 Experimental Dimensioning Procedures . . . . .        | 33          |
| 5.2.1 Early Photographic Attempts . . . . .               | 33          |
| 5.2.2 Farrand's Photogrammetric System . . . . .          | 34          |
| 5.2.3 Utility Data Corporation's Experiments . . . . .    | 35          |
| 5.2.4 BSRA Approximate Photogrammetric Solution . . . . . | 37          |
| 5.2.5 Hitachi Ranging Devices. . . . .                    | 38          |

|          |                                                                                                       |    |   |
|----------|-------------------------------------------------------------------------------------------------------|----|---|
| 5.3      | Dimensioning Processes in Present-Day Use . . . . .                                                   | 38 |   |
| 5.3.1    | Manual Take-Off . . . . .                                                                             | 38 |   |
| 5.3.2    | Vickers' Optical Triangulation System . . . . .                                                       | 39 |   |
| 5.3.3    | The Hitachi "Draft-Camera" . . . . .                                                                  | 40 |   |
| 6.       | NEW CONCEPTS FOR PHOTOGRAMMETRIC DIMENSIONING . . . . .                                               | 43 |   |
| 6.1      | Shortcomings of Previous Efforts for Mechanized<br>Dimensioning . . . . .                             | 44 |   |
| 6.2      | The Marriage of Design Modeling, Photogrammetry and<br>Computer Aided Piping Design Systems . . . . . | 4  | 5 |
| 6.3      | The Photogrammetric Camera . . . . .                                                                  | 48 |   |
| 6.4      | Conceptual Photogrammetric Digitizing Systems . . . . .                                               | 49 |   |
| 6.4.1    | Functional Requirements . . . . .                                                                     | 49 |   |
| 6.4.2    | A Stereoplotter/Mini-Computer System . . . . .                                                        | 50 |   |
| 6.4.3    | A Monocomparator/Mini-Computer System . . . . .                                                       | 52 |   |
| 6.4.4    | Relative Merits of the Digitizing Systems . . . . .                                                   | 52 |   |
| 6.4.4.1  | Preparation of Model . . . . .                                                                        | 53 |   |
| 6.4.4.2  | Aiming the Camera . . . . .                                                                           | 55 |   |
| 6.4.4.3  | Measuring Speed . . . . .                                                                             | 56 |   |
| 6.4.4.4  | Accuracy . . . . .                                                                                    | 59 |   |
| 6.4.4.5  | User Skills . . . . .                                                                                 | 60 |   |
| 6.4.4.6  | Software Requirements . . . . .                                                                       | 60 |   |
| 6.4.4.7  | Ability to Interface to Computer-Aided<br>Design Systems . . . . .                                    | 62 |   |
| 6.4.4.8  | First Cost . . . . .                                                                                  | 63 |   |
| 6.4.4.9  | Suitability for Distributive Systems<br>Other Than Piping . . . . .                                   | 64 |   |
| 6.4.4.10 | Suitability for Other Shipyard Work . . . . .                                                         | 64 |   |
| 6.4.4.11 | Summary of Relative Merits . . . . .                                                                  | 65 |   |
| 6.5      | Associated Model Building Techniques . . . . .                                                        | 66 |   |
| 6.5.1    | Model Sectioning . . . . .                                                                            | 66 |   |
| 6.5.2    | Minimal Use of Plexiglas . . . . .                                                                    | 67 |   |
| 6.5.3    | Removable Machinery Components . . . . .                                                              | 68 |   |
| 6.5.4    | Wire and Disc Presentation . . . . .                                                                  | 68 |   |
| 6.5.5    | Color Coding . . . . .                                                                                | 68 |   |
| 6.5.6    | Tagging . . . . .                                                                                     | 69 |   |
| 6.5.7    | Finishes . . . . .                                                                                    | 69 |   |
| 6.5.8    | Reference Marks . . . . .                                                                             | 69 |   |
| 6.5.9    | Circumferential Pipe Markings . . . . .                                                               | 70 |   |
| 7.       | RECOMMENDATIONS . . . . .                                                                             | 72 |   |
| 7.1      | Phase II . . . . .                                                                                    |    |   |
| 7.1.1    | General Recommendations . . . . .                                                                     | 73 |   |
| 7.1.2    | Model Building . . . . .                                                                              | 73 |   |
| 7.1.3    | Photogrammetry . . . . .                                                                              | 75 |   |
| 7.1.4    | Computer-Aided Piping Design System . . . . .                                                         | 77 |   |
| 7.2      | Other Research . . . . .                                                                              | 77 |   |

APPENDIX A - Abstracts of Pertinent Literature

APPENDIX B - Glossary of Terms

## LIST OF ILLUSTRATIONS

| <u>FIGURE</u> | <u>TITLE</u>                                                                                       | <u>PAGE</u> |
|---------------|----------------------------------------------------------------------------------------------------|-------------|
| 1.1           | Photograph of a Portion of a 3/4" = 1' Machinery Space Model . . . . .                             | 5           |
| 1.2           | Elevation Drawing of a Portion of Machinery Space Model . . . . .                                  | 6           |
| 3.1           | A Stereoplotter . . . . .                                                                          | 13          |
| 3.2           | A Monocomparator . . . . .                                                                         | 17          |
| 3.3           | illustrating Analytical Photogrammetric Triangulation . . . . .                                    | 18          |
| 4.1           | A Hardware Configuration of the RAPID System. . . . .                                              | 23          |
| 4.2           | Sample Output Documents From the RAPID System. . . . .                                             | 29-32       |
| 5.1           | Orthographic Photograph Produced by the Hitachi "Draft-Camera" . . . . .                           | 42          |
| 6.1           | The Marriage of Design Modeling, Photogrammetry and Computer-Aided Piping Design Systems . . . . . | 46          |
| 6.2           | A Precision Photogrammetric Camera . . . . .                                                       | 47          |
| 6.3           | A Stereoplotter/Mini-Computer Photogrammetric Digitizing System . . . . .                          | 5 1         |

---

## LIST OF TABLES

| <u>TABLE</u> | <u>TITLE</u>                                                               | <u>PAGE</u> |
|--------------|----------------------------------------------------------------------------|-------------|
| 6.1          | Estimated First Costs of Photogrammetric Dimensioning Systems . . . . .    | 63          |
| 6.2          | Summary of Relative Merits of Photogrammetric Digitizing Systems . . . . . | 65          |

1. INTRODUCTION

## 1. INTRODUCTION

### 1.1 Background

In July 1976 the U.S. Maritime Administration in co-operation with Todd Shipyards Corporation published a National Shipbuilding Research Program report entitled "Photogrammetry in Shipbuilding".<sup>1</sup> Efforts put forth in the conduct of that project represented the U.S. shipbuilding industry's first exposure to photogrammetry, the science of obtaining reliable two and three dimensional measurements of objects from photographs. Several shipbuilders quickly recognized the productivity of photogrammetric dimensioning, particularly for the measurement of large structures. Even before the project concluded one shipyard committed to the use of photogrammetry for the survey of spherical LNG cargo tanks, with subsequent calculation of their sounding tables. Other examples of implementation which have since materialized include:

- \*measurement of mating faces of a very large three-section jacket of an offshore drilling platform
- \*measurement of Conch-type LNG tanks for the purpose of generating sounding tables
- \*survey of mating faces of two 126,000-dwt tankers built in halves and mathematical prediction of the fit between the forward and after ends
- \*determinations of circularity at various transverse sections though cylindrical vessels

<sup>1</sup>This report is available as Publication PB-262-130/AS through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Also see Abstract #1, Appendix A.

The "Photogrammetry in Shipbuilding" project incorporated four demonstration photogrammetric surveys, all of which were conducted under real shipyard conditions. One of these employed photogrammetry for the purpose of "lifting" dimensional data from models of machinery spaces. Photographs of a machinery space model were used to produce an accurate composite drawing of a portion of the model. Figures 1.1 and 1.2 illustrate the initial and end-products of that demonstration.

Although the demonstration was considered to be rather crude, it did definitely establish the feasibility of the process. Of this it was stated further:

Since a stereoplotter measures in all three dimensions simultaneously and since each axis can be digitized (a very common practice), the points defining a pipe can be digitized.

Such digital representations could be manipulated to automatically plot system arrangement drawings, composites or isometrics at any desired scale. Also, pipe bending details could be automatically generated as has been demonstrated elsewhere. Ultimately, the digital data could be merged with other automated design systems. For these potential applications it is clear that photogrammetry could serve as an excellent input "device" which would permit a combined pipe-systems designer/model maker to put his inherently interference-free piping arrangements into a computer. "

## 1.2 Scope of the Current Project

The present project is a natural outgrowth of the original work described above. Objectives of Phase I, as set forth in the Statement of Work are:

\*to develop an understanding of design modeling

- \*to become familiar with processes involved in the production of distributive systems drawings
- \*to develop a basic understanding of how pipe fabrication data are generated
- \*to become acquainted with events leading to the generation of bills of material
- \*to study the capabilities and input requirements of existing computer-aided distributive systems design programs

Knowledge gained from these investigations is either inherent or set forth explicitly throughout the remainder of this report. At the same time suggestions are made with regard to:

- \*conceptual model building techniques which may facilitate take-off of dimensions by photogrammetric methods
- \*conceptual photogrammetric systems (hardware, software and procedures) which might be employed for three dimensional digital take-off of dimensions in a format compatible for direct input to an existing computer-aided piping design program
- \*continuation of the project into a demonstration phase

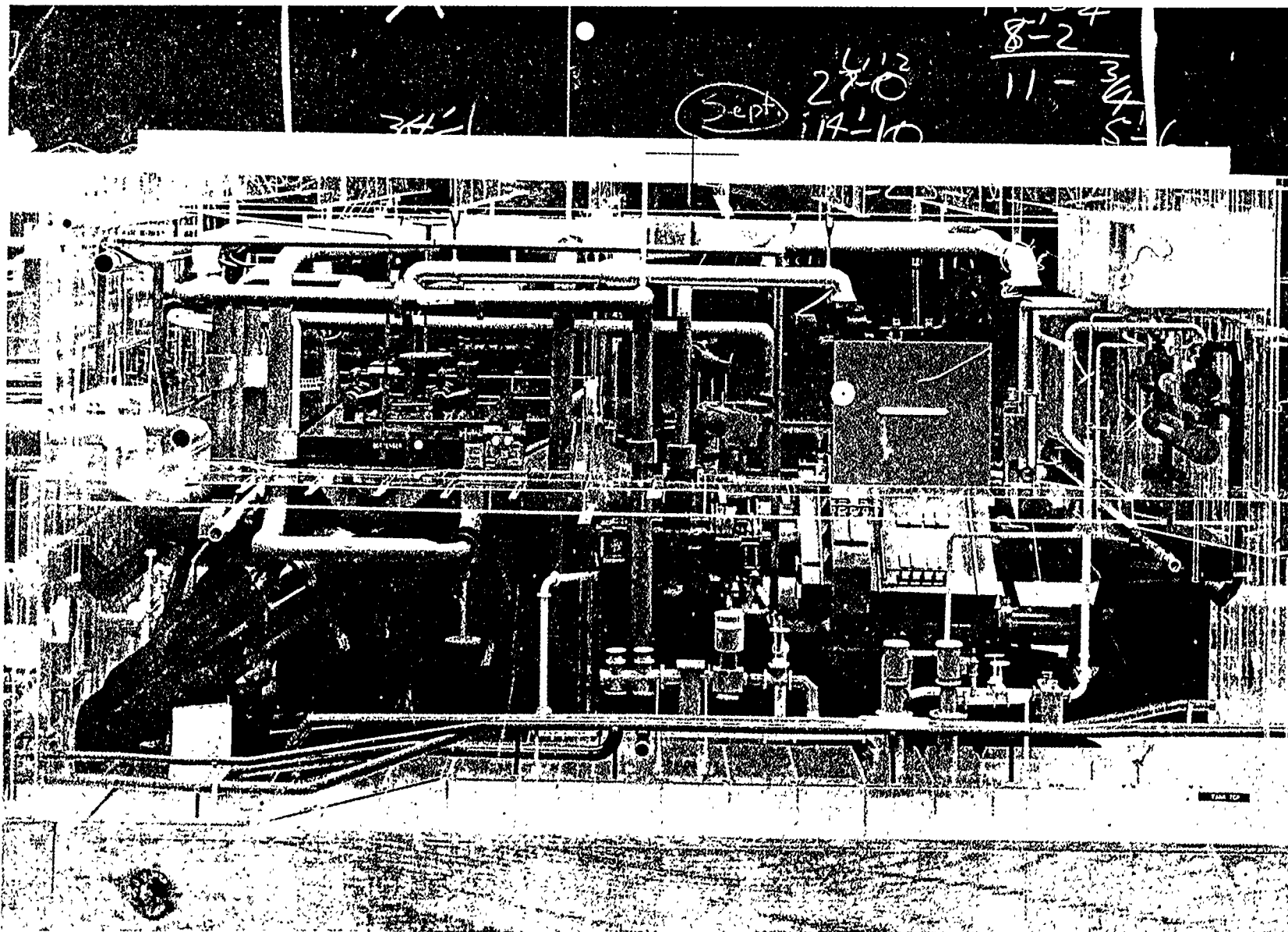


FIGURE 1.1: Photograph of a Portion of a  $3/4" = 1'$  Machinery Space Model. This print was made directly from one of several glass plate negatives used for the photogrammetric work.





## 2. DESIGN MODELING

U.S. shipbuilders are certainly familiar with and have made use of a variety of models. These uses are documented in the report "Use of Scale Models as a Management Tool"<sup>1</sup> which was also produced by the Maritime Administration and Todd Shipyards Corporation in conjunction with the National Shipbuilding Research Program. That report, however, only briefly touched upon the concept of design modeling, probably because it is not generally practiced within the U.S. shipbuilding industry.

The brief discussion of design modeling given herein is intended only to acquaint the reader with the technique. While this report is not intended to promote design modeling per se, it is significant that European and Japanese shipbuilders do rely heavily on the method, as do many designers of oil, chemical and process plants within the U.S.

### 2.1 The Basic Concept

Quite simply design modeling is just one alternative to the design of distributive systems. Designers, planners and model builders (or persons disciplined in two or more of these areas) usually start only with a general specification for the vessel or plant, diagrammatics or flow diagrams, the basic structural design and predetermined major machinery items. A scale model of the structure is built to a high degree

<sup>1</sup>This report is available as Publication COM-75-10923/AS through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. Also see Abstract #2, Appendix A.

of accuracy primarily from Plexiglas and similar materials. Alternate arrangements of machinery are usually studied next, directly on the model. Once the optimum arrangement is decided upon, routing of piping systems, wireways and HVAC is then also performed directly on the model. Most of the "parts" used for this purpose are made of plastic and many of these are commercially available items. This is particularly true of standard diameter pipes and industry-standard valves, pumps, fittings, etc. Abstracts #3 through #21 contained in Appendix A are exemplary of many available articles on design modeling.<sup>1</sup> From these the reader will quickly determine that there are many variations in procedures, sophistication and even in opinions, all having been developed as that which best suited a particular organization's structure.

It is important to appreciate, as stated above, that design modeling is an alternative design technique. An organization employing design modeling most certainly would not build a model of all distributive systems on-board a ship. It should be obvious that design modeling would be productive in congested areas such as engine and pump rooms but that traditional methods of design would be more productive in non-congested areas of the ship.

<sup>1</sup>Abstracts #3 through #10 are for general articles on design modeling whereas #11 through #21 are for articles more relevant to the marine industry. Abstracts #17 and #18 should be of particular interest to shipbuilders since these describe a very sophisticated and complete design modeling system employed by Odense Steel Shipyards, Ltd.



### 3. PHOTOGRAMMETRY

Photogrammetry is the science of extracting reliable dimensions of an object from measurements made on two or more photographs of the object. While the science has only been recently adopted within the shipbuilding industry it has been in various stage's of development for over 100 years. Technological advances which have dramatically altered the course of the development of photogrammetry were the invention of the airplane and the digital computer. 95% of all of the earth's topographic maps are now produced by photogrammetry and it is state-of-the-art to produce very precise measurements of objects such as ship's sections and cargo tanks.

#### 3.1 Basic. Principles

Inasmuch. as photogrammetry is treated in great detail in the report "Photogrammetry in Shipbuilding" (see footnote 1, page 2 ), only general concepts pertinent to the present project shall be discussed herein. However, a complete glossary of terms is contained within Appendix B.

##### 3.1.1 Stereoscopic Perception

The fact that three dimensional data can be obtained from two or more photographs of an object is not mysterious when one relates to his own experience in viewing stereoscopically. Surely the reader has seen a "3D" movie so popular in the 1950's or has mused over his family's antique stereopticon. Both of these viewing experiences hold one basic

commonality - the viewer's eyes are instantaneously presented two photographs of the same scene, but each is taken from different vantage points. It is this difference in vantage points which allows the viewer to "see" in three dimensions when the two photographs are viewed. Suffice it to say that if it is possible to create a three dimensional reproduction of a scene, it is also possible to introduce a means to make measurements within this perceived scene.

#### 3.1.2 The Stereoplotter

A stereoplotter is nothing more than a sophisticated device for simultaneous viewing of two photographs (see Figure 3.1). If the two photographs are of the same scene but taken from different points of view, the operator of the instrument actually sees a three dimensional rendition or "optical model" of the scene. The stereoplotter also has a measuring reticle which the operator may move in contact with the optical model. Movement of this reticle may be digitized (X,Y and Z) by means of encoders just like those on digitizing tables used in mold lofts. Hence, it is possible for the operator to digitize, in all three dimensions, any point he chooses within the optical model. The motion of the

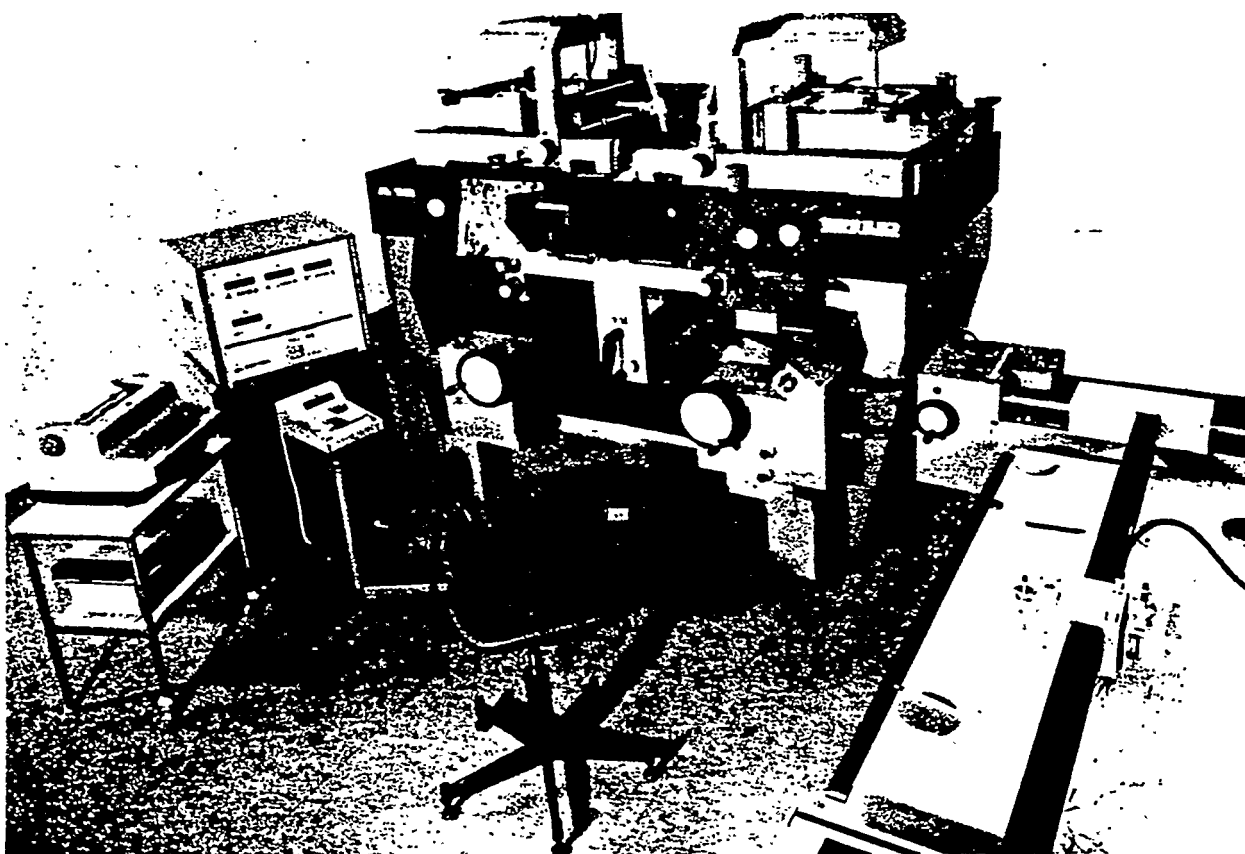


FIGURE 3.1: A Stereoplottor. This particular instrument was used to map the machinery space model of Figure 1.1 and produce the drawing shown as Figure 1.2. The instrument allows the operator to view two photographs simultaneously and perceive the scene photographed in three dimensions. Points of interest can be digitized in three dimensional coordinates or shapes and features can be mapped in the form of line drawings. Photograph courtesy of Wild Heerbrugg Instruments, Inc., Farmingdale, Long Island, New York.

reticle may also be followed by mechanical or electronic linkages connected to a drawing table, such as the one pictured on the right of Figure 3.1, permitting the operator to draw a map of the object. It is this mode of operation which was used to produce the piping drawing shown in Figure 1.2. But, it is the digital mode of operation which is being pursued in the present investigation.

### 3.1.3 The Analytical Approach

To create the third dimension from photographs it is necessary that the photographs image the same scene from differing vantage points. Oftentimes, however, an entire scene contains relatively few points of engineering significance. For example, in predicting the fit of ships built in halves, it is only necessary to determine the relative locations of "hard" points on each of the mating faces. Hence, photographs of the transverse sections need only contain images of these hard points and the remainder of the scene need not appear at all! It would be entirely permissible to take photographs at night with tiny lights placed at the hard points, which of course would result in photographs having only a few dots where the lights were imaged. In practice photographs are taken during the day but the hard points are nonetheless signalized, not

with lights but with high contrast targets. Although an entire transverse section is imaged, only the targets are of interest.

Photographs containing only images of targets can be used in a stereoplotter<sup>1</sup> and three dimensional locations of the targets can be digitized. These photographs can also be measured individually, i.e. one at a time on an instrument known as a comparator (see Figure 3.2). The comparator performs precisely the same function as the digitizing table in a mold loft, the only difference being that the comparator measures over a smaller area but with much greater resolution. Hence, the comparator allows its operator to digitize the locations of the target images. Note, however, that the measurements are only in the plane of the photographs and do not (yet) relate to the three dimensional scene photographed.

Measurements from a comparator must be processed through a computer program in order to derive the three dimensional locations of the targets. The mathematical process is readily visualized with the aid of Figure 3.3. In this diagram it is seen that a line or "ray" may be

-But with restrictions placed on the separation and parallelism of camera axes when the two photographs are taken. These restrictions are imposed by mechanical limitations of the stereoplotter.

projected from an exposure station (i.e. the location of the camera lens when the photograph was taken), through the comparator-measured xy location of a target image on into space and the object itself. Actually, a single ray to a target will continue through the object to infinity unless the ray is intercepted by another ray (or rays) to the same target but from a different photograph(s). The principle illustrated is simply one of three dimensional triangulation by means of intersecting rays; the location of the target in the user-defined XYZ coordinate system of the scene is simply that point at which rays to the same target intersect.<sup>1</sup>

1A more complete discussion of this technique may be found in "Predicting the Fit of Ships Built in Halves" by J. F. Kenefick and D. Douglas Peel, prepared for presentation to the International Society of Photogrammetry Inter-Congress Symposium "Photogrammetry for Industry", August 14-17, 1978, Stockholm, Sweden.

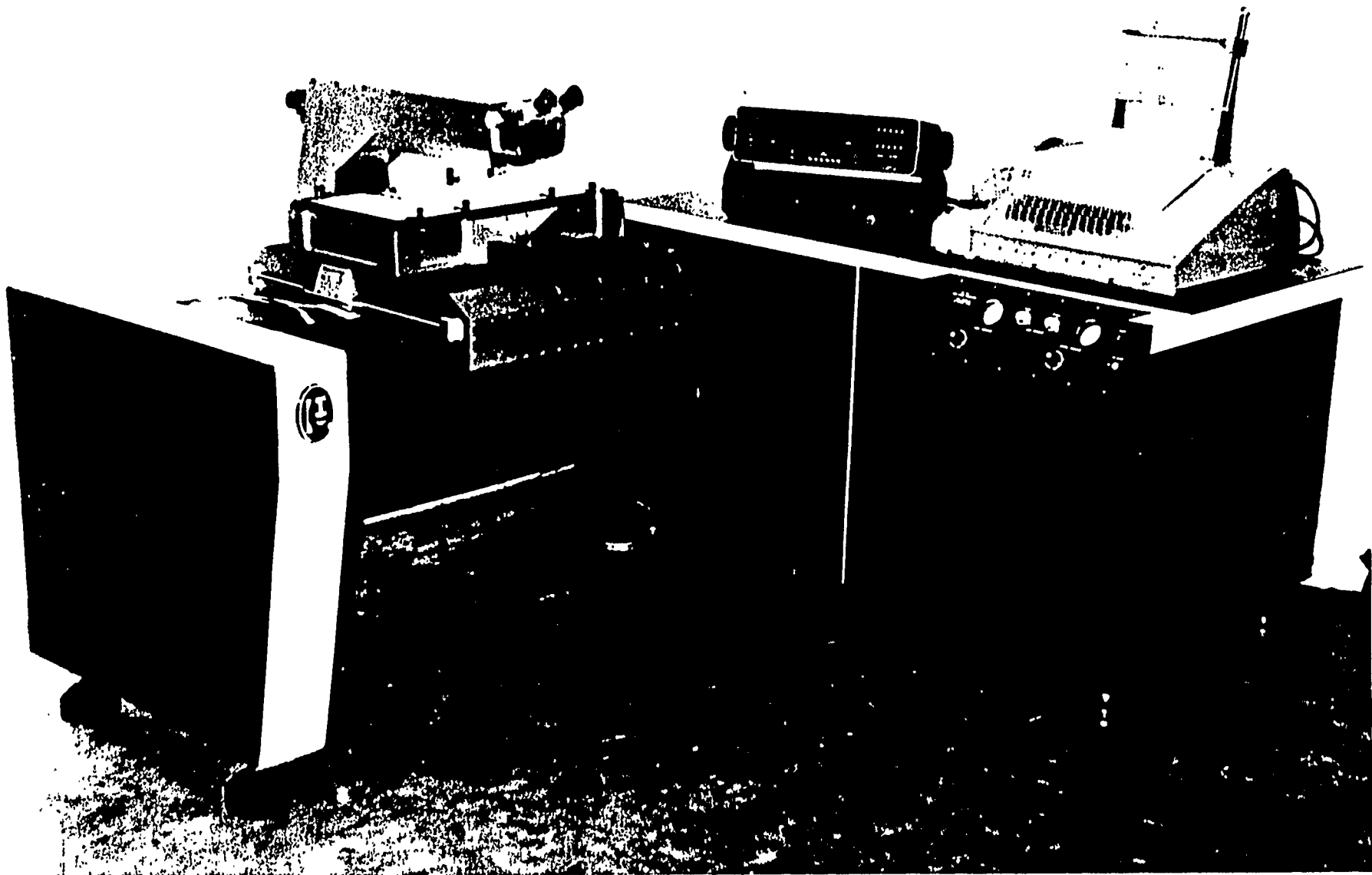


FIGURE 3.2: A Monocomparator. This type comparator is designated as a "mono" comparator because the operator views only one photograph at a time; i.e. there is no stereoscopic perception. Photograph courtesy of Keuffel and Esser Company, H. Dell Foster Operation, San Antonio, Texas.

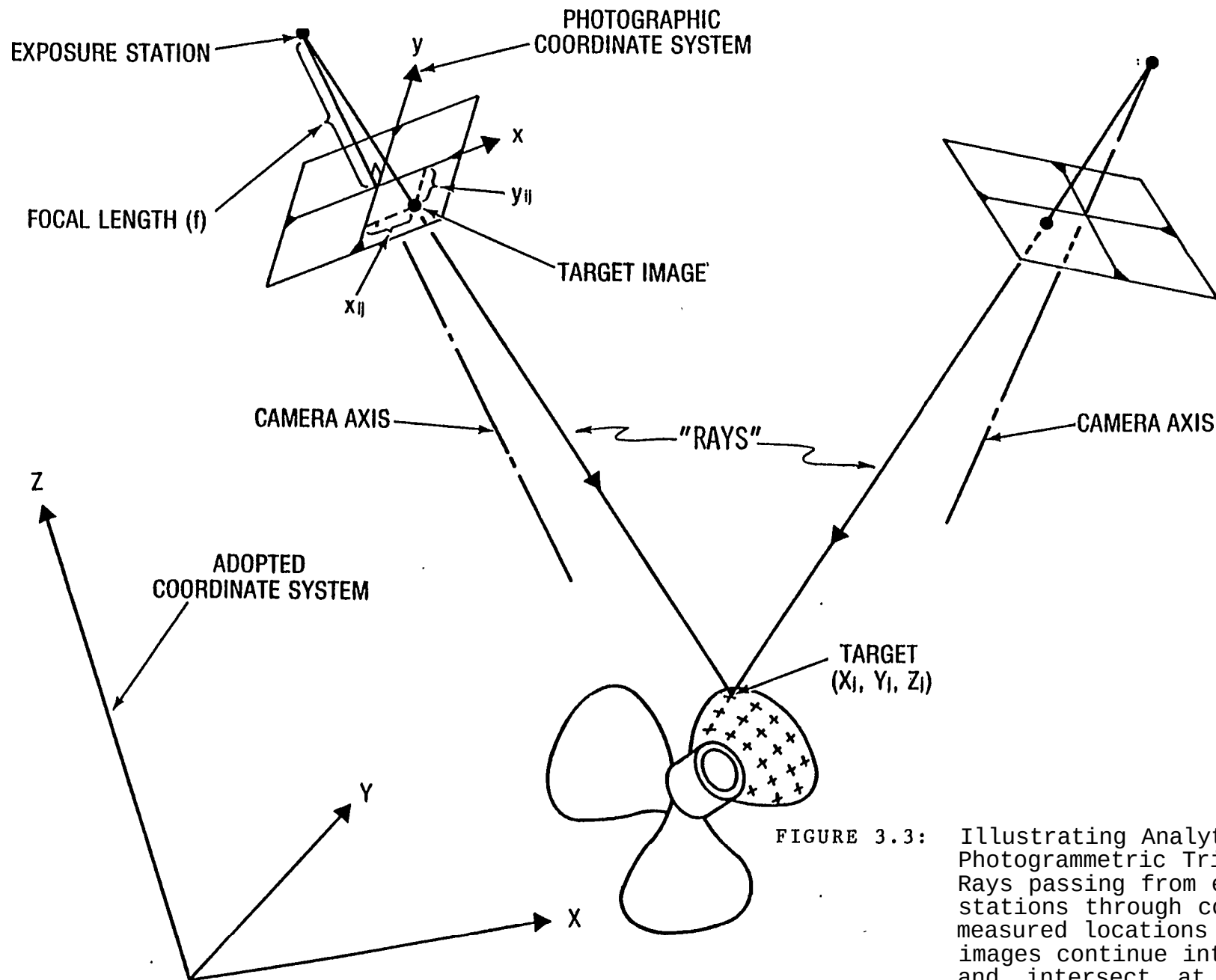


FIGURE 3.3: Illustrating Analytical Photogrammetric Triangulation. Rays passing from exposure stations through comparator measured locations of target images continue into space and intersect at a target to produce its XYZ coordinates.

4. COMPUTER-AIDED PIPING  
DESIGN SYSTEMS

#### 4. COMPUTER-AIDED PIPING DESIGN SYSTEMS

##### 4.1 Variations in Degree of Automation

Nearly all shipbuilders nowadays have introduced some degree of computer automation in their distributive systems design processes. The extent to which automation has been implemented varies widely, however. In some yards, usually smaller ones, this automation may be relegated to stress calculations or computation of fabrication data. In some larger yards (especially foreign) the design of congested areas of a ship may be almost entirely automated, even to the extent that the designer inputs his conceptual designs at a CRT<sup>1</sup> from rough sketches and immediately interacts or "converses" with the computer to finalize his design.<sup>2</sup> Because of this wide variation in automation it is simply not possible to review all variations of computer-aided distributive system design. Accordingly, only the more comprehensive systems were studied by the investigator since the capabilities of less sophisticated systems would inherently be covered by such an approach. It is also worthy of mention that all automated systems are almost exclusively concerned with piping and not with electrical and HVAC. Obviously this is because piping design, fabrication and installation consumes a major portion of the total shipbuilding process. However, once computer-aided piping design approaches near

<sup>1</sup>Cathode Ray Tube

<sup>2</sup>This process is commonly referred to as "interactive graphics". Such design systems are not yet entirely perfected, but systems with somewhat less than this full capability are operational.

perfection it is logical that other distributive systems will be given greater attention.

#### 4.2 The Newport News RAPID System<sup>1</sup>

##### 4.2.1 Reasons for Detailed Review

The Newport News RAPID (Interactive Piping Design) system was chosen for particularly detailed review for several reasons:

- a. The system (in the opinion of the investigator) is a practical one being based upon five years experience in automated generation of pipe fabrication data at Newport News. System development is directed by individuals intimately familiar with shipbuilding functions.
- b. While the system offers the potential to be expanded to interactive design, its present capabilities are predicated upon traditional design wherein piping geometry is prepared in the form of arrangements and/or composites. From this point forward (as will be described shortly in greater detail) the process is computer-aided . In these respects the system is essentially the same as it would be if the piping geometry were defined on a model rather than on the drafting board. In fact, the RAPID system simply

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<sup>1</sup>Also see Abstract #22, Appendix A.

accepts piping geometry as one of its basic inputs; whether this geometry comes from arrangement drawings or models is of no real consequence.

- c. The system is being developed by Newport News under a cost-sharing arrangement with the U.S. Maritime Administration. Because of this arrangement RAPID technology is scheduled to be released to the U.S. shipbuilding industry during 1978. Logically, efforts of this project should dovetail with the development of RAPID, but without being dependent upon the existence of RAPID.

#### 4.2.2 RAPID Hardware.

Figure 4.1 illustrates a possible RAPID hardware configuration. The word possible is emphasized since many variations are logical, depending upon a given shipyard's needs.

Functions of the hardware components are:

\*Mini-computer - contains all of the RAPID programs which accept and store input data, process data and output data. In addition, the mini-computer can communicate (for purposes to be described shortly) with the shipyard's main computer. Beyond minimum requirements, the mini-computer can have a range of central memory and auxiliary magnetic storage devices such as discs and magnetic tapes.

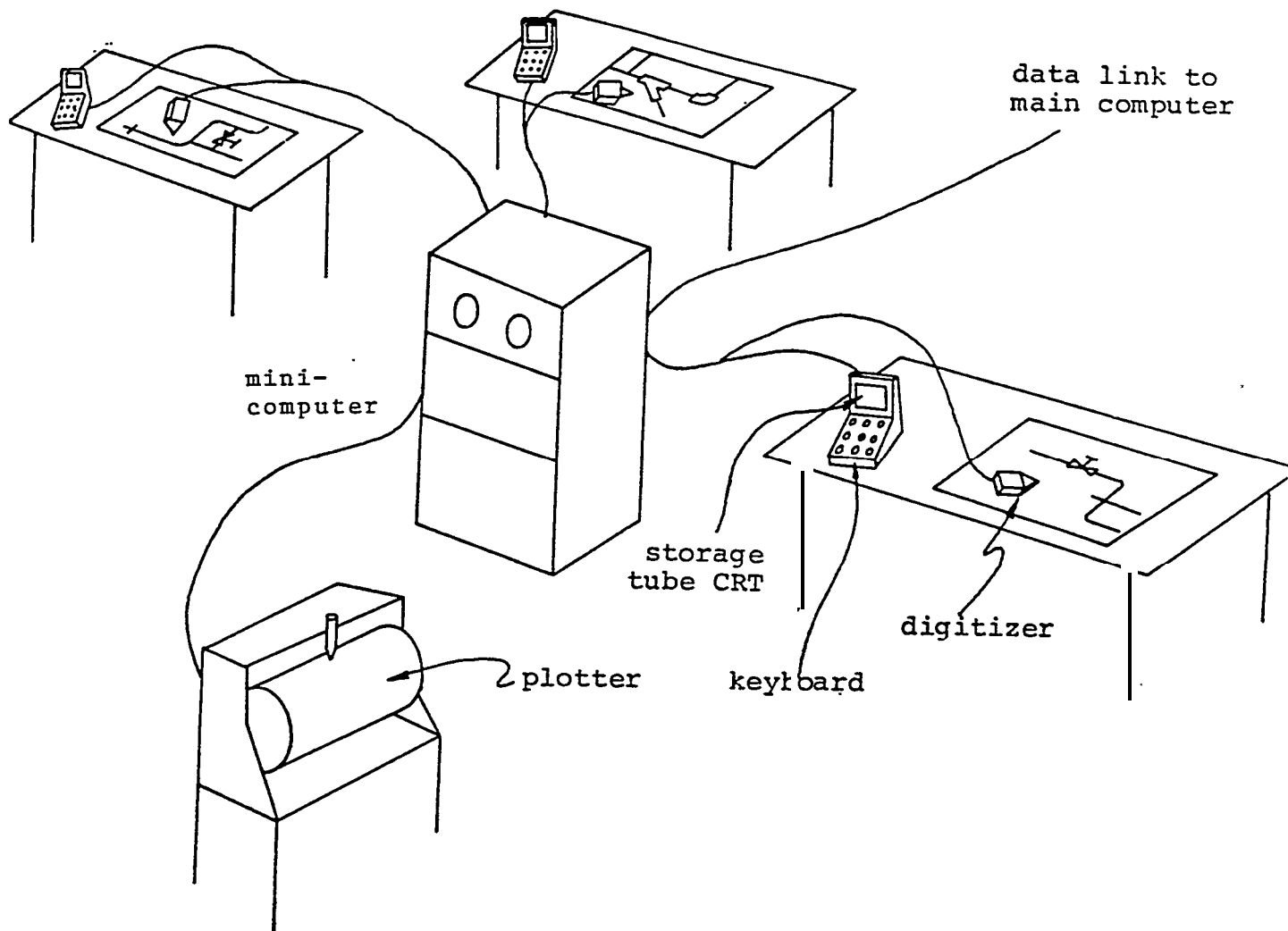


FIGURE 4.1: A Hardware Configuration of the RAPID System. Other configurations are also possible. Illustration is taken from the report described in Abstract #22, Appendix A.

\*Digitizing table - is simply a recording device which allows the user to input locations of pipes, fittings, valves, etc. in terms of their relative locations in an XY coordinate system.

\*CRT - serves both input and output functions. The operator can input by means of a standard keyboard attached to the CRT. For example, if he is digitizing a plan view of an arrangement, he can manually enter corresponding elevations of points digitized. He can also use the keyboard to enter text information to be attached to items he is digitizing. Finally, the keyboard may also be used to request the mini-computer to execute certain pre-programmed functions such as calculation of pipe bending instructions.

The television-like display tube of the CRT allows the user to graphically see the path he has digitized. The tube also displays information typed in at the keyboard or information (text and/or graphical) retrieved from the mini-computer through commands typed at the keyboard by the operator.

\*plotter - is simply a means for permanently recording graphical and text information. For example, an isometric for a piping sub-assembly.

#### 4. 2.3 RAPID Capabilities

Basic capabilities of the RAPID system are best understood by dividing discussions into logical steps of operation.

##### 4.2.3.1 Input

Input of piping geometry by digitizing arrangement drawings is the fundamental input process. As the operator follows a given run on his digitizing table, each pipe "event" such as start, stop, tee, flange, valve, etc. is digitized. At any time the operator can request a check-plot by inputting commands at the CRT keyboard. The operator can also key in identifiers (also called attributes) to be associated with each digitized event. An identifier may be as elementary as a pipe diameter, but it can also be more comprehensive and include, for example, a shipyard stock number.

It is also possible for the user to modify pipe geometry at any time by utilizing appropriate digitizing and keyboard inputs. For instance, an extrusion can be inserted at a location defined by the digitizer simply by inputting the corresponding command at the CRT keyboard. Or, a pipe can actually be "broken" and, for example, a tee inserted.

Another input convenience allows the user to collect together and/or divide piping arrangements into assemblies, sub-assemblies, etc. for shop fabrication and installation. In some shipyards this function is performed by the design group whereas in other yards the shop assumes this responsibility. In recognition of this variation the RAPID system is designed to accept commands input from a "shop station". But, commands from a shop station cannot alter the design of the piping; they can only effect divisions of the piping systems for fabrication and installation purposes. The shop station can also request output of drawings, material lists and fabrication instructions.

The remainder of the input capabilities of RAPID are commands which invoke data processing and/or output functions. These are taken up separately in the following two paragraphs.

#### **4.2.3.2 Data Processing**

Once piping geometry is defined, automatic 'component selection may be invoked by the operator through commands entered at the CRT keyboard. If a component has previously been specifically identified by a shipyard stock number (for example)

it is "looked up" in a master parts catalog which resides on disc storage within the mini-computer. Geometric data is taken from the catalogue and automatically merged with the piping geometry data. Also, fitting orientation is automatically calculated. Since there are frequent situations where designers call for parts by generic name (as examples a turn or branch) rather than by specific descriptors such as shipyard stock numbers, the operator can input component selection rules to be used by the automatic component selection program.

Another data processing function performs error checks on a user-specified group of piping. Basically, the checks are to determine if everything is completely and logically defined for subsequent production of fabrication instructions and generation of bills of material. A third data processing procedure actually calculates the fabrication instructions and at the same time checks for situations that cannot be handled by the manufacturing facility; for example, bends that hit the floor. Finally, it is also possible to invoke a data processing function which allows the user to make modest changes to piping geometry in order to eliminate errors.

#### 4.2.3.3 Output

Output which can be generated by RAPID has already been inferred from the above discussions. In summary these are:

- \*piping drawings, with labels and dimensions if input (RAPID does not presently include an automatic dimensioning capability)

- \*material lists

- \*pipe fabrication instructions

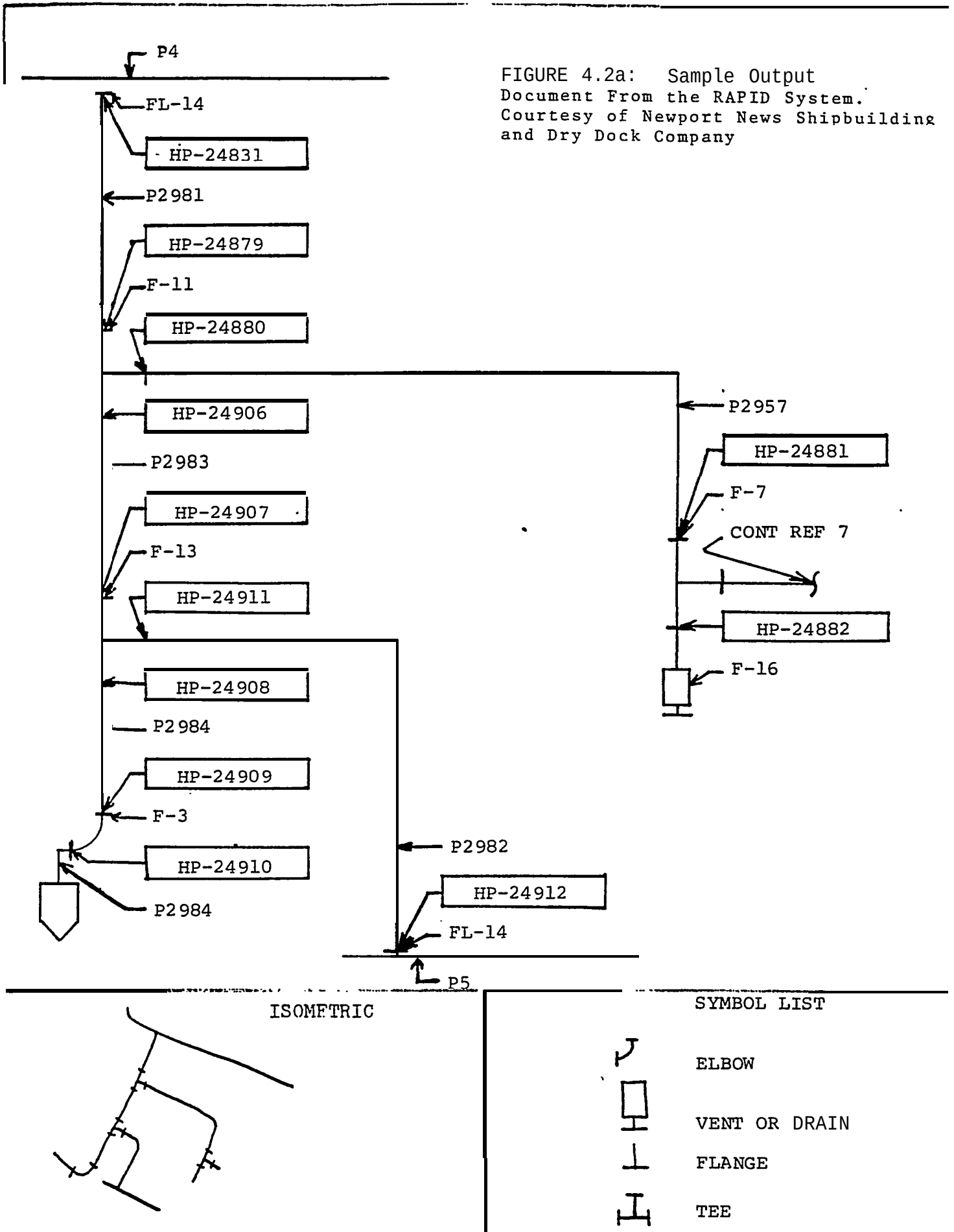
- \*schematic (joint map) drawings

With regard to the output of piping drawings it is worthy of mention that the user can "compose" his own views of a given sub-assembly. These may be orthographic or isometric views of an entire subassembly and/or of any user-selected details thereof.

Sample RAPID output documents are presented in Figures 4.2. These have been prepared manually since RAPID was not completely operational in February 1978 when the system was studied.

# Sample Joint Map (Partial)

FIGURE 4.2a: Sample Output  
Document From the RAPID System.  
Courtesy of Newport News Shipbuilding  
and Dry Dock Company



# Sample Pipe Detail Plot

Location and orientation of views and labels selected interactively by designer..  
Dimensioning performed automatically by computer.

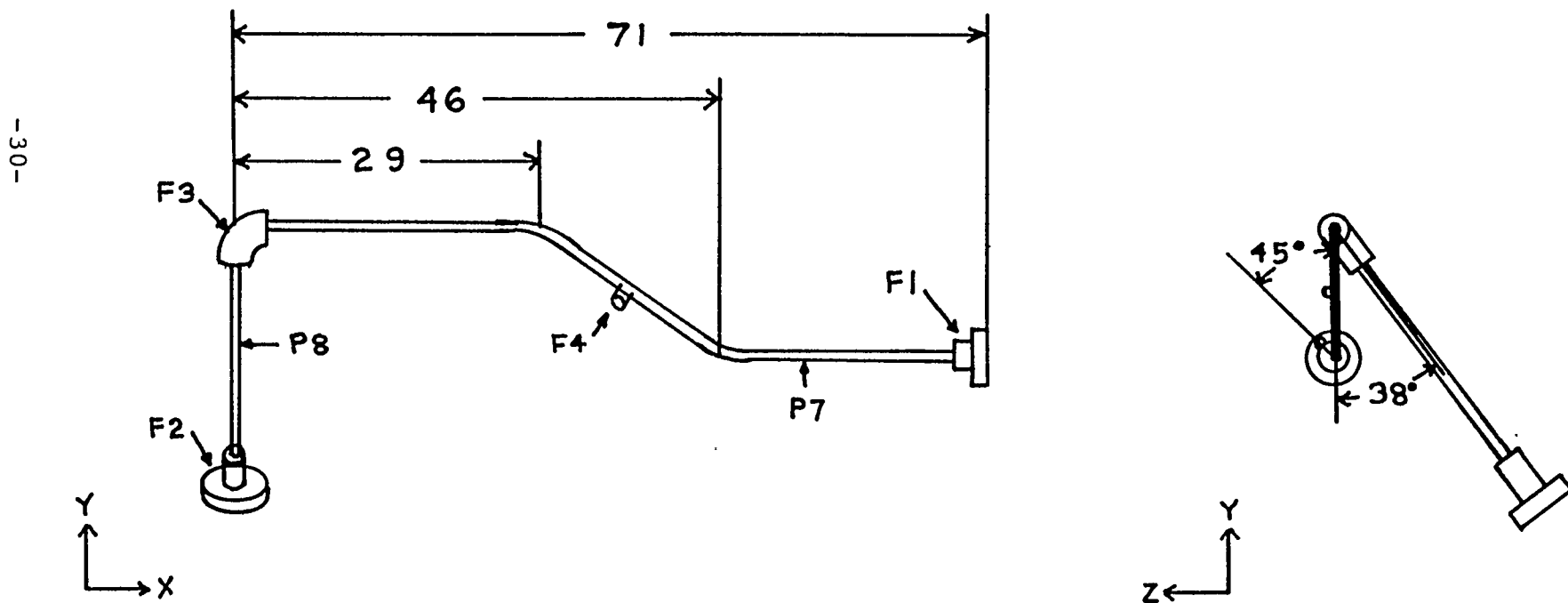


FIGURE 4.2b: Sample Output Document From the RAPID System. Courtesy of Newport News Shipbuilding and Dry Dock Company.

PIPE DETAIL NO. 1234567, HULL XYZ PIPE MANUFACTURING INSTRUCTIONS

| PIPE CUT & PREP | PIPE      | STOCK NO.     | END PREP OR TEMPLATE |            | LENGTH | MATERIAL |
|-----------------|-----------|---------------|----------------------|------------|--------|----------|
|                 | <u>P7</u> | <u>251763</u> | <u>END</u>           | <u>END</u> |        |          |
|                 | P8        | 251763        | Sw                   | SW         | 84.5   | C U N I  |
|                 |           |               | Sw                   | --         | 20     | CUNI     |

| FITTINGS LIST | PIECE     | STOCK NO. | DESCRIPTION   | MATERIAL    |
|---------------|-----------|-----------|---------------|-------------|
|               | <u>F1</u> |           | <u>Flange</u> | <u>CUNI</u> |
|               | F2        | 112781    | Flange        | CUNI        |
|               | F3        | 754163    | Elbow         | CUNI        |
|               | F4        | 639172    | Boss          | CUNI        |

| STRAIGHT PIPE PRE-FAB | PIPE      | PRE-FAB<br>ATTACHING | PIECE | DIST. FROM<br>END | ORIENT<br>ANGLE | JOINT NO.     | JOINT TYPE |
|-----------------------|-----------|----------------------|-------|-------------------|-----------------|---------------|------------|
|                       | <u>P8</u> |                      |       | <u>END</u>        | <u>ANGLE</u>    | <u>J13728</u> | <u>SW</u>  |
|                       | P8        | F2                   |       | 0                 | 0               | J13728        | SW         |
|                       |           | F3                   |       | 0                 | 90              | J13729        | SW         |

| BEND & MARK | PIPE      | OPERATION   | AMT         |                        |
|-------------|-----------|-------------|-------------|------------------------|
|             | <u>P7</u> | <u>FEED</u> | <u>21.3</u> | End to 1st TANGT       |
|             |           | BEND        | 30.0        |                        |
|             |           | FEED        | 23.5        | 1st TANGT to 1st TANGT |
|             |           | ROTATE      | 165.0       |                        |
|             |           | MARK        | 17.1        | From 1st TANGT for F4  |
|             |           | ROTATE      | 15.0        |                        |
|             |           | BEND        | 30.0        |                        |
|             |           | CUT         | 33.4        | From 1st TANGT         |

| MAIN FABRICATION | MAIN<br>PIECE | ATTACHING | PIECE     | ORIENT      | JOINT NO.     | JOINT TYPE |
|------------------|---------------|-----------|-----------|-------------|---------------|------------|
|                  | <u>P7</u>     |           | <u>F1</u> | <u>45.0</u> | <u>J13726</u> | <u>Sw</u>  |
|                  | P7            |           | F4        | 75.0        | J13727        | BW         |
|                  | P7            |           | F3        | 38.0        | J13730        | Sw         |

FIGURE 4.2c: Sample Output Document From the RAPID System.  
Shipbuilding and Dry Dock Company.

# SAMPLE BILL OF MATERIALS

## PIPE LIST

| <u>PIPE</u> | <u>STOCK OR P.O.</u> | <u>LENGTH</u> | <u>NOM DIA</u> | <u>OD</u> | <u>THK</u> | <u>MATL</u> | <u>SPEC</u> | <u>REMARKS</u> |
|-------------|----------------------|---------------|----------------|-----------|------------|-------------|-------------|----------------|
| P6          | 257136               | 47.5          | 1              | 1.315     | .005       | CU          |             |                |
| P7          | 258215               | 118.0         | 0.75           | 1.050     | .065       | CUNI        |             |                |

## VALVE & FITTING LIST

| <u>PIECE</u> | <u>STOCK OR P.O.</u> | <u>QTY</u> | <u>SIZE</u> | <u>DESCRIPTION</u> | <u>MATL</u> | <u>SPECS</u> | <u>REMARKS</u> |
|--------------|----------------------|------------|-------------|--------------------|-------------|--------------|----------------|
| V1           | 441273               | 1          | 2           | Globe Valve        | CUNI        |              |                |
| F19          | 311762               | 4          | 1-1.5       | Union              | CUNI        |              |                |
|              |                      |            |             |                    | 7030        |              |                |

## HANGER LIST

| <u>HANGER</u> | <u>STOCK OR P.O.</u> | <u>STD?</u> | <u>LENGTH</u> |
|---------------|----------------------|-------------|---------------|
|---------------|----------------------|-------------|---------------|

FIGURE 4.2d: Sample Output Document From the RAPID System. Courtesy of Newport News Shipbuilding and Dry Dock Company

5. A REVIEW OF DIMENSIONING  
FROM DESIGN MODELS

## 5. A REVIEW OF DIMENSIONING DESIGN MODELS

### 5.1 The Need

When modeling is employed as a means for the design of distributive systems, the completed model can be likened to a single composite drawing. But, unlike composites, there are no source documents (such as arrangement drawings) to which one can refer for detailed dimensional information. The model is the design and it exists nowhere else in any form. Also unlike composites, the model is inherently free of interferences. Although the model in itself serves as an excellent medium for transmitting design concepts among the many persons requiring such information, there is the unquestionable ultimate need to convert the design into other mediums of communication.

### 5.2 Experimental Dimensioning Procedures

#### 5.2.1 Early Photographic Attempts

It is intuitive that photographs of a model are very useful visual aids. Indeed, model photography has been and remains an integral part of all serious model building programs. As an example, see Abstract #23, Appendix A.

In the early years of design modeling, however, attempts were made to use photographs as if they were orthographic projections. That is, measurements were scaled directly from the photographs. Because an ordinary photograph is a perspective view rather than an orthographic one, the photograph does not have a unique scale. While the scale will be constant for all detail

in a given plane parallel to the focal plane of the camera, the scale varies for different parallel planes. Hence it is not possible to scale accurate dimensions directly from an ordinary photograph if the object photographed has depth.

To reduce the effects of this variable scale (oftentimes referred to in the literature as "perspective" or "parallax") some organizations tried using very long focal length cameras, but ultimately, the entire concept of scaling from ordinary photographs was abandoned.

#### 5.2.2 Farrand's Photogrammetric System

In the early 1960's Richard Farrand, then employed by Imperial Chemical Industries (U.K.), saw the potential for utilizing photogrammetry to "lift" dimensional information from their design models of chemical plants. To determine the potential productivity of such a system Farrand conducted a series of experiments which allowed a comparison of manual versus photogrammetric take-off of dimensions from a piping model. The results were astonishing in that the photogrammetric method was at least twice as productive and yet devoid of the blunders which almost always crept into the manual measurements.

Based on the favorable outcome of these experiments, Imperial Chemical commissioned a well-known manufacturer of photogrammetric hardware to build camera and stereoplotter equipment specially designed for Imperial Chemical's work. In contrast to conventional stereoplotters such as the one shown in Figure 3.1, Farrand's stereoplotter had two drafting tables. On one table an elevation view of piping would be produced while the plan view was simultaneously drawn on the second table. Pipe drawings produced in this way were to an exact scale and drawn upon a stable-base drafting material. Although draftsmen later added annotations, dimensions were never shown. Instead, whenever dimensions were needed they were simply scaled from the drawings.

Farrand's system was never put into production. Reportedly, traditionalists in fear of their own status in the face of such a productive system, moved to scuttle the entire endeavor. Additional details on Farrand's work may be found in Abstract #24, Appendix A.

#### 5.2.3 Utility Data Corporation's Experiments<sup>1</sup>

In 1972 Utility Data Corporation ("UDC") experimented with the use of analytical photogrammetry (similar to that described in paragraph 3.1.3) to determine three dimensional

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<sup>1</sup>Information obtained from William Folchi, photogrammetrist, formerly employed by Utility Data Corporation. Mr. Folchi conducted the experiments described.

coordinates of pipe events as portrayed in a design model. A model of a petrochemical plant was loaned to UDC by the M. W. Kellogg Company who encouraged UDC to investigate the potential of the photogrammetric method.

As a control reference for the photogrammetric work a 1-centimeter grid was placed on the model base. To assure that various features of interest on the pipes would be exactly identified on different photographs, ordinary dotted line tape available in office supply stores was wrapped on the features to be located by photogrammetry. A large number of photographs were taken with a Pentax camera. Selected points on the 1-centimeter grid and selected dots on the dotted line tape were then measured on a monocomparator similar to the one shown in Figure 3.2. Use of the non-photogrammetric camera, however, created some unexpected difficulties which required special correction procedures to account for large lens-induced distortions in the imagery of the negatives.

Points measured on the comparator were "triangulated" in the same fashion as illustrated in Figure 3.3. A separate computer program connected points to produce line drawings of pipes.

As indicated earlier, this work was done on an experimental basis. No funding was involved and, therefore, a commitment to fully investigate the potential of dimensioning models in this way did not exist. Moreover, even if a workable system were developed, UDC did not believe a marketable service would accrue to their company.

#### 5.2.4 BSRA Approximate Photogrammetric Solution

In the early 1970's the British Ship Research Association (BSRA) investigated an approximate photogrammetric method for digitizing pipe runs directly from measurements made on two overlapping photographs of a machinery space model.<sup>1</sup> The digitizing was performed on-line with a mini-computer which was programmed to calculate pipe bending instructions.<sup>2</sup> A cathode ray tube displayed the path of a pipe run in isometric view as it was digitized. The only system accuracy reported was  $\pm 3\%$  for depth dimensions (i.e. in a direction to and from the observer) and even this appears to be a one-standard deviation figure rather than a tolerance.

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<sup>1</sup> See Abstract #25, Appendix A.

<sup>2</sup> See Abstract #26, Appendix A.

#### 5.2.5 Hitachi Ranging Devices

As a part of a joint effort with the Japan Ship's Machinery Development Association, Hitachi Shipbuilding and Engineering Company, Ltd. has developed two prototype three dimensional ranging systems for the purpose of lifting three dimensional coordinates from design models of machinery spaces. One system is acoustical while the other utilizes laser light. Beyond this there is little available detail, although, pictures of the two systems have been published (see Abstract #20, Appendix A). Reportedly,<sup>1</sup> both systems are being investigated for their potential to tie dimensional information inherent in the models to Hitachi's computer systems in order to automatically prepare outfitting data. Refinements are necessary to achieve practicality.

### 5.3 Dimensioning Processes in Present-Day Use

#### 5.3.1 Manual Take-Off

The most common method of dimensioning distributive systems models is simple manual measurement. This procedure is used, for example, by Continental Engineering, N.V.<sup>2</sup> and Odense Steel Shipyards, Ltd.<sup>3</sup> In the case of the former organization, some of the spatial locations of pipe "events" are measured and recorded on tags attached to the model at these locations during the course of building the model.

<sup>1</sup>Correspondence with Y. Tomita, Hitachi Shipbuilding and Engineering Company, Ltd.

<sup>2</sup>See Abstract #27, Appendix A. The firm is now known as Kellogg Continental, B.V. (Netherlands).

<sup>3</sup>See Abstracts #17 and #18, Appendix A.

In Odense's case it appears that all dimensions are measured only after the portion of the model of interest is completed. In both organizations, the dimensional data are eventually input to computer programs for preparation of fabrication documents, material lists, etc.<sup>1</sup>

#### 5. 3.2 Vickers' Optical Triangulation System

Vickers Shipbuilding Ltd. (U.K.) has implemented a system called CODEM (Computerized Design from Engineering Models). A major element of the system is dual telescopic sighting system. Each of the two telescopes may be moved along its own horizontal rail which forms an angle of 90 degrees with the other. Each telescope may be moved independently on its own vertical rail as well. A distributive system model (or portion thereof) is placed "inside" of the rails and piping "events" such as nozzles, tees, branches, etc. are sighted, one-by-one, through the two telescopes. Spatial locations of the telescopes are continuously monitored by digitizing equipment attached to the horizontal and vertical rails. These locations coupled with the pointing angles of the telescopes allow an on-line mini-computer to calculate (i.e. triangulate) the three dimensional location of each pipe event. These three dimensional locations are supplemented by descriptive information which is

See Abstracts #17, #18, and #27, Appendix A.

manually typed at the mini-computer's keyboard visual display unit. Eventually, all of the data are processed on a larger computer for the purpose of generating isometric drawings, fabrication instructions, bills of material, etc. Additional details on CODEM may be found in Abstracts #18 (last two pages thereof) and #19, Appendix 'A.

#### 5.3.3 The Hitachi "Draft-Camera"

Hitachi Shipbuilding and Engineering Company has implemented a photographic system which produces a nearly true orthographic photograph. That is, the photograph does not contain the perspective distortions inherent in ordinary photographs (see paragraph 5.2.1). The orthographic photograph is produced by a camera whose lens remains fixed while the model in front of the lens and film behind the lens are moved at relative speeds which produce a sharp negative. A narrow slit in front of the film allows only the near-parallel incoming rays of light to be imaged, resulting in a negative which has virtually no perspective distortion. Because of the narrow slit width it is necessary to scan the model in a series of parallel "swaths" of equal width. Hence, the entire negative is actually exposed over a period of time which is in contrast to ordinary photography wherein the negative is obtained practically instantaneously with a single release of the shutter.

Prints of the orthographic photographs are later measured by hand to extract dimensions in the plan view.<sup>1</sup> These dimensions plus other descriptive information are prepared on registered overlays to the negatives. A sample of the final product is shown in Figure 5.1. Additional information may be found in Abstract #20, Appendix A.

<sup>1</sup>It is not known for certain how elevation data are obtained. Since they cannot be obtained from the orthographic photographs it is believed that manual measurement of the model must be the means by which elevations are obtained.



6. NEW CONCEPTS FOR  
PHOTOGRAMMETRIC DIMENSIONING:

## NEW CONCEPTS FOR PHOTOGRAMMETRIC DIMENSIONING

### 6.1 Shortcomings of Previous Efforts for Mechanized Dimensioning

From Chapter 5 it is clear that there is widespread interest in mechanized methods for lifting dimensional data from design models of distributive systems. But, it is also obvious from these same discussions that the majority of the investigations to date can be classified as being "half-hearted" in the context of one or more of the following:

- \*lack of a real commitment (usually funding) to fully investigate alternate methods
- \*failure to address the total design process resulting in a procedure or system which, at best, only clumsily or partially interfaces to other design functions
- \*lack of expertise (e.g. shipbuilders attempting to be photogrammetrists)

Two exceptions to the above are Farrand's photogrammetric work (paragraph 5.2.2) and the Vickers CODEM optical triangulation system (paragraph 5.3.2). While Farrand's process may appear cumbersome by today's standards it was in fact well designed considering the state-of-art of photogrammetry in the early 1960's. Had the system been put into production it would very likely have evolved from a graphical output type of system to be digital one -- probably very much like one to be proposed later in this Chapter. Farrand himself did envision this possibility.

As for the Vickers CODEM system, this does seem to be a viable one, although, additional development is needed to directly interface the measuring system to the main computer

for greater flexibility and productivity. Nonetheless, it is believed that systems to be described in subsequent paragraphs will be far more adaptable to the overall shipbuilding process, provide greater flexibility and be more productive.

## 6.2 The Marriage of Design Modeling, Photogrammetry and Computer-Aided Piping Design Systems

In Chapter 1 discussions centered upon design modeling as an alternative method for the design of distributive systems in congested regions of ships. In Chapter 5 it was seen that a number of attempts have been made to mechanize the takeoff of dimensions from design models, usually for the purpose of inputting such data into some form of computer program. But, results of these attempts have not been entirely satisfactory. Although photogrammetry has been previously investigated (to some extent) it has never been properly applied to the task of dimensioning distributive systems models.<sup>1</sup> Hence, photogrammetry still remains as a strong candidate for mechanizing the dimensioning task.

In Chapter 4 computer-aided piping design systems were discussed. Here it was seen that piping geometry is a fundamental input to such systems.<sup>2</sup> Hence, the output from any mechanized dimensioning system should be in a form so as to be readily accepted by computer-aided design, systems.

<sup>1</sup>Except for Farrand's work; see paragraphs 5.2.2 and 6.1.

<sup>2</sup>Except for totally interactive design systems where the designer need only start with rough sketches. These systems are not yet entirely perfected, however.

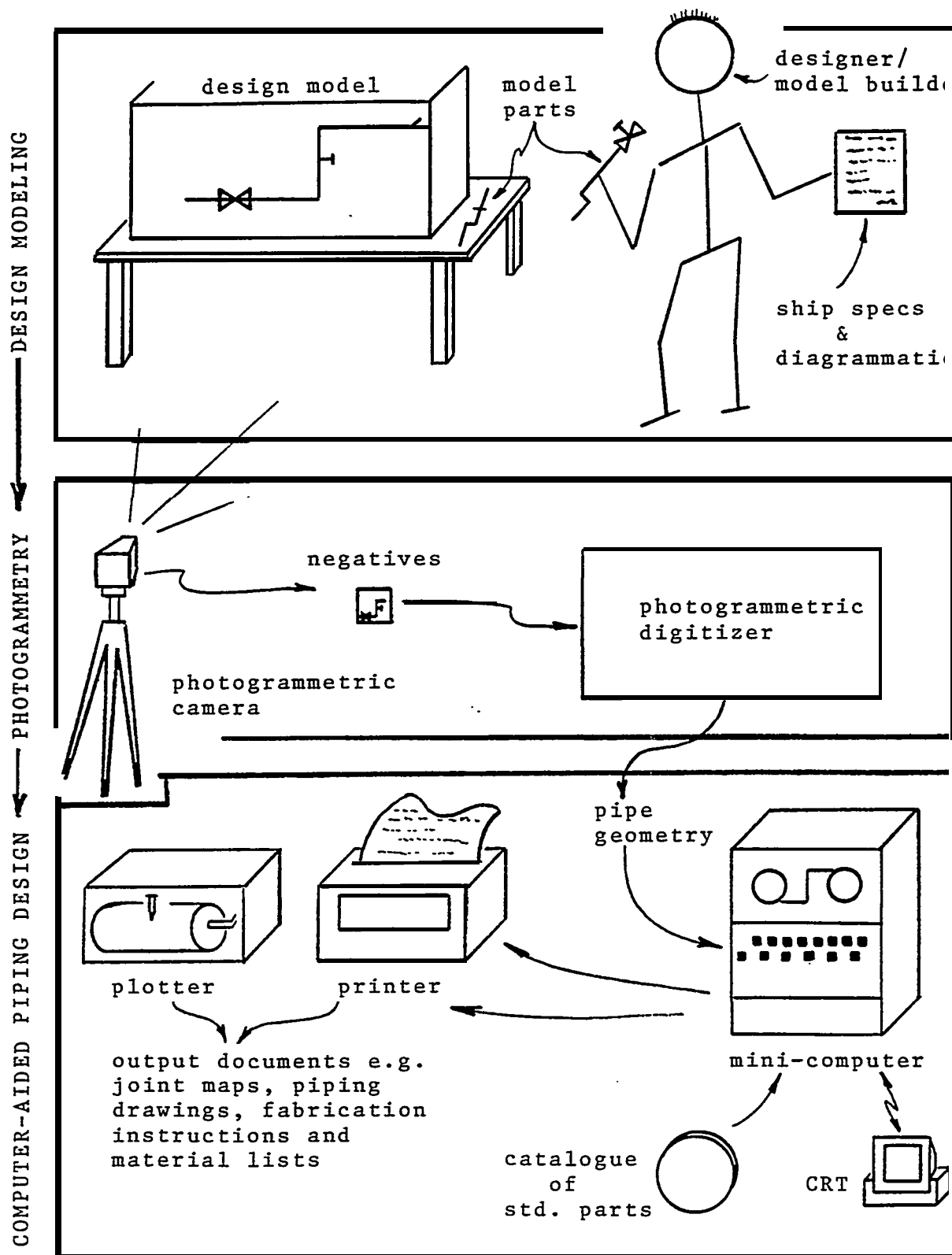


FIGURE 6.1: The Marriage of Design Modeling, Photogrammetry and Computer-Aided Piping Design Systems.

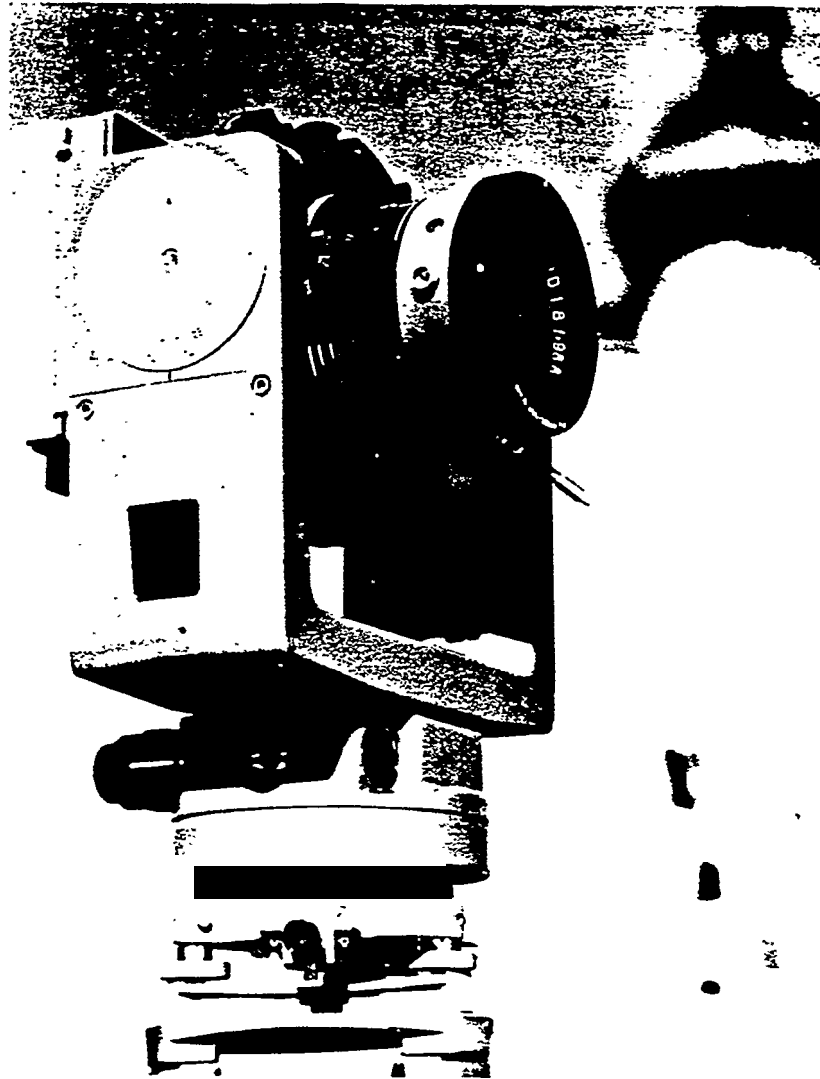


FIGURE 6.2: A Precision Photo grammetric Camera. This particular camera can be focussed over a wide range of distances by the user. It accepts single frames of cut film or glass plates and is characterized by its distortion-free lens. Photograph of P31 Universal Terrestrial Camera courtesy of Wild Heerbrugg Instruments, Inc., Farmingdale, Long Island, New York.

In summary, the path from initial design via design models to the production of fabrication documents can conceivably be a smooth-flowing one without extensive manual dimensioning if photogrammetry is inserted in the path. The total process is illustrated in Figure 6.1.

### 6.3 The Photogrammetric Camera

A wide selection of photogrammetric cameras are manufactured for terrestrial (as opposed to aerial) work. These were discussed in some detail in Appendix B of the Photogrammetry in Shipbuilding report (see footnote 1, page 2). Of the two basic types of camera configurations, single camera and double or stereometric cameras, the single camera such as the one shown in Figure 6.2 is best suited to the variety of measurement tasks which exist within a shipyard. A single camera can perform all of the functions of a dual camera system with the possible exception of simultaneous exposure. of an object in motion.<sup>1</sup>

In the past, advantages of the double camera were that the fixed relationship between the cameras allowed simplification in taking photographs, reduced hardware requirements for the stereoplotter and/or less complicated stereoplotter procedures. These advantages are not particularly significant in view of the mini-computer aided photogrammetric digitizing systems to be suggested in the next paragraph. Moreover, limitations of the double cameras, such as fixed distance between cameras and fixed focus suggests that they are not well-suited for general use within shipyards.

<sup>1</sup>But, the shutters of some double camera systems are not sufficiently synchronized to permit this either.

## 6.4 Conceptual Photogrammetric Digitizing Systems

### 6.4.1 Functional Requirements

Precisely what capabilities and flexibility should be required of a photogrammetric dimensioning system are quite simply considerations of ease of implementation and, ultimately, productivity. Several of the system requirements listed below could apply to other dimensioning systems as well.

- a. the system and procedures should basically be the same regardless of whether the model is true-to-scale or wire and disc
- b. drastic changes in current model building techniques should not be required
- c. specially built photogrammetric hardware should not be required
- d. the camera must have the ability to be focussed over a range of photographic distances
- e. extensive preparation of the model should not be required
- f. extreme care in-positioning the camera or the model should not be required
- g. black and white photographs should be used if it is possible to do so without seriously affecting productivity
- h. gathering of raw data (i.e. taking photographs) should be fast so as not to interfere with the use of the model by designers, planners, etc.
- i. digitizing from the photographs should be simple procedurally so that an expert photogrammetrist need not be employed
- j. the digitizing instrument should not be significantly limited in photographic focal length, allowable base between camera stations and lack of parallelism between optical axes of adjacent photographs

- k. coordinate data produced by the system must be of sufficient accuracy so as to be compatible with manufacturing and installation needs
- l. the data must be formattable so as to be compatible with existing computer-aided pipe detailing and fabrication programs
- m. if possible, photogrammetric equipment should also be usable for other shipyard measurement tasks such as dimensioning large steel units

#### 6.4.2 A Stereoplotter/Mini-Computer System

Paragraph 3.1.2 introduced the concept of the stereoplotter which allows overlapping photographs of a scene to be viewed stereoscopically so that dimensions and/or graphic maps of the scene photographed may be produced. Stereoplotters such as the one shown in Figure 3.1 are commonly fit with encoders to permit digital recording of XYZ coordinates. While it is conceivable that such an instrument could serve as the "photogrammetric digitizer" depicted in Figure 6.1, functional requirements g and h set forth in paragraph 6.3.1 would not be entirely satisfied and requirement k would not be satisfied at all.

An alternate stereoplotter which can satisfy all of the functional requirements is a computer controlled stereoplotter such as the one shown in Figure 6.3. As a practical matter this modern instrument is very similar to the one shown in Figure 3.1 with the exception that many of the mechanical mechanisms (which are really analog computers) of the older type instrument are now

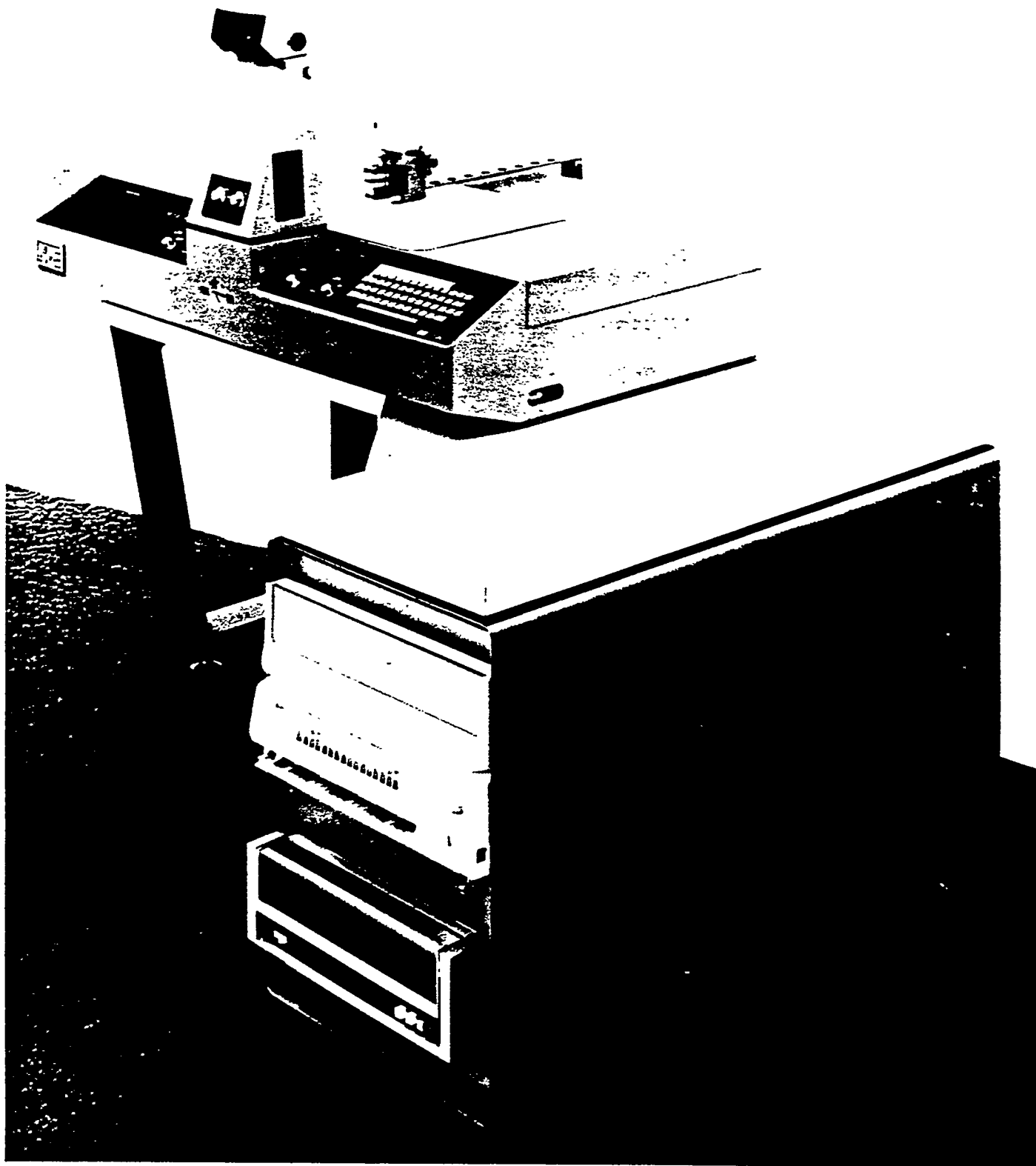


FIGURE 6.3: A Stereoplotter/Mini-Computer Photogrammetric Digitizing System. Though not shown, a drafting table can also be connected to this system. Photograph courtesy of Keuffel and Esser Company, H. Dell Foster Operation, San Antonio, Texas.

handled by a mini-computer. By its very presence the mini-computer allows greater flexibility in uses of the stereoplotter. For example, the center for a series of points measured about a circular arc on a pipe surface could be calculated on-line. or, two lines representing pipe centerlines could be extended to their intersection. Also, the instrument can be used as a monocomparator for the purposes envisioned when establishing functional requirement k. Computer-controlled stereoplotters are now commercially available from several manufacturers.

#### 6.4.3 A Monocomparator/Mini-Computer System

Inasmuch as dimensions desired from design models can be obtained from measurements to specific points on the models, there is no real need to view the photographs of the models stereoscopically. That is, it would be totally sufficient to measure locations of the points directly on two or more photographs with a monocomparator like the one shown in Figure 3.2. Preferably the monocomparator would be on-line with a mini-computer which could immediately triangulate the three dimensional positions of the points as illustrated in Figure 3.3.

#### 6.4.4 Relative Merits of the Digitizing Systems

It is believed that either of the two digitizing systems described in paragraphs 6.4.2 and 6.4.3 can accomplish the task of extracting reliable dimensions from models of distributive systems. But, there are

several differences between the systems which must be evaluated. For convenience of discussion hereafter the stereoplotter/mini-computer digitizing system shall be referred to as the "stereo system" and the monocomparator/mini-computer shall be referred to as the "mono system".

#### 6.4.4.1 Preparation of Model

As pointed out in paragraph 6.4.3 use of the mono system requires that the image of each specific point of interest on the model must be exactly identified on two or more photographs. This was discussed even in more general terms in paragraph 3.1.3 where it was stated further that placement of targets upon these points of interest is the preferred means by which this image identification need is satisfied. Hence, it will be a requirement that such targets be placed on the model. Hereinafter these shall be referred to as "identification targets".

In principle, the stereo system does not require identification targets since the matching of images of the same point is automatically accomplished when viewing the photographs stereoscopically. But, as a practical matter, some identification targets will be needed, especially on outside surfaces of pipes. This is because

it will be necessary to reduce measured locations of points to their respective centerlines. To do this the location of a measured point relative to its centerline must be known. (A scheme for accomplishing this shall be described in paragraph 6.5.9.) In summary then, the mono and stereo systems will both require identification targets -- neither system has an advantage over the other in this particular respect.

When using the mono system a second type of target may also be required. Before the computer can triangulate the locations of identification targets it must first calculate the spatial orientation of one photograph to another. This orientation is determined by measuring (on the monocomparator) a set of, say, a dozen target images which are common among all photographs and well distributed over the area covered by each photograph. Hereinafter these shall be referred to as "orientation targets". Physically there need be no difference between identification and orientation targets; only their function differs. Hence, it is possible in some instances that identification targets can also serve as orientation targets.

As implied earlier, determination of the relative orientations of photographs when using the stereo system does not require orientation targets because matching of common imagery between photographs is automatic when the photographs are viewed stereoscopically. But the computer does have to calculate the orientations nonetheless. In the final analysis then, the stereosystem has an advantage in that special targets are never necessary for determining relative orientations of photographs.

#### 6.4.4.2 Aiming the Camera

Since the photographs are never viewed stereoscopically in the mono system (only target images are measured on individual frames) there is no need to exercise care in maintaining near parallelism between optical axes of photograph pairs. In fact, there may well be instances where it will be desirable for viewing into the model to have considerable convergence between optical axes of successive photographs.

Mathematically the stereo systems' mini-computer can accommodate convergence of optical axes, but the operator must still be able to view stereoscopically with high accuracy. This stereoscopic perception can be degraded with increasing convergence of optical axes. Hence, the freedom in camera pointing allowed by the mono system is considered to be an advantage of the mono system.

#### 6.4.4.3 Measuring Speed

To address this consideration it is necessary to describe the basic operational procedures envisioned for both digitizing systems once the negatives are in hand. In both modes of operation it is believed that items to be digitized will first be marked up on paper prints according to a predetermined scheme. This preparation work will probably consume somewhat greater time for the mono system since all prints would have to be marked up because individual photographs are measured with this system. Conversely, with the stereo system only one photograph of a photo-pair needs to be marked up.

As for the measuring procedures, these are markedly different for the two systems. In the mono system four to six photographs would be set on the stage of the comparator at once, but for the purpose of discussion let us assume four frames. Of these, two could be overlapping photographs comprising an elevation view of the model and the other two could comprise a plan view. For maximum accuracy in determining the location of a measured point in the model the ---- point should be measured on both plan view and both elevation view photographs. Measurements only on one or the other views will likely result in a three dimensional location which is

of high accuracy in the plane of the view in which the measurements were taken, but relatively poor in a direction to and from the camera.

The reason for the imbalance in accuracy lies in the need to take successive photographs with a distance between camera stations that is small relative to the distance from the camera stations to the model. This in turn is necessitated by the fact that wider separations result in photographs which do not have many points of interest common between them owing to obscurations caused by the complexity of the model detail. The net result of the short baseline between cameras is that "rays" triangulating a target intersect at a small angle which leaves the intersection with a relatively high degree of uncertainty in the direction to and from the camera.

Because the picture taking process is the same for both digitizing systems, this accuracy imbalance is common to both digitizing systems, but it is not caused by either system. Instead, the difficulty is inherent in the photographs. As is probably already evident, measurements on, say, a pipe in both plan and elevation views can be accomplished with a single set-up of the photographs in the mono system. With the stereo system, however, only two photographs can be in

the instrument at any one time. Once all measurements are taken on points of interest in, say, an elevation view, these photographs would be replaced with the plan view photographs. Obviously then, a new instrument set-up (probably about 20 minutes) is required for each photograph-pair.

As for the measurements themselves there will typically be twice as many with the mono system simply because every point of interest must be measured on at least two photographs. With stereoscopic viewing of the photographs only one measurement is needed for each point of interest.

To summarize, the mono system will require more preparation on the photographs and perhaps as much as twice the number of measurements as the stereo system. But, the stereo system requires twice as many instrument setups and possibly more if the mono system can accommodate six photographs at a time rather than four. It is doubtful that the mono system can be as fast as the stereo system, but the real difference may not be so unattractive as to rule out the mono system as being productive. Experience is needed to determine actual speeds.

#### 6.4.4.4 Accuracy

Theoretically the mono system is capable of somewhat greater accuracy since a point's image may be measured on more than two photographs and triangulated by as many rays as there are measurements. Also, the mono system is not dependent upon the operator's visual acuity to see and measure stereoscopically. As a practical matter though, it is not believed that the difference in accuracy between the two systems will be significant relative to the accuracy required of the measurements.

At this point it is well to mention that "required accuracy" is a value dictated by pipe fabrication and on-board installation needs. In the literature and among shipbuilding personnel there is a range of opinions as to what this requirement should be. At the moment it is believed that a tolerance on the order of  $\pm 1/2$  inch on-board a ship is a practical requirement. Conversion of this figure to design models of 1:10 to 1:15 scale indicates that measurements of such models should have a tolerance of about  $\pm 1$  mm. In turn, dimensioning models via photogrammetry to this level of accuracy seems to be well within the state-of-the-art for either the mono or stereo systems.

#### 6.4.4.5 Operator Skills

As indicated throughout discussions of the stereo system, it is required that the operator view two photographs at a time stereoscopically. For accurate dimensioning work it is necessary for the operator of the digitizer to have keen stereoscopic perception. In contrast, the mono system does not require stereoscopic perception at all since images are measured only on one photograph at a time. Hence, the skill level requirements for the operator of the mono system are lower. In both systems, though, the operator must be an "organized" individual who can methodically keep track of his work.

#### 6.4.4.6 Software Requirements

Both of the digitizing systems under consideration simply produce XYZ coordinates of points. Generally speaking these points will not be points which are desired for input to a computer-aided piping design system. This is because these piping systems work with pipe centerlines and pipe centerlines cannot be directly "seen" and digitized photogrammetrically. Instead, photogrammetry produces coordinates of points on pipe (or fitting) surfaces. It must also be recognized that, because of the complexity of design models, it will not generally be possible to "see" a continuous pipe run as an

unbroken series of events. These peculiarities lead to the necessity for the following basic but special computer program operations (which would likely reside in the mini-computer of either digitizing system):

- \*identify pipe "events" such as start, stop and intervening valves, bends, tees, couplings, etc.
- \*conversion from the digitizing coordinate system to the ship's coordinate system
- \*allow projection of digitized points on surfaces of pipes and fittings to their centerline values
- \*extend centerlines of pipes to inter-section at bends
- \*collect segments of the same pipe run into a continuous run
- \*format each continuous run so as to be directly acceptable to existing computer-aided piping design systems

Beyond the special computer program requirements set forth above which are common to both digitizing systems, the mono system requires additional unique programming for determination of the relative orientations of the photographs as described in paragraph 6.4.4.1. The stereo system requires a similar program, but not a specially developed one -- the necessary programming is delivered as a

standard "part" of all commercially available stereoplotter/mini computer digitizing systems.

In summary, both digitizing systems require a number of data manipulation routines to convert raw digitized data into logical pipe geometry acceptable to a computer-aided piping design system such as RAPID. The mono system requires additional programming to determine the orientations of the photographs with respect to one another. Similar programming is not required for the stereo system since it is already developed by the manufacturers of mini-computer controlled stereoplotters.

#### 6.4.4.7 Ability to Interface to Computer-Aided Design Systems

Since stereoplotter/mini-computer digitizing systems are sold as hardware packages the interface to a computer-aided design system such as RAPID would require a computer-to-computer link. This connection could be a hard-wired (i.e. on-line) one or be indirect such as by transfer of magnetic tape or disc cartridge.

The proposed mono system is a marriage between a monocomparator and a mini-computer, both components being of separate manufacture. But, it does seem feasible to interface the monocomparator directly to the mini-computer of the RAPID system in lieu of a separate mini-computer

of its own. While this same possibility theoretically exists for the stereo system, it is an unlikely one since the manufacturer's delivered computer programming which operates the stereoplotter digitizer is tied to one brand of mini computer manufacture. Clearly then, the mono system offers greater flexibility for stand-alone operation or direct tie into a system such as RAPID.

#### 6.4.4.8 First Cost

Table 6.1 itemizes estimated first costs which are anticipated for the two proposed photogrammetric systems. It is doubtful whether any of the equipment could be leased from the respective manufacturers.

TABLE 6.1

Estimated First Costs of Photogrammetric  
Dimensioning Systems

| <u>Cost Item</u>               | <u>Mono System</u>  | <u>Stereo System</u> |
|--------------------------------|---------------------|----------------------|
| 1. Camera                      | \$ 20,000           | \$ 20,000            |
| 2. Monocomparator              | 35,000 <sup>1</sup> | N/A                  |
| 3. Mini-computer               | 30,000 <sup>2</sup> | N/A                  |
| 4. Stereoplotter/mini-computer | N/A                 | 130,000 <sup>3</sup> |
| 5. Programming                 | <u>30,000</u>       | <u>20,000</u>        |
|                                | \$ 115,000          | \$ 170,000           |

<sup>1</sup>Anticipated upper limit; allows for instrument which can accommodate the largest number of frames at one time.

<sup>2</sup>Cost could be reduced by two-thirds or more if monocomparator were interfaced to mini-computer of the computer-aided piping design system.

<sup>3</sup>Minimum expected cost -- other available systems are more expensive by as much as \$100,000.

#### 6.4.4.9 Suitability for Distributive Systems Other than Piping

If it were desired to digitize cable trays and HVAC, digitizing procedures would probably be the same as for piping. In fact, the only basic difference between distributive systems is that their cross sections and fittings are different geometrically. To the extent that "parts" of other distributive systems are standard, the relative merits of the two photogrammetric systems would be the same as already considered for piping. But, for digitizing non-standard shapes, as are still often used in rectangular vent ducts, the stereo system would be the best suited of the two digitizing systems.<sup>1</sup>

#### 6.4.4.10 Suitability for Other Shipyard Work

As indicated in Section 1.1 several productive shipbuilding applications of photogrammetry have already been implemented and all of these involve dimensioning large steel or aluminum structures. Moreover, the photogrammetric technique employed is identical in all cases and is precisely that outlined in paragraph 3.1.3 and illustrated in Figure 3.3.

<sup>1</sup>Even rectangular vent ducts are becoming more standardized with an eye toward increased productivity and also compatibility with computerized parts catalogues. For instance, see "Rectangular Vent Duct Standards" published by the U.S. Maritime Administration in cooperation with Todd Shipyards Corporation.

Since a monocomparator is used to measure the photographs for these other applications, the mono system is better suited to these tasks. There is no question that the stereo system can be used for these applications too (if operated in a monoscopic mode), but it would be slower and with an estimated 20% reduction in accuracy.

#### 6.4.4.11 Summary of Relative Merits

Table 6.2 summarizes the relative merits of the two proposed digitizing systems. Refer to the referenced paragraphs for discussions of the individual items of comparison.

TABLE 6.2

#### Summary of Relative Merits of Photogrammetric Digitizing Systems

| <u>Point of Comparison</u>                                | <u>Paragraph</u> | <u>Mono System</u> | <u>Stereo System</u>         |
|-----------------------------------------------------------|------------------|--------------------|------------------------------|
| 1. Preparation of model                                   | 6.4.4.1          |                    | less preparation             |
| 2. Aiming the camera                                      | 6.4.4.2          | less care required |                              |
| 3. Measuring speed                                        | 6.4.4.3          |                    | may be faster                |
| 4. Accuracy                                               | 6.4.4.4          | no practical       | difference                   |
| 5. User skills                                            | 6.4.4.5          | lower              |                              |
| 6. Software requirements                                  | 6.4.4.6          |                    | least                        |
| 7. Ability to interface to computer-aided design systems  | 6.4.4.7          | most flexible      |                              |
| 8. First cost                                             | 6.4.4.8          | least              |                              |
| 9. Suitability for distributive systems other than piping | 6.4.4.9          |                    | best for non-standard shapes |
| 10. Suitability for other shipyard work                   | 6.4.4.10         | best               |                              |

## 6.5 Associated Model Building Techniques

In paragraph 6.4.1 it was stated that one functional requirement of any photogrammetric dimensioning system should be that drastic changes in current model building techniques are not required. There are, however, a number of model building procedures which must be considered as being desirable; these are discussed in the following sub-paragraphs. Before proceeding with these discussions though, it is well to mention an obvious, but most important point. With any photographic work involving models it is necessary that the photographs clearly show modeled detail of the distributive systems. This basic requirement holds true regardless of whether photogrammetry is to be employed. With this in mind then, it will be understood why many of the model building techniques described below are intended to aid the photographic aspects of photogrammetric dimensioning of distributive systems models.

### 6.5.1 Model Sectioning

The model must be built on several model bases.<sup>1</sup> Divisions at midships and bulkheads are likely boundaries for a model base, although, divisions according to outfitting sections is certainly a possibility. In fact, any convenient divisioning is suitable; the intent being to allow better photographic views into the interior of the total model. Within a model base divisions at deck levels are also needed for the same reasons. These

<sup>1</sup><sub>A</sub> model base is a rigid table upon which a model or portion thereof is constructed.

sectionalizing procedures are common practices for European model builders and for domestic builders of chemical plant models and the like. Builders of ships distributive systems models, however, have not generally sectionalized their models to any great degree.

An aside benefit of sectionalizing is that it allows freer access to the interior of the model for initial design layout of the machinery and distributive systems and then for photographic and study purposes.

#### 6. 5.2 Minimal Use of Plexiglas

A photographic view through Plexiglas results in a geometrically distorted image on the negative. While this is not of concern and perhaps not even noticeable in pictorial work, it is detrimental to photogrammetric dimensioning. Maximum use of cut-outs in Plexiglas is a necessity and, wherever possible, Plexiglas should be dispensed with altogether. For example, much of the outer hull need not be shown on a model.

Here again, the recommended model building technique would also make the initial design work easier since the model builder would have better access to the interior of the model. It is recognized, however, that modified stiffening may be required to hold dimensional accuracy as the use of Plexiglas is reduced.

#### 6.5.3 Removable Machinery Components

To facilitate photographic "access" to the distributive systems it is desirable to utilize removable machinery components -- particularly for major machinery.<sup>1</sup> Of course, removal of machinery should be possible without disturbing the geometry of the remainder of the model.

#### 6.5.4 Wire and Disc Presentation

Representation of piping by wire and disc is preferred purely for photographic viewing reasons. But, the trend in design modeling seems to be for true-to-scale piping. Because of this trend, photogrammetric procedures to be developed in Phase II will be nearly identical regardless of whether wire and disc or true-to-scale piping is utilized in the model.

#### 6.5.5 Color Coding

Color coding of different piping systems seems to be almost universally adopted regardless of whether wire and disc or true-to-scale piping is employed. The desirability of color coding is nonetheless mentioned here if only to avoid a possible misconception which could arise from an earlier statement in paragraph 6.4.1 regarding the use of black and white photographs. Even if it is ultimately determined that black and white photographs can be productively used in lieu of color photographs, color coding is still a desirable

<sup>1</sup>This practice was found in one German firm; see Abstract #15, Appendix A.

model building procedure. This is because variations in colors will register on black and white negatives with difficult gray tones. Moreover, it is envisioned that color snapshots would also be taken to aid the photogrammetric work.

#### 6.5.6 Tagging

Placement of tags on pipes, even though they may be color coded, is a very desirable practice. A tag is very simply an adhesive label adhered to a pipe. Hand lettering on the tag gives basic information about the pipe such as diameter, system and flow direction. The use of tags seems to be a standard procedure in U.S. model building, except within the shipbuilding industry. It should be noted that tagging is useful for any photographic documentation program regardless of whether photogrammetry is involved. Also, tags facilitate model reviews by persons not intimately involved in its construction.

#### 6.5.7 Finishes

Finishes of structural, machinery and piping components of the model should not be highly reflective. Dull finishes are preferred inasmuch as these reflect incident light in a diffuse manner which reduces "glare" on the photographs.

#### 6.5.8 Reference Marks

As a minimum, three reference marks of known offset, elevation and longitudinal position (e.g.

frame location) must be attached to each model section. These marks allow photogrammetric measurements to be converted to the ship's coordinate system. It is possible, however, that placement of the marks could occur just before photographs are taken rather than during the model building phase proper.

#### 6.5.9 Circumferential Pipe Markings

In paragraph 6.4.4.1 it was indicated that a special pipe marking scheme would be needed so that coordinates of points digitized on surfaces of pipes can be reduced to their centerline values. It is envisioned that this scheme will involve fine painted or adhesive circumferential rings with tick marks or dots at 45 degree intervals. These rings or pipes with rings already upon them would be oriented so that one tick mark would be nominally "up" on horizontal runs or nominally forward on vertical runs. The tick marks serve two functions. First, for the mono system, they allow identification of the same point on a pipe on the various individually measured photographs. Second, knowing the nominal orientation of a tick (e.g. to the port and 45 degrees below the horizontal through the centerline of the pipe) the correction necessary to reduce the digitized three dimensional location of the tick to the pipe's centerline is readily calculated if the diameter of the pipe or its scale representation

is known. This applies to both the mono and stereo systems.

## 7. RECOMMENDATIONS

## 7. RECOMMENDATIONS

### 7.1 Phase 11

#### 7.1.1 General Recommendations

There is no question that start-up of Phase II is warranted. From numerous other attempts at mechanizing the dimensioning of design models (see Chapter 5) it is clear that manual take-off of dimensions is not particularly favored. Moreover, except for Farrand's work (see paragraphs 5.2.2 and 6.1) there has never been a concerted effort for determining the real capability and productivity of photogrammetry for this purpose. Finally, all but one<sup>1</sup> of several other investigations into mechanizing the dimensional take-off have been rather narrow in scope. The marriage of design modeling, photogrammetry and computer-aided piping design systems as proposed herein considers the total piping design process.

#### 7.1.2 Model Building

To support development of photogrammetric dimensioning procedures in Phase II it will be necessary to have access to and photograph a design model. Because special model building techniques are germane to the overall dimensioning process (see paragraph 6.5) it is recommended that a design model be specifically built for this project. It is not necessary, however, that a total model be constructed. Instead, three or four adjacent model sections complete unto themselves are all that is

<sup>1</sup>See paragraph 5.3.2.

required. A true-to-scale representation of piping is recommended since this method of model building is more predominate than wire and disc.<sup>1</sup>

Four potential suppliers of model building expertise were visited during the course of Phase I in anticipation of the need for having a model built in Phase II and also to gain further insight into design modeling in general. The four firms visited were:<sup>2</sup>

\*Offshore Power Systems (Jacksonville, Florida)

\*Sun Shipbuilding and Dry Dock Company (Chester, Pennsylvania)

\*United Scale Models, Inc. (Concordville, Pennsylvania)

\*J. J. Henry Company (Moorestown, New Jersey)

Of the four firms visited Offshore Power Systems ("OPS") is the most logical choice for obtaining model building expertise within Phase II. The most significant reasons for this choice are:

\*OPS extensively utilizes modeling for the design of their floating nuclear power plants.<sup>3</sup> However, OPS' use of design models is combined to some extent with traditional design procedures (e.g. compositing in some cases) resulting in a process which is acknowledged to be redundant to some extent. Also, dimensional information inherent in their models is extracted by means of draftsmen preparing dimensioned orthographic sketches at the model. OPS is very interested in streamlining their use of design models, particularly with respect to eliminating these two processes to the maximum possible extent.

<sup>1</sup>But, also see paragraph 6.5.4.

<sup>2</sup>Bechtel Power Corporation (San Francisco) was also visited, but only for the purpose of gathering first-hand information on design modeling in an industry other than shipbuilding.

<sup>3</sup>See Abstract #13, Appendix A.

\*OPS has recently installed an interactive drafting system and, at present, manually enters dimensions from the orthographic sketches into the drafting system. OPS views photogrammetry as a possibility for inputting such data directly from photographs of their models.

\*OPS has expressed an earnest desire to be involved in Phase II, even to the extent of cost sharing a model building effort.

\*OPS has several areas of a floating nuclear power plant which must yet be subjected to design modeling. OPS is willing to allow these areas to also be utilized for Phase II of this project, provided that the areas are deemed sufficiently representative of complex piping found in congested areas of merchant ships.

\*OPS' present work load is such that participation in Phase II can be undertaken without interference to OPS' production design work or undue delays in the performance of Phase II.

It is recommended further that a meeting be held between JFK, L. D. Chirillo of Todd Pacific Shipyards and representatives of OPS for the purpose of establishing specific model sections to be built and how JFK and OPS should interface. Such a meeting will allow OPS to assess labor and material costs involved and, together with JFK, allow planning of a production schedule.

#### 7.1.3 Photogrammetry

There are three aspects of the photogrammetric work to be considered. First, there is the picture taking for which appropriate equipment is already within JFK's inventory. It is recommended that black and white photographs in particular be

evaluated with respect to their suitability for photogrammetric dimensioning. It is believed that the use of color photographs in a production environment will introduce the undesirable requirement for a color processing capability. Moreover, color processing is more time consuming and expensive. However, JFK is equipped for color work should it be determined that black and white photographs are not entirely satisfactory. In any event it is recommended that color snapshots always be taken as further documentation and as an aid to interpretation of black and white photographs.

The second aspect of the photogrammetric work is the digitizing effort. Here it must be emphasized that it is beyond the scope of Phase II to produce a totally operational mono or stereo system complete with the special computer routines described in paragraph 6.4.4.6. For the purpose of demonstration then, it will be necessary to utilize some existing equipment and software and to write some basic new programs which together will produce output data in the form required by RAPID. This makeshift mode of operation will parallel, as closely as possible, the anticipated procedures outlined in paragraph 6.4. The major difference will be that some processing of data which would preferably be done on-line with the mini-computer of either photogrammetric digitizing system will probably be

done off-line; i.e. in a separate step(s) on a stand-alone computer. It is recommended that both the mono and stereo systems be evaluated in this way during Phase II.

#### 7.1.4 Computer-Aided Piping Design System

It is obvious from paragraph 4.2, for reasons stated therein, that output from the photogrammetric work should be made compatible with the Newport News RAPID system. Newport News has informally indicated their willingness to cooperate in Phase II of this project. It is recommended that following the proposed meeting with OPS, JFK and L. D. Chirillo of Todd Pacific Shipyards Corp. meet with representatives of Newport News to define the level of effort required on the part of Newport News and an approximate schedule,

#### 7.2 Other Research

A disturbing conclusion reached early in Phase I is that the U.S. shipbuilding industry possesses very little knowledge of design modeling as an alternate to traditional design processes. As mentioned elsewhere, foreign shipbuilders have productively implemented the method as have many U.S. firms engaged in the design of petro-chemical plants and the like.

Nowhere in the course of a very extensive literature search was it found that design modeling had been investigated or utilized within the U.S. shipbuilding industry<sup>1</sup>

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<sup>1</sup>Subsequent to a visit to Sun Shipbuilding and Dry Dock Company it was learned that Sun decided to utilize design modeling for the layout of on-deck machinery and piping of two product carriers. Reportedly, Sun's desire to redesign an original layout combined with a very short design and building schedule led to the decision to use the design model approach.

But, several references to the use of models in the context of design were found and these generally were unfavorable with respect to the usefulness of models in the design phase of shipbuilding. The manner in which these comments were made would leave the casual reader with a definite impression that models in design work were not productive (usually the complaint was that they are finished too late in the production cycle). Only the careful reader would see, however, that these discussions were not in reference to design models. Instead, the subject was usually interference control wherein model building followed traditional design. This is not the case with design modeling where there is no traditional design process.<sup>1</sup> The model is the design and interference control is an automatic by-product as the model building progresses.

Upon the above observations it is believed that a separate project should be funded for the purpose of introducing design modeling to the U.S. shipbuilding industry.

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<sup>1</sup>As emphasized in Chapter 2, design modeling is viewed as being productive in congested areas of a ship. Traditional design procedures would normally be followed in non-congested areas.

APPENDIX A

ABSTRACTS OF PERTINENT LITERATURE

Abstracts contained herein are not those of the original authors. Instead, these abstracts were specially prepared for this report in order to place greater emphasis on content deemed pertinent to this project. To some extent, however, styles of the original authors have been retained.

Abstracts #3 through #10 are for general articles on design modeling whereas #11 through #21 are more pertinent to the shipbuilding industry per se. Abstracts #17 and #18 should be of particular interest because they describe a very sophisticated design modeling system used by Odense Steel Shipyards, Ltd.

| <u>ABSTRACT #</u> | <u>TITLE</u>                                                           | <u>AUTHOR(S)</u>                                       | <u>DATE</u>  |
|-------------------|------------------------------------------------------------------------|--------------------------------------------------------|--------------|
| 1                 | Photogrammetry in Shipbuilding                                         | Maritime Adm.<br>Todd Shipyards                        | July<br>1976 |
| 2                 | Use of Scale Models as a<br>Management Tool                            | Maritime Adm.<br>Todd Shipyards                        | May<br>1974  |
| 3                 | Model Procedure Manual                                                 | Engineering<br>Model Assoc.                            | 1976         |
| 4                 | Centerline Model Piping                                                | John P. Elich<br>Flour Corp.                           | 1971         |
| 5                 | Full Scale Model Piping                                                | Howard H. Kaplan<br>Chemical Const.<br>Corp.           | 1971         |
| 6                 | Problems of Starting a Piping<br>Design Model Program                  | W. R. Burns<br>The Badger Co.                          | 1972         |
| 7                 | A Model Program in the Paper<br>Industry                               | E. Walker and<br>L. Tiger<br>Rust Eng. Co.             | 1977         |
| 8                 | Use of Models on Small Projects                                        | R. E. Miller, Jr.<br>The Proctor and<br>Gamble Company | 1971         |
| 9                 | Model Information Systems and<br>Procedures                            | Louis Willstein<br>The Lummus Company                  | 1972         |
| 10                | How Models Pay Off                                                     | Norbert J. Reder<br>The Proctor and<br>Gamble Company  | 1973         |
| 11                | The Use of Models in the<br>Shipbuilding Industry                      | Ronald A. Phillips<br>Marine Services and<br>Systems   | 1972         |
| 12                | Second Generation Models for<br>Deep-Water Oil Production<br>Platforms | Dereck Ward<br>Worley Eng. Ltd.                        | 1975         |

| <u>ABSTRACT #</u> | <u>TITLE</u>                                                                                   | <u>AUTHOR(S)</u>                                          | <u>DATE</u>     |
|-------------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------------|
| 13                | Floating Nuclear Power Plants --<br>A New Approach to Energy<br>Generation                     | Vito Riggi<br>P. Ross Ramsay<br>Offshore Power<br>Systems | 1977            |
| 14                | Piping Layout Rationalism by<br>Means of Design Models                                         | Peter Kayser                                              | Dec.<br>1967    |
| 15                | From Construction Model to<br>Practice                                                         | Maschinenbau<br>Gabler                                    | Feb.<br>1970    |
| 16                | Ten Years Experience with the<br>Building of Scale Models                                      | P. Kayser<br>H. Stulpner                                  | 1977            |
| 17                | Advanced Pipe Technology -<br>Detailed Final Report                                            | Maritime Adm.<br>Bath Iron Works                          | Dec.<br>1976    |
| 18                | A Systems Approach to Total<br>Ships Outfitting                                                | P. Beth<br>Odense Steel                                   | Apr.<br>1976    |
| 19                | Recent Developments in the<br>Design and Production of<br>Marine Piping Systems                | G. Standen<br>D. E. Gilbert<br>Vickers Shipbldg.          | Jan.<br>1977    |
| 20                | Abstract of Model Engineering<br>Technique in Hitachi Zosen                                    | Hitachi Ship-<br>building and<br>Engineering Co.          | 1977            |
| 21                | Installation of the Nerve<br>System of Ships by Use of Scale<br>Models                         | L. Nohse                                                  | 1968            |
| 22                | Rapid Report R1; Users Manual,<br>Preliminary<br>Interactive Piping Design<br>Software Package | P. W. Rourke<br>Newport News<br>Shipbuilding              | June<br>1977    |
| 23                | The Use of Engineering Design<br>Models as the Vehicle for<br>Engineering                      | G. R. Neeley<br>Bechtel Power                             | 1977            |
| 24                | Photogrammetry Applied to Pipe<br>Systems of Chemical Plant                                    | R. Farrand<br>Imperial Chemical                           | October<br>1965 |

| <u>ABSTRACT #</u> | <u>TITLE</u>                                              | <u>AUTHOR(S)</u>                 | <u>DATE</u>  |
|-------------------|-----------------------------------------------------------|----------------------------------|--------------|
| 25                | Photogrammetry as an Aid to<br>Manufacture of Ship Piping | W. G. Smith<br>BSRA              | 1971         |
| 26                | Pipe Production Information:<br>A Computer-Aided Method   | B. Dodd<br>J. B. Jack<br>BSRA    | 1974         |
| 27                | One Step Isometrics From Models                           | J. Birkhoff<br>Continental Engr. | July<br>1972 |

"Photogrammetry in Shipbuilding", report published by the U.S. Department of Commerce Maritime Administration and Todd Shipyards Corporation in Conjunction with the National Shipbuilding Research Program, July 1976.

A survey of potential applications of photogrammetry in shipbuilding, ranging from design to post-delivery, is supported by detailed accounts of four actual demonstration projects. Appendices provide a glossary of photogrammetric terms, a layman's explanation of photogrammetry and exhaustive compilations of pertinent literature and sources of photogrammetric hardware and services.

Once of the demonstrated applications established the technical feasibility for generating dimensioned arrangement drawings from photographs of a design model. A series of stereopairs of photographs, viewing from inboard to outboard, were taken of a portion of the starboard side of,  $3/4" = 1'$  machinery space model. A single frame glass plate camera was used to obtain all photographs. Within the region photographed, a  $3/8" = 1'$  elevation view of the main steam piping was produced on a stereoplotter. Fixed machinery was shown in phantom. This drawing was then placed upon a digitizing board to obtain dimensions from deckheads and bulkheads to pipe centerlines. A check of 20 such dimensions against design values showed average and maximum differences of  $1-1/8$  inch and  $2-5/8$  inch at the scale

of the ship. These values, however, included error in the model itself since the model was built from a design produced first on paper. (In design modeling this source of error would not be present.) While the graphical presentation of piping served the immediate purpose of the demonstration, it was concluded that a digital "take off" from the photographs should be preferred in order to be compatible with other automated piping systems and to allow drawing of arrangements, composites, isometrics and pipe details at will.

"Use of Scale Models as a Management Tool", report published by the U.S. Department of Commerce Maritime Administration and Todd Shipyards' Corporation in conjunction with the National Shipbuilding Research Program, May 1974.

This rather broad overview of the use of models in shipbuilding covers types of models, benefits accrued through the use of models, model building methods, costs of building models and a list of references and model building vendors.

"Model Procedure Manual", published by Engineering Model Associates, Inc., first edition, 1976.

This manual covers basics of implementing an engineering model program. Although it is directed mainly to the chemical and petrochemical process industries, many fundamentals covered are applicable to shipbuilding as well. These include, advantages and cost-effectiveness modeling, discussions of model types, model facility and equipment requirements, personnel considerations, estimation of model costs and model specifications. Individual chapters are devoted to specific model types such as preliminary/study models and design models with the latter being considered for full scale and for centerline presentation of piping systems. A brief treatment of modeling instrumentation, electrical and HVAC is also included. Consideration is as given to such topics as checking models, model review sessions, model finalization, photography and crating and shipping.

"Centerline Model Piping" by John P. Elich, Flour Corporation, published in the proceedings of the American Engineering Model Society 1971 Seminar.

Flour Corporation uses centerline piping models of 95% of their projects. However, full scale model piping is used for large diameter and alloy piping. Advantages attributed to the centerline method are:

- \*less model building skill is required of piping engineers and designers who run piping on the model, without the aid of sketches or paper layouts
- \*power tools are not required for model building and, therefore, job accidents and insurance premiums are minimized as are distractions inevitably created by the noise generated such tools
- \*revisions are readily implemented and generate less frustrations in model building personnel
- \*training of wire bending technicians is relatively simple
- \*ease of installation of piping (relative to full scale modeling) leads to reduced labor costs and calendar days for completion of the model; this has been confirmed by several in-house studies over a 20-year period
- \*material costs are about one-third of that for full scale modeling
- \*extra light is permitted to enter the model which allows the viewer greater depth and detail either from direct visual inspection or by means of photographs
- \*the client is able to access single items more readily

"Full Scale Model Piping" by Howard H. Kaplan Chemical Construction Corporation, published in the proceedings of the American Engineering Model Society 1971 Seminar.

Chemical Construction Corporation typically utilizes a model scale of  $3/8" = 1'$ . The piping designer runs piping directly on the model using the engineering flow sheets as the source of information. In doing this with full scale piping he can truly anticipate spatial requirements and points of initial support. The full scale offers the following additional advantages:

- \*representation of piping as a proportion scale item enables the piping isometrician to better visualize and detail the pipe
- \*more information can be put directly on the piping in the form of adhesive tags
- \*points of field welds can also be indicated
- \*clearances between pipes and pipes to equipment and pipe to steel are portrayed more accurately
- \*office personnel who seldom have the opportunity to visit a completed plant can truly visualize the full scope and magnitude of the size and space required by each item of equipment, piping, structures, instrumentation and electrical facilities
- \*by limiting color coding, materials inventory can be held down so as to make the method competitive with the centerline method from a model building cost point of view

\*time saved in installation and checking clearances,  
however, more than offsets the materials cost differential

\*client relationships are greatly enhanced by the true  
proportion presentation

\*operator training is best facilitated by the full scale  
model

"Problems of Starting a Piping Design Model Program" by W. R. Burns, The Badger Company, Inc., published in the proceedings of the American Engineering Model Society 1972 Seminar.

Original utilization of models was via of sub-contract wherein the models were constructed at the model-makers facility from sketches developed from ongoing detailed piping studies being performed on paper. Upon its completion the model was moved to the job-site. It was eventually realized that maximum benefits from modeling would be achieved only when the design itself was worked out on the model. Hence, an in-house design model program was initiated. Important start-up considerations, based upon the first three years experience, are presented in detail.

"A Model Program in the Paper Industry" by E. Walker and L. Tiger, Rust Engineering Company, published in the proceedings of the American Engineering Model Society 1977 Seminar.

Steps toward setting up the facility, personnel and procedures for the use of design modeling and computer drawn isometrics are described. For Rust's first project in which computer drawn isometrics were used, their model tags were designed to contain all of the information necessary to draw an isometric. Separately, a valve book, instrument book and a nozzle information book were kept. These books contained coordinate locations, elevations, face-to-face dimensions and other details needed to prepare the isometrics. After each line was checked by the piping section, the isometric of the line was prepared. First, it was sketched using short codes. These codes were then input to a computer validation program which tested for dimensional closure and specification accuracy. After checking results of the validation program the data were then reprocessed for final plotting of the isometric and preparation of the bill of materials.

"Use of Models on Small Projects" by R. E. Miller, Jr.  
The Proctor and Gamble Company, published in the proceedings  
of the American Engineering Model Society 1971 Seminar.

Models are first introduced to a project at the project definition stage to allow engineers to develop their design intents. These models are typically at scales of  $1/4"$  to  $1/2" = 1'$ . Various alternatives studied by the engineers are recorded with the use of snapshots. Once the most favorable alternate is selected, a preliminary equipment arrangement model is built to a scale of  $3/8"$  or  $1/2" = 1'$ . In this model considerations are given to location of equipment, sanitary or clean design, access to equipment, routing of major piping, location of ladders, platforms, etc., safety and major electrical and instrument locations. Again, alternates are documented with snapshots.

Once the final version of preliminary equipment arrangement model is established, designs which are not modeled are drawn up. These drawings typically include tanks, pressure vessels, structure, architecture and wiring. When these drawings are about 80% complete construction of a  $3/4" = 1'$  engineering model commences. Equipment is modeled from inquiry drawings, catalogue information or vendor's drawings if available. Locations of equipment are taken from the structural drawings or the preliminary model if a given piece required no structural considerations. The structure is also made from drawings and the model is sectionalized so that it may be split apart at each floor level. Grid lines are established for referencing dimensions on the model and on the job. At this time an equipment work sheet is drawn up for the purpose of documenting grid-referenced dimensions of the equipment.

Piping design is performed directly on the model using true scale and color coding techniques. The designer first studies a given line on a flow sheet to gain an understanding of items such as valves, instrumentation, pressure indicators, material specifications, drains, insulation, etc. to be considered. Also, he checks the piping specifications to determine allowed fittings and face-to-face dimensions of valves and in-line instruments along with their specification and other special requirements. It is estimated that this research amounts to 15 to 20 minutes for each line designed. As the line is fit into the model no sketching is performed unless instances of very close fit-ups are encountered. However, tagging is performed concurrently. Data such as pipe size, number, centerline elevation and grid locations are shown on the tag. Electrical power conduit is routed after the piping and with few or no studies performed in advance on paper. However, electrical technicians have followed progress of the piping design making suggestions as to areas which should be reserved for electrical conduit.

Formerly, the company constructed their models with horizontal and vertical sectioning suited for photography with a "parallax free" camera which produced scalable photo-drawings. But, field forces advised of little need for these inasmuch as the model itself is placed on the job-site. Moreover, sections of the model are put at various locations on the job.

Upon completion of the modeling phase the model designer prepares a freehand isometric for each pipeline. All pipe above 1" diameter are completely dimensioned so that they may be prefabricated in the shop. These sketches instruct the pipe fabricator as to

size of pipe, type of material, type of fittings, cut lengths, orientations of valves, flow direction and location of the line. Fractional adding machines and programmable desk top computers are used to aid in developing dimensional data including cutting lengths for bends, lengths of offset pipes and triangulation problems. As these sketches are made the model is further tagged to show locations of hangers and field welds. The model and isometrics are then shipped to the job-site.

"Model Information Systems and Procedures", paper presented to the 1972 Seminar of the American Engineering Model Society by Louis Willstein, The Lummus Company.

Lummus' use of preliminary and design models has progressed to the point where piping design is performed directly on plastic models. A final model along with computer generated isometric drawings are delivered as the engineering piping package. To link information inherent in the model with the computer programs, a detailed model tagging system is utilized. A person preparing input to the computer programs only requires about four days of training. Aside from general job instructions his source documents consist only of a master isometric index sheet, a table of temperature and insulation requirements and a set of flow diagrams. All other data are read directly from the model tags.

A Lummus-developed program package designated as PICS (Piping Isometric Computer System) incorporates a "spec master" which the computer refers to for details of standard pipes and parts. It also includes a capability to break a plant down into separate process or geographical areas. Along with isometric drawings, piping bills of material and a node and segment table are produced.

"How Models Pay Off" by Norbert J. Reder, The Proctor and Gamble Company, published in the proceedings of the American Engineering Model Society 1973 Seminar.

Estimates of actual dollar savings through the use of design models are presented for chemical process plants. Reductions in design engineering costs can be as high as 40%. Field engineering costs can be reduced by as much as 2.5% of the total construction cost.

"The use of Models in the Shipbuilding Industry" by Ronald A. Phillips, Marine Services and Systems, Canadian Vickers Ltd., published in the proceedings of the American Engineering Model Society 1972 Seminar.

The history of the firm's marine design drafting organization is prefaced by the statement that while models are ideal for many purposes, they are not "the complete answer on the total ship concept and we have to revert to other control methods". (Primarily, naval shipbuilding is being addressed.) An in-house master composite service eliminates the need for modeling the entire vessel. These composites are likened to model-making since they perform the same functions. But, models are built for areas containing vast equipment and systems where maintenance or habitability considerations, for example, are paramount. Such models are developed in parallel with the composites.

Models occasionally developed include:

- \*display model
- \*anchor storage model
- \*half block model
- \*damage control model
- \*machinery space model

Discussion of machinery space models includes details of setting up an in-house program for a specific naval warship. Modularization of the model and the model erection sequence are discussed, as are benefits which are believed to have accrued from the model. The model was ultimately delivered to the lead shipyard. It is advocated, however, that a less exotic model be utilized for commercial vessels.

In a summarizing list of benefits it is said:

“If one picture is worth a thousand words,  
one model is worth a thousand pictures”.

"second Generation Models for Deep-Water Oil Production Platforms" by Dereck Ward, Worley Engineering Ltd., published in the proceedings of the American Engineering Model Society 1975 Seminar.

A description of Mobile Oil's "Condeep" platforms built for drilling in the North Sea is concluded with a statement that . . . "the models were expensive pieces of engineering too, in their own way, but the cost was justified many times over." Models built included a small-scale model of the complete structure and a  $3/8" = 1'$  model of the platform deck and a  $1/4" = 1'$  model of the utility shaft.

The platform model included full bore piping and full details of structural sections, cableracks and other equipment so that design personnel could check operational and maintenance clearances. Even the cranes were modeled to ensure there would be no cranage problems. The entire model was some 7.5 feet square by 6 feet high.

The model of the utility shaft was actually built at a scale smaller than desirable for engineering purposes but size considerations were overwhelming. Even at the  $1/4" = 1'$  scale, the model was over 7 feet tall. In addition to housing heavy equipment such as ballast pumps, there are firewater pumps, oil transfer pumps and ballast storage tanks at five different levels. The shaft also contains an elevator and each floor is

fitted with a large hatch to allow transfer of equipment through its entire length. And finally, the shaft carries all services, risers and instrumentation. All of these items were modeled.

The three dimensional complexity and physical restrictions involved were such that both models allowed the designers to work out problems which could not have been solved on paper. The two models allow their own design to proceed and at the same time proved essential for concluding the interface between the shaft and the platform. Paperwork generally followed development of the models. Construction was only one step ahead of the models and as each unit of a model was completed it was shipped to the construction site where it was studied by planning, fabrication and erection engineers.

"Floating Nuclear Power Plants -- A New Approach to Energy Generation" by Vito Riggi and P. Ross Ramsay, Offshore Power Systems, published in the proceedings of the American Engineering Model Society 1977 Seminar.

The history and concept of floating nuclear power plants are treated in considerable detail. These plants are particularly unique in their construction in that conventional shore-side and shipbuilding technology are necessarily married. Three types of models are used extensively for design functions. Preliminary models are used to optimize equipment layouts through the use of alternate studies, long before vendor drawings are available. Study models are built with the aid of designers and engineers for areas congested with HVAC, cable trays and piping. Equipment is made of styrofoam since the primary function of a study model is the development of systems and the envelope of space which the equipment occupies. The models are built in removable sections to permit sections to be brought to an individual's work station where he may model his system and develop preliminary drawings.

The final detail model is built only by professional modelmakers. The floating platform which supports a power plant is made of clear plexiglas to maintain maximum visibility inasmuch as many distributive systems are contained within the platform. The platform is also modularized with removable compartments for

ease of handling and accessibility. A total of 44 model tables are needed to make up the entire platform which is some 17 feet square.

"Piping Layout Rationalism by Means of Design Models", by Peter Kayser, (in German) published in Hansa-Schiffahrt-Schiffbau-Hafen No. 24, December 1967.

A goal of shipbuilding design offices must be to simply and quickly produce piping systems design documents. Demands on the quality of the office workers should not be exceedingly high but the documents must be complete and easy to understand. This goal has been achieved over the past 10 years in the design of land-based chemical and oil plants with the aid of design models. Application of this technology in shipbuilding is described and is based upon experiences of shipyards of different sizes building different types of ships.

The process of design modeling within a shipyard starts with the hull drawings. From these models are built of those portions of the ship corresponding to areas where piping is to be designed by modeling. A structural model is typically made of plexiglass, can be taken apart at several places, does not include the outer hull, is at a scale of 1:10 to 1:20 and built with an accuracy of  $\pm 2\text{mm}$ . Three to six weeks are required to build the structural model of a machinery space. In parallel with this effort, models of machinery and instruments are also constructed, often-times out of styrofoam.

Machinery and instruments are initially installed in the structural model according to the diagrammatic drawings. (Revisions are made as seen necessary as the piping design progresses.) From this point all cable runs, stairs and galleries can be visualized. Layout of piping is performed with plastic pipes and commercially available parts. Ideas of the design engineers are readily incorporated, resulting in shorter runs of pipe and fewer curved pieces. A by-product of designing in this way is that interferences are automatically eliminated. Also, discussions with customers and regulatory agencies are greatly facilitated; requests for changes are brought out in a timely manner.

While pipes are being installed in the model, isometric sketches are prepared by hand. Although these are not to scale all dimensions are shown. A complete parts list is included on each sketch. Any other drawing can be constructed, if necessary, from these isometrics. In addition to the usual isometrics, workshops are also presented with the model itself as it is needed. However, pre-fabrication of piping commences well before the model is complete. Pre-fabrication commences as soon as isometrics are drawn for piping design solidified early in the model building process. Up to 2/3 of all piping can be pre-fabricated based on the isometric sketches.

Movement of the model among the various workshops is minimized to some extent through the use of color photographs (piping systems are color coded). Photographs are also used for initial orientation during installation of pipes. In some instances it is possible to use photographs, annotated with dimensions, to serve as guides for the workshops in lieu of the usual pipe plans.

Implementation of design modeling should be done gradually. Design engineers must be encouraged to work primarily on the model rather than on the drawing board. Shop personnel must work with complete drawings and not incorporate changes without first contacting the designers. Prefabrication should not be in too great a proportion initially. To facilitate transition to design modeling it is sometimes helpful to generate traditional arrangement drawings -- which can be done quite rapidly from the isometrics. It is also advisable to initially allow some workshop personnel to participate in building of a model.

Utilization of design modeling leads to better preparation in the design offices and workshops, thereby leading to reduced shipbuilding costs.

"From Construction Model to Practice" by Maschinenbau Gabler G.m.b.H., February 1970.

The construction model is built of plexiglass at a scale of 1:5, 1:10, 1:20 or 1:25 depending on budgeted model building costs. To facilitate installation of pipelines, ventilators, exhaust pipes, etc., the model is built in several main divisions. Typically these divisions are midships, at bulkheads and along deck levels. Care is taken to assure true scale is maintained when these sections are assembled together or disassembled. When the main position of a ship's piping is confined to a relative small area of the ship, it may suffice to model only that portion of the ship. If the ship is to be built in pre-outfitted blocks, the model is planned accordingly and machinery is installed so as to lie completely within blocks and the blocks are made to be removable from the model. Such removable blocks and their use by the pipe shop and fitters may eliminate the need for isometric drawings. Connection of pipes across block boundaries is by means of "made-to-place" pieces.

Before distributive systems can be installed in a model it is necessary to build the structural model first. This is done typically with the aid of hull drawings. Models of machinery, large valves, etc. are also built from conventional drawings. Machinery is installed in the model according to existing machinery arrangement plans or without such plans if none are prepared in advance. In the latter case temporary seatings are used so as to allow minor adjustments when the distributive systems are installed. Ventilation ducts, cable ways, etc. which may

define "outer limits" for piping are installed next. Pipes, stairs, gratings, etc. are the last items to be installed in the model. Of these, pipes "under floor" are typically installed first just as they would be onboard the ship.

Pipes are installed on the model simply from the diagrammatic plans. The piping designer installs the pipes in collaboration with (typically) two model builders. Preferably model builders are or were members of the workshop force as this background work experience will allow shipyard procedures to influence the model. This is particularly true where considerable pre-outfitting is employed.

The pipes and fittings such as elbows, branches, reducers, valves, drains, etc. are obtained from an outside vendor specializing in such scale model components. The availability of ten colors allows each distributive system to be shown in a different color. Pipes are bent using a hot-air apparatus. Tolerances maintained when installing machinery and piping are typically 50 mm and 20 mm on board the ship. These tolerances are relative meaning, for example, from pipe-to-pipe. Once a pipe is installed it is immediately tagged with an adhesive label bearing an identification number which corresponds to the flow diagram. Any pipe piece connecting to a fixed item such as an engine, pump or the hull is specially designated as "made-to-place" on the model and on all drawings. This is also the case for connections across pre-outfitted blocks.

One isometric draftsman usually works with the model builders to prepare an unscaled isometric of each line after it is installed. Measurements of a line are taken with a flexible steel rule.

These measurements include lengths of straight runs (to tangents where bends are involved), locations of all fittings along the pipe and dimensions relative to structure and/or the ship's coordinate system. These "on-line" isometrics along with inscribed or attached material lists should contain sufficient data to allow preparation of pipe shop drawings. An alternate form of isometric presentation is according to blocks of space.

Completion of all work on the model should be generally complete before the first pipes are installed on the ship. At this time the model should be made available to outfitting supervisors and fitters for the purpose of self-instruction. The model along with isometric drawings are sufficient for proceeding with onboard installation. Photographs of the model are also sometimes used but these are useful only if taken at various phases of the model construction. If appropriate, sectional views are taken with obscuring machinery removed.

The remainder of this document treats manual preparation of pipe shop drawings for fabrication.

"Ten Years Experience with the Building of Scale Models" by  
P. Kayser, H. Sennert and K. Stulpner (in German), published  
in Zentralorgan fur Schifffahrt-Schiffbau-Hafen, Heft 14, 1977.

A general overview of the development of  
design modeling for the shipbuilding industry  
(particularly German) is presented. Discussions  
of anticipated future advancements cover me-  
chanization of the "take-off" from design models.  
The Vickers CODEM system is outlined.

"Advanced Pipe Technology - Detailed Final Report", published by the U. S. Department of Commerce Maritime Administration and Bath Iron Works Corporation in conjunction with the National Shipbuilding Research Program, December 1976.

This report documents domestic and foreign state-of-the-art technology for piping design/engineering, piping fabrication and piping assembly/installation. Within the domain of piping design/engineering, input to and output from specific phases and ancillary functions are given detailed treatments. Particular phases and functions addressed are contract definition, schedule and special material identification, piping diagrams, piping arrangement, pipe detail, hanger design, operating gear design, supporting lists and schedules, technical documentation and revision.

With respect to the piping diagram phase of piping design/engineering, very little difference was found in practices employed by surveyed domestic design-agents and shipbuilders. Foreign shipbuilders, however, place greater emphasis on accuracy and detail at this stage. Both orthographic and isometric types of layouts are discussed without a stated preference. But, regardless of the type of layout, minimum requirements for such diagrams are:

- \*simplified structural background

- \*display of approximate arrangement and configuration of piping runs, pipe sizes, special valves, special fittings, equipment and tanks

- \*symbol list

- \*title block

- \*accompanying list/tables defining materials, pipes, special valves, special fittings, equipment, tanks and pump characteristics

Relative to this phase of the piping design/engineering process it is concluded that the use of pre-printed structural backgrounds and computer programs for pipe sizing and related calculations are the most significant cost-effective methods utilized by the surveyed domestic design agents and shipyards. But, even in the variable ship design environment of domestic shipbuilding (in contrast to a few standard designs offered by foreign yards) significant cost-saving potential lies in completely computer-generated diagrams as is being developed at Italcantieri.

Within the piping arrangement phase of piping design/engineering, three-view orthographic presentations are used by all domestic design agents and shipbuilders. Isometric presentations are used by one domestic shipbuilder to aid installation of piping systems. Whichever method of presentation is employed, desirable attributes are:

- \*accurate structural background with compartments clearly labeled

- \*display of exact arrangement and configuration of piping runs, pipe sizes, all valves, all fittings, equipment and tanks

- \*presentation at a scale which will permit accurate preparation of pipe details

- \*dimensions referenced to well-defined and accessible objects
- \*neat, clear lettering which will not lose clarity when reduced
- \*inclusion of or references to all information required for material ordering, fabrication and assembly/installation
- \*references to applicable design documents, interfacing systems and approval documents
- \*symbols and abbreviations **lists**
- \*title block including data needed in-house and by regulatory bodies

Considerable attention is given to the subject of interference control. Various techniques utilized by surveyed design agents and shipyards include:

- \*designer liaison method
- \*space composite method
- \*space composite based on "piping conduits" (i.e. reserved zones)
- \*overlay method
- \*mockup method
- \*computer aided detection system
- \*model method
- \*photogrammetry method<sup>1</sup>

In discussions of the model method it is stated that only three surveyed domestic shipyards use models for interference control and in all cases, only for special cases in isolated areas of a ship's design. Only one surveyed foreign shipyard (Odense)

<sup>1</sup>This treatment of photogrammetry as a means for interference control is incorrect. Photogrammetry can be used to lift dimensional data from models -- the model itself is actually the mechanism for interference control.

uses models, but in this instance, models are used exclusively for design of machinery and distributive systems arrangements. Design data manually lifted from the model are computer-processed to produce symbolic pipe details, fabrication instructions and material lists.

Relative to the piping arrangement phase of piping design/engineering it is concluded that although orthographic presentations are the most widely used, isometric presentations appear to offer significant advantages for certain applications. Moreover, the development of such sketches directly from design models is significant in that the combined process eliminates much of the duplicative effort seen in domestic model-building/design-engineering practices. It is also stated, however, that models are not well suited for interference control because of the long lead time requirements and the need for special personnel and facilities. Hence, the space composite is the most widely used interference control techniques.

Subsequent to discussions of the pipe detailing phase of piping design/engineering it is concluded that computer-aided pipe detail programs is one of the most significant advancements in marine piping technology. In addition, it is the first logical step toward integrated piping design/engineering systems. Currently these computer-aided systems facilitate cost effective pipe fabrication but they are not yet so for design.

To this point the report addresses piping design/engineering in terms of individual phases in the order of their occurrence in a traditional design/engineering process. Discussions now turn to various totally integrated systems under development in a number of domestic and foreign shipyards. Typically these integrated systems are based on design via interactive graphics or upon digitizing designs first prepared upon paper. However, a unique variation from these concepts is the Odense computer-aided design model system.

At Odense the use of models originated as a tool to study new ship designs and to aid in marketing of these designs. However, models were ultimately incorporated as a part of the regular design process because of their numerous advantages:

- \*portrayal of complex arrangements without the need for skilled designers
- \*ready realization of best arrangement of machinery and piping, thereby optimizing the layout of piping, ventilation, wireways and gratings
- \*handling and overall space requirements are easily determined and staging requirements are minimized
- \*interferences are easily detected and virtually eliminated at the design stage
- \*models serve as common basis of communication between the owners, regulatory bodies and the shipbuilder

These advantages are seen to far outweigh the basic disadvantage of long lead time requirement. With the adoption of design modeling the design department abandoned the traditional methods

of preparing arrangement drawings, composites and pipe details. Under the new scheme of operation using design models nearly 90% of a ship may be pre-outfitted as compared to 15% with the old method.

To facilitate building of models a portion of the design department has been made into a model shop. Of 81 persons involved in machinery outfitting design 13 to 16 of these are responsible for construction of engine room models. Fabrication of a model is by designers who are also experienced in model building. They work directly from machinery arrangement diagrams and vendor equipment drawings to first establish a final machinery arrangement. Deviations from the preliminary arrangement are noted on those diagrams to permit appropriate weight and moment calculations. Next, outfitting of all systems is performed using the outfitting system diagrams as a guide. However, a system-sequence is more or less followed in accordance with pre-assigned system priorities. For example, the main steam system is often designed first followed by other systems requiring a great deal of space, such as vent trunks and wireways. Finally, smaller systems are added to the model. Inasmuch as pipe down to 1/2" is designed in this way, 90% of all engine room piping is portrayed on the model. Typically, the model scale is 1:15 and, in Odense's case, the structural portion is purchased by sub-contract. Pipes are shown in full scale representation with standard items such as valves and fittings portrayed by commercially available scale model

components. The structural portion of the model is built with a tolerance of  $\pm 1$  mm whereas the outfitting is built and measured on the model to  $\pm 2$  mm.

Although changes can occur at any time in the design process, an attempt is made to finalize systems having high priorities at an early stage in the overall design process. In this way, fabrication in the pipe shop can commence before completion of the model. Oftentimes the model is only about 50% complete when the first pieces are fabricated.

Actual production of the piping fabrication and installation documents is performed with the model itself as a basic source of input information; no system arrangement or composites are ever prepared. Instead, outfitting systems are first divisioned off (on the model) into smaller units suitable for sub-assembly fabrication and installation. Each such sub-assembly is then drawn freehand in the form of an isometric sketch showing dimensions (manually scaled from the model using special steel scales) and all valves and fittings identified as to type and size. Each sketch then serves as an input document to a computer-aided pipe detail program as well as an installation sketch.

Data manually extracted from the isometric sketches are entered on computer input sheets. Upon entry into the computer these data are first checked for validity

and against certain theoretical closures. If necessary the data and/or model are modified. Once corrected (if necessary) the data for a given system are further computer-processed in the presence of "catalogues" of standard and unique parts which are defined in terms of geometry and materials. Output from this processing includes symbolic undimensioned pipe detail sketches, bending and assembly instructions, material lists, actual costs to produce each subassembly and the optimum production path to achieve efficient machine loading in the pipe shop (overloading is flagged by the computer). After isometrics are sketched at the model about eight weeks are required to prepare the computer input and generate the installation documents for a given system.

For the purpose of outfitting a ship is broken down into structural blocks. Hence, the isometric sketches are grouped and bound in booklets corresponding to these same blocks. But, later on, these sketches are regrouped by systems for delivery to the owner in lieu of arrangement drawings. Computer generated pipe fabrication documents, on the other hand, are bound into booklets to suit production lines in the pipe shop. Information needed to deliver finished piping according to outfitting blocks is also provided.

Development of a typical engine room model requires about 10,000 man hours, exclusive of the hull which is obtained via subcontract. Reportedly, regulatory agencies were initially apprehensive over the substitution of models in

the place of traditional arrangement and composite drawings. Now, however, they prefer the model and generally visit it every three weeks.

"A Systems Approach to Total Ships Outfitting" by P. Bech, paper presented to Seascope '76 Conference on Developments in Shipboard Outfitting, University of Newcastle upon Tyne, April 1976.

This paper addresses increased productivity resulting from design with due regard to production methods and facilities, to planning and to production preparation. In this context the use of design models at Odense Steel Shipyard is described along with computer systems for transforming design data into production information. The paper also deals with production flow of prefabs, sub-units and super-units. Also, the economics of integrated methods used at Odense are discussed. Finally, observations are made as to how far a designer should go to ease the production burden.

Outfitting system diagrams are developed from a general arrangement and the specification describing the function of the vessel. This leads to basic decisions on major machinery components. Next, design of the main layout of the engine room is accomplished with a model of scale 1:40. A model at this stage of design allows quicker and better decisions while providing a ready mechanism by which production personnel and owner's representatives may review the arrangement of major components, major auxiliaries, main ventilation, access during the building phase, securing of space for pipe withdrawal and exchange of major components and, finally, functioning of the engine room once the vessel is placed into service. The model is also used to decide upon subdivision of the engine room into production blocks of suitable size (up to 575 tons at Odense)

Detailed design work is carried out on a model of 1:15 scale. All piping down to 1½" is laid out in the model, complete with positioning of valves, cable trays, lighting fixtures and all

other equipment in the engine room. The model is very expensive to build up and typically requires ten people working on it continuously over a period of six months. At Odense the hull or structural model is obtained via subcontract; Odense's model workshop concentrates only on machinery items and piping arrangements.

As with the 1:40 scale model, frequent decision making meetings are held around the model to decide upon the best possible arrangements from the shipyard's and the customer's point of view. For examples, positioning of maneuvering valves, piping details amenable to easy overhaul, temporary supports in the blocks. decisions regarding sub-units, etc. It is also seen that machinery components are located free of block divisions.

Initially design modeling was intended primarily to achieve better layouts of engine rooms. This was considered a goal of such significance that it alone justified the modeling approach to design, even though the advantages would be difficult to count in a monetary sense since they consist of quicker decisions in design and fewer manhours in production. Once implemented, however, the model building program led to another development covering a third design stage; creation of production information.

The Odense "pipe sketching system" starts at the model where coordinates of bends, joints, flanges and other piping armatures are "lifted" from the model and used for a handmade isometric sketch. A basic angle calculation program is used to determine angles in bends. Where possible, these initial angles are modified to be standard values. Corrected data along with material specification/dimensions, prefab block numbers, fabrication

operation schedule and assembly block numbers are fed into a computer data base. Output from this consists of:

- \*symbolic pipe sketches
- \*pipe bending instructions
- \*piece work rate for each operation
- \*pipe "batching" work orders
- \*planning data from piece work rates and work orders
- \*pipe mounting lists

In its present form the pipe sketching system requires a long period between design and production owing to the step-by-step manual input to the computer with attendant data correction and resubmission. In the past this has not been a problem where order stock in the yard was large. But in the present shipbuilding market Odense has been forced to change its product program and such time consuming methods can no longer be tolerated. Accordingly, the pipe sketching system has been streamlined by addition of a visual display unit placed next to the model itself. Coordinates lifted from the model are entered at the display unit and immediately processed to verify the input for closure, adjust angles of bends, produce an isometric pipe sketch and list material data, armature lists, etc. Hard copy of the display can also be made at the unit. Then, all correct results are transferred to the data base for subsequent use in production preparation and in production. Obviously this streamlining of the system will save man hours in design but more importantly, it drastically shortens calendar time between design and production of fabrication and planning documents.

Odense's experience to date indicates that a little more than two ships of the 45,000 to 70,000-dwt class can be handled per year with a single visual display unit.<sup>1</sup>

The remainder of this article describes other computer aided outfitting systems in use at Odense, but these are not pertinent to this project. However, a discussion by D.E. Gilbert of Vickers Shipbuilding Limited is of particular significance. He states that there are many advantages to design models but the key to success is dimensional accuracy. Vicker's experience indicates that this accuracy is lost when model scales smaller than 1:10 are employed. In their models the structural portion is built to a tolerance of +0, -2 mm per 1000 mm while equipment and pipe work are modeled to "measurable accuracy". Because the model is an interdisciplinary design tool it is the focal point for all drawing offices. This results in faster generation of production information.

There are few disadvantages of design models. Perhaps the most serious is the cost involved. It can be argued that this cost is justified if the ship is complex or if a series building program is involved. In the case of a "one-off" commercial ship it may only be economical to model particularly congested areas. Another criticism sometimes leveled is that ergonomic problems are not readily appreciated. However, Vickers has successfully used models to demonstrate maintenance and operating operations.

It is debatable whether the two-model approach used by Odense has any advantage over the more conventional single model system. Certainly the detailed design model can be also used to establish the equipment arrangement. At Vickers piping is represented true-to-scale rather than by wire and disc.

<sup>1</sup>The author states that development is underway to extend use of the system to electrical equipment, cabling, HVAC, etc.

Vickers has developed a system called "CODEM" (Computerized Design from Engineering Models) which is unique in that it is used to extract information directly from a three dimensional model, thus providing a real savings in time and money. Prior to developing the system it was very necessary to completely standardize pipework documentation in the form of isometric drawings, parts lists, numerical information and single line arrangement drawings. Once this common methodology was established the computer was introduced to replace much of the manual effort required to produce such documentation.

The first stage of CODEM is the design model itself which is made very accurately in sections not larger than about 6x6x6 feet. All machinery, piping, electrical equipment, ventilation ducting, structural items, walkways, control panels, etc. are accurately modeled. When the model sections are completed they are placed one at a time on a fixed table of a three dimensional telescopic unit. This unit consists of two telescopes which travel on rails constructed at right angle to one another. Both telescopes can also move in a vertical direction independent of one another. Locations of the telescopes are continuously encoded so that their locations relative to the model are always known, or at least can be computed by the on-line mini-computer to which the telescopic unit is connected. To enter data into the computer for a given piping system, an operator at a typewriter-like keyboard/visual display unit manually keys in a coded description of the pipe. When geometric data are needed the operator "instructs" the computer to accept the current locations of the two telescopes. (Presumably the horizontal and vertical angles at which the telescopes are pointed are also encoded -- pointing of the telescopes at pipe

locations is probably manual.) Data entered in this way are stored on magnetic tape. This tape is later fed to a main computer in which details of all pipe components are stored. As the magnetic tape is read by the computer, each general description of a pipe element is matched with the appropriate details. Calculations for length, weight, quantities, etc., are performed and another magnetic tape is generated for automated plotting of isometric drawings. These drawings are fully dimensioned and labeled with all information necessary to manufacture the pipes, bending instructions included. Parts lists and summary lists are also generated.

"Recent Developments in the Design and Production of Marine Piping Systems" by G. Standen and D. E. Gilbert, Vickers Limited Shipbuilding Group, paper presented to the Institute of Marine Engineers, January 1977.

Several advances made over the past few years in the development of pipe production systems within Vickers are discussed. Included is the use of design models and a system for dimensioning from the models. In recent years the building program has been concentrated on naval vessels. All important areas involving pipework are mocked up in full scale or scale model form. Information from these models was formerly lifted manually and presented as orthographic drawings or as isometric sketches. Such drawings were available early in the building program and, therefore, facilitated manufacture of pipework. Pipe bending data was calculated by computer but only after manual input of information shown on the isometrics.

To improve productivity, means for going directly from a model to the pipe fabrication documents was sought. Photogrammetry and similar techniques were investigated and, in particular, techniques used in the chemical industry. The result of this was that the technique used by the Lurgi Company of Frankfort, West Germany was judged to be most suitable and the basic hardware concept and software was purchased from Lurgi. The hardware was designed and built and software was completely overhauled to suit the special requirements of shipbuilding. The complete system is designated

CODEM" for Computer Design from Engineering Models.  
A description of this system may be found in the latter half of the abstract of "A Systems Approach to Total Ships Outfitting". Even though CODEM has been designed for pipework, its extension to electrical and HVAC seems natural and is under consideration.

"Abstract of Model Engineering Technique in Hitachi Zosen"  
by Hitachi Shipbuilding and Engineering Company, Ltd.<sup>1</sup>

The title of this document is somewhat misleading inasmuch as the substance of the text addresses the use of design models. Faced with increasing size and complexity of machinery spaces, Hitachi investigated methods of mechanizing the outfitting design. In 1971 a model of a 240,000-DWT turbine-tanker machinery space was built on an experimental basis. By 1972 design modeling was instituted as a standard design procedure. Through 1974 a total of seven machinery spaces were designed in this way.

In 1974 and 1975 Hitachi Zosen and the Japan Ship's Machinery Development Association jointly developed sonic wave and optical ranging systems for obtaining three dimensional coordinates from machinery space models. Also, a photographic system was developed which produces orthographic photographs of such models. (Pictures of all three types of equipment are contained in the report as are sample ortho-photographs.) In conjunction with these developments, methods for manufacturing model parts and for model construction were developed.

In 1976 and 1977 the same organizations further developed the photographic system to the point that it has been designated "Draft-Camera" and released for commercial use. A procedure for display of descriptive and dimensional information on the pictures was also developed for the purpose of interfacing the model to an existing computer-aided production and outfitting management system.

<sup>1</sup>Date is believed to be late 1977.

Advantages attributed to the design model are:

- \*lower skill and experience level required of outfitting design engineers
- \*design faults and interferences are visualized at an early stage
- \*models can be used for many purposes such as initial design, outfitting design, customer approvals, display, reference at the work site, as an aid to reconstruction, etc.
- \*the variety of working in three dimensions is attractive to the designers

"Installation of the Nerve System of Ships by Use of Scale Models"

by L. Nohse (in German), published in Jahrbuch der Schiffbautechnischen Gesellschaft, 1968.

A review of the development of design modeling for ships machinery spaces is accompanied by discussions of benefits accrued from design modeling. Comments by discussers are appended to the article.

"RAPID Report R1; Users Manual, Preliminary" technical report on the Interactive Piping Design Software Package by P. W. Rourke , Newport News Shipbuilding and Dry Dock Company, June 1977.

The RAPID system is a package of computer programs being developed by Newport News Shipbuilding and Dry Dock Company under a project jointly funded by the U.S. Maritime Administration. This software package is designed to support computer-aided piping design and to generate piping manufacturing documents. Completion of the programs is schedule for March 1978.

Input provisions allow the user to:

- \*define geometry of pipe runs,
- \*define decision rules for selection of components,
- \*define assemblies, sub-assemblies,
- \*define graphic output with arbitrary scales and viewing directions, and to interactively label and dimension these drawings.

Processing on user request allows:

- \*application of decision rules to inputted pipe geometry and to automatically select piping components,
- \*check for design errors by testing pipe geometry against physical constraints of the pipe shop,
- \*make modest changes to pipe geometry to eliminate errors.

Output provisions, which may be elected for collections of piping specified by the user include:

- \*piping drawings of any kind (with dimensions if input)
- \*material lists,
- \*pipe bending instructions,
- \*schematic (joint map) drawings

The Newport News prototype system utilizes a mini computer with disc storage, a magnetic tape cartridge unit, a digitizing table, a plotter/printer and a graphics CRT. However, the software is not limited to this hardware configuration.

"The Use of Engineering Design Models As the Vehicle for Engineering, Designing and Constructing Nuclear Power Plants" by G. R. Neeley, Bechtel Power Corporation, published in the proceedings of the American Engineering Model Society 1977 Seminar

A complete overview of Bechtel's use of design modeling for the Palo Verde Nuclear Generating Station is presented. Much of the effort follows contemporary practices of design modeling. But, several interesting variations include:

- \*The total model is split up into independent model bases to assure mobility and to facilitate photography. Splits are made along column centerlines or outside surfaces of walls. Each model base is also split in horizontal planes at each major building level.
- \*Exterior walls are constructed of clear plexiglass and opaque white plexiglass is used for interior walls. But, in both cases the bulk of the walls are cut out for designer access and to reveal the interior for photography.
- \*Isometrics drawn directly from the model are issued to "stress" for approval and to develop hanger locations. When approved and returned from stress an approval tag is added to the model and hangers are installed.
- \*Model building progress is documented via video tapes with audio.
- \*When the model is about 90% complete each section of the model is photographed in color. The color

photographs are organized to depict plan and elevation views as well as special close-up views . They are sealed in clear plastic and then secured in a hard-cover binder along with a legend, key index and a blue line copy of the revision control index. These color composites take the place of traditional drafted composites, but in the case of the photographic versions, much of the information conveyed is via the model tags which can be seen in the photographs. The binders are issued to the field for preconstruction planning about four months prior to installing systems. Installation is guided by the isometric developed from the model.

"Photogrammetry Applied to Pipe Systems of Chemical Plant"  
by R. Farrand, Imperial Chemical Industries, Plastics  
Division, U.K., The Photogrammetric Record, October 1965.

When designing the routes of piping for a chemical plant the design is produced directly on a skeleton three dimensional model of the plant which can be separated into sections for access to central areas. Electrical and instrument lines are not shown unless they occupy important space relative to the pipes. Vessels and other plant equipment such as pumps are modelled from drawings of these specific components. Their positions, together with general paths of large pipes and pipe galleries are pre-determined by means of rough layout models and flow sheets. Precise routes and details of pipework are then designed as far as possible directly on the model. Pipe centerlines are represented by color-coded wires while their diameters are portrayed by sliding discs. Fittings such as valves and instruments are represented by symbolic shapes. Intricate and close-fitting details are planned by isometric sketching before being modeled.

Many advantages are attributed to modeling piping design. For example, hundreds general arrangement drawings are eliminated, the design-is more quickly understood and the number of interferences in construction is greatly reduced. Upon completion of the model, however, shapes and dimensions of pipes must still be generated on paper for use by the pipe fabricators and plant erectors. This is normally done by sketching isometrics as the model is put together; general arrangement drawings are then developed from these sketches and by referring back to the model

itself. But, difficulties in measuring direct from the model by hand forces the draftsman to estimate many dimensions.

Photogrammetry was seen as an accurate method of extracting dimensional information and recording it to scale on paper. A crude initial experiment indicated that photogrammetry could produce twice as many measurements in the same time as the fastest draftsman lifting dimensions by hand. Moreover, data derived by photogrammetry were free of blunders inherent in the manually produced data. Based upon these very favorable results, a serious development program was undertaken.

A special camera system and stereo plotter were built by Officine Galileo of Florence, Italy. The camera system included a pair of identical cameras mounted on a horizontal bar which in turn was supported by a pair of vertical columns rising from a base plate which set on the floor for stability. The cameras could be raised or lowered on the vertical columns and the horizontal bar could be rotated to allow pointing the cameras up or down. Separation between the cameras was variable the camera axes could be adjusted to converge or be parallel and the focus of each camera could be varied to accommodate an expected range of distances between the cameras and the model. Color reversal or black and white "120" roll film was used in the cameras; a vacuum system in the backs of the cameras provided flattening of the film. In operation, the camera system was adjusted once for a particular series of photographs. Thereafter, the model, which was placed upon a table which ran on horizontal tracks, was moved, bay-by-bay, in front of the cameras.

The stereo plotter is an adaptation of a standard design, the major modification being the addition of a second set of linkages and second plotting table. These additions allow simultaneous plotting of pipe runs in both plan view and in elevation. That is, as the operator of the instrument views a pair of photographs in three dimensions through the instruments optical system and moves his measuring reticle along a given pipe as he views it in the instrument, both plan and elevation views of the movement of his reticle are recorded on the separate drawing tables. Typically, the drawing scale is  $3/4" = 1'$ . Because of a rather short distance between the cameras and the model, an accuracy of  $\pm 1/4"$  at the scale of the plant is achieved.<sup>1</sup> Initial results indicate that about 95% of all required detail can be extracted from the model strictly via photogrammetry.

An overlay system is used to convert the undimensioned (but nonetheless "to scale") sketches generated by the stereoplotter to piping drawings. First, an accurate background drawing is made on stable-base drafting film using the plant steelwork drawings and vessel detail drawings as a source -- basically the same drawings as used to construct the skeleton model. Then, the stereoplotter-produced pipe sketches are registered to this background drawing at reference points on the steelwork or "hard" features such as nozzles, which are also sketched at the stereoplotter at the same time the pipes are sketched. The pipes are then traced onto the background drawing by a draftsman who also adds other data such as pipe numbers and valve references, but not dimensions. Schedules of coordinates of end-points and pipe details such as diameters, valves and other fittings are prepared to supplement the drawing.

<sup>1</sup>It is not known whether this is a tolerance or one standard deviation

Duplicates of the master drawing are made on stable base drafting film for distribution. The fabricator scales his particular dimensions from his copy of the drawing.

Investment in the photogrammetric method has been fairly substantial and at the time of writing the paper, the method has some appearance of being cumbersome and slow, especially at the stereoplotter. But, even though the technique has not yet been applied to a complete project it has already been at least indirectly responsible for a variety of new ideas for streamlining the design process. As a result, reductions in construction time are now measured in months rather than weeks. Aside from goals of increased accuracy and speed, photogrammetry may also allow greater freedoms in design. On many occasions a designer might formerly route pipes with a view toward avoiding difficult measurement situations on the model.

"Photogrammetry as an Aid to Manufacture of Ship Piping", The British Ship Research Association Report NS 306 by W. G. Smith, 1971.

The conventional method of generating pipe manufacturing data through preparation of arrangement drawings and sketching of pipes at the ship is considered unsatisfactory. This attitude has developed with the evolution of large shipbuilding groups, centralization of drawing offices and the tendency for increasing physical separation of these offices from the pipe shop and the ship itself. Moreover, computer based management systems being introduced into shipbuilding require, for maximum effectiveness, early availability of operational data. The traditional pipe sketch is not suitable for any of the present-day conditions described.

Because shipboard piping systems are becoming increasingly complex, some yards, in the interest of productivity, have turned to design modeling to assist pipework design. Design modeling also allows early availability of data for use in computer based management systems. But, the method has also introduced problems in lifting dimensional data needed for the manufacture of piping systems. To present, this has been performed by manual measurement with a rule, followed by the preparation of isometric sketches and pipe-arrangement drawings. This process is not entirely satisfactory owing to limited access for measurements, duplication of data inherent in the model

portrayed also as arrangement drawings and lack of data being in a ready form for computer processing by information and manufacturing programs.

Photogrammetric measurement provides a more satisfactory solution; its principal advantage lying in that it is virtually non-contacting. The specific photogrammetric technique adopted for study is described as comparative photogrammetry. Important features of this particular method are that it is not necessary to know the focal length of the camera lens nor the distance between cameras; hence, a relatively inexpensive camera may be used. Measurement of the photographs may be performed with inexpensive equipment also. While this method is considerably less precise than more rigorous photogrammetric methods, its experimentally determined accuracy of about  $\pm 3\%$  is considered adequate for the need.<sup>1</sup> It is anticipated that over 80% of an engine room's pipes can be dealt with by photogrammetry. Also, due to inaccuracies in photogrammetry, the model and ship construction it is fully expected that some sketching will always be required at the ship for closing lengths and made-to-place piping.

A single camera is mounted upon a horizontal bar which in turn is supported by a pair of vertical

<sup>1</sup>It is believed that this is a one standard deviation figure -- not a tolerance.

columns rising from a base. For aiming purposes the camera may be moved along the horizontal bar and the bar itself may be moved along the vertical columns. Care is taken to align the focal plane of the camera parallel to a vertical plane containing the horizontal bar. For photography the camera system is aligned with the model such that the horizontal bar is parallel to the horizontal datum of the model and that the vertical columns are parallel to vertical datum of the model.

Prior to exposing the photographs, one scale is placed on the model in the foreground and one is placed in the background. Also, a grid is drawn on the model base or, alternately, special markers are placed on the model to aid in subsequent location of the optical centerlines of the photographs. A series of highly overlapping pictures (relative to extent of model photographed on one picture) is then exposed across the front of the model. Experimental lighting consists of two 500-watt photoflood bulbs aimed with convergence upon the model from a distance away about equal to the distance of the camera from the model. The lights are adjusted to provide uniform illumination as the camera is moved between them. Care is exercised to avoid casting of deep shadows of wires as the shadows on the photographs can be mistaken for wires themselves.

Measurement of the photographs may be performed with a steel rule, on a Farrand Overlap Comparator or on a digitizing table. Enlargements of the original photographs

are first scribed with special reference lines to locate the optical centerlines of the pictures. The photographs are then taped side-by-side to the digitizing table, usually with the optical axes of the pictures aligned with one axis of the digitizing table. Measurements are then made on both photographs to their optical axes (as previously scribed), both ends of both scales and points on the pipes of interest. These measurements which simply consist of digitizing table X-coordinates are recorded on paper tape for subsequent processing through an elementary computer program which, in its present form can produce only the depths of the pipes from the datum surface parallel to the focal plane of the camera. (However, the process can be extended to incorporate Y coordinates of the digitizing table which will also permit calculation of heights and lengths.)

Actual experiments entailed a series of photographs of a 1/10 scale wire and disc model of the engine room of a dredger; the model being split along its longitudinal centerline. Two different cameras utilized, an f/2.8 Rolleiflex and a Nikkenflex were selected primarily for their ready availability but were not considered entirely satisfactory because their twin reflex characteristics presented aiming difficulties at the short ranges involved (about 1 meter from the camera to the front of the model). Black and white films were used for both the original and enlarged photographs inasmuch as the piping was not color-coded.

A first set of experimental pictures were measured both on the Farrand Overlap Comparator and on a digitizing table. A number of pipe depths were calculated from both sets of measurements and compared to the known depths. For the two methods of measurement respectively, mean differences amounted to 6.3 inches and 2.4 inches whereas the maximum errors were 44.9 inches and 10.6 inches at the full scale of the ship.

However, a second set of pictures taken with greater care in aligning the camera system with the model, measured on the digitizing table produced results at least twice as good as these.<sup>1</sup>

Conclusions are that accuracy is best improved by refinement of the measuring system -- expensive cameras are not warranted. Great care must be exercised in locating the optical centerline on each photograph. Consideration should be given to a means (i.e. colored wires) by which pipe systems can be identified. Further investigation is required to determine how photogrammetry can be interlinked to other production information systems. Pre-sketching of pipes by photogrammetry or any other method is limited to an estimated 80% of the pipes shown on the model -- this limit being imposed primarily by accuracy with which the ship and pipe can be manufactured. The entire procedure of comparative

<sup>1</sup>Due to the manner in which these particular data were reported, it was not possible to convert them to physical discrepancies at the scale of the ship.

photogrammetry requires very little training for its implementation. An accuracy of  $\pm 3\%$  for depth measurements can be achieved.<sup>1</sup>

Appendix I presents the geometric theory of comparative photogrammetry, Appendix II gives a sample calculation of a pipe length, a brief analysis of photogrammetric errors is set forth in Appendix III, notes on design modeling are presented in Appendix IV and Appendix V shows a flow chart for the computer program to calculate pipe lengths.

<sup>1</sup>It is believed that this is a one standard deviation figure -- not a tolerance.

"Pipe Production Information: A Computer-Aided Method", The British Ship Research Association Report NS396 by B. Dodd and J. B. Jack, 1974.

A major disadvantage of current practices for developing pipe manufacturing data is that the pipe shop does not receive the data with sufficient lead time so as to allow planning and batching of pipes for the bending machines. Moreover, the machine operator normally works from pipe sketches and, in some instances, may even prepare a small wire model of a pipe or engage in a lofting process on the plumbing shop floor. The operator's productive could be increased if he were provided directly with a concise clear list of instructions for each pipe, from which he could work directly. Also, any system which can reduce the number of tried-in-place pipes would also increase productivity.

When design modeling is employed pipe dimensions and angles are normally manually lifted from the model by a draftsman. But, a previous study documented in the British Ship Research Report NS 306

"Photogrammetry as an Aid to Manufacture of Ship Piping" demonstrated the potential for photogrammetric dimensioning of design models. Since that report, continued research produced computer programs which can convert data from the photogrammetric digitizing into spatial coordinates defining a pipe's ship.

Isometrics can be plotted, but the process is cumbersome in that it is entirely an "offline" procedure; i.e. computer processing and drafting is entirely separate from photogrammetric digitizing. In an independent development, another computer program was developed to generate pipe bending data from coordinates defining a pipe's shape. And, yet separately, Imperial College was in the process of developing a computer aided drafting system.

Work reported in this BSRA report represents efforts to combine all of the above developments so that pipe bending instructions can be produced, on-line, directly from photographs of a design model. The hardware system for digitizing the photographs and producing the required bending data consists of a digitizing table, a PDP-8 mini computer with 8K words of memory, a teletype for program instruction input and printed output and a CRT for display of isometrics. To start up the system it is first necessary to input certain definition parameters via the teletype and to digitize certain reference points on the photographs which are taped to the digitizing table. The minicomputer immediately performs an accuracy test on these data and signals the operator (via the teletype) whether the data are acceptable. Once this stage is completed successfully, a given pipe of interest is identified through the use of a "menu" on the digitizing table and then digitized on the photographs. As the digitizing proceeds, the path of digitizing is displayed

on a CRT in isometric view as a visual check. The CRT tube may be photographed if it is desired to use the isometric display as a replacement for the pipe sketch. Once the digitizing is completed, the pipe bending program is invoked and calculated bending data are printed out on the teletype along with messages (if any) regarding improper floor clearance, clamping length and radii which is too small.

For a single pair of photographs about one minute is required to digitize the set-up data and another minute is required for each pipe to be digitized. Calculation of bending data is about one second per pipe but the printout is at a lesser rate owing to the slow speed of the teletype. However, the teletype is easily replaced by a faster device. Hence, most pipes within a typical model section<sup>1</sup> can be digitized and corresponding bending instructions generated in an hour or two. However, the present system is not considered complete inasmuch as there is no capability for detailing pipes -- this will be considered in the next stage of development. It is also suggested that consideration be given to utilizing this system during the design modeling process to assure that practical designs are developed utilizing standard shapes, lengths, angles, etc.

<sup>1</sup>"Model section" is not defined in terms of size relative to an entire design model.

The balance of this report gives finer details on the computer program concepts for converting digitized data to pipe coordinates and then translating these to bending instructions. Flowcharts of the programs and a typical *output are given* in appendices.

"One Step Isometrics From Models" by J. Birkhoff,  
Continental Engineering, N.V. (Amsterdam), published in  
Hydrocarbon Processing, July 1972.

Design models can be used to develop better designs but seldom have they reduced design costs. Computers, on the other hand, are a major factor in reducing design costs. Proper interfacing of models and computers can produce better designs, lower design costs and on-schedule completions.

Once a model is completed, the normal procedure has been to prepare arrangement drawings from it, and then to produce isometrics from the arrangement drawings. An improved procedure, however, is to create the isometrics directly from the model with the aid of a computer. To do this, an XYZ coordinate system is established on the model. All piping is physically located in this coordinate system and tags bearing this information are attached to the various components in the model. Experience has shown that if a model is so prepared, manual coding of coordinates and piping components and subsequent computer generation of isometrics requires about one-half the time required for conventional arrangement drawings. It has also been found that when a client requires arrangements, the time required to build a model and then produce the drawings is about the same as producing the drawings without a model.

It would seem that after a completed model is shipped to a job-site, it would be difficult for designers to respond to questions from the owner or personnel on the job-site. To avoid this potential difficulty, a special model photography program was instituted.

In the past, preparation of isometrics, bills of material, cutting lists, etc. by conventional methods was very time consuming and costly. To improve this situation and recognizing the trend toward increasing labor costs but stable computer costs, a firm was contracted to develop a computer program for automated preparation of isometrics and bills of material. Basic requirements of this program were:

- \*isometrics should look like handmade ones
- \*the designer or draftsman coding input data should need only be concerned with coordinates, class number and part identifications (i.e. code numbers for parts)
- \*operation with only 64K bytes of computer memory

In addition to coded input to the program, information is automatically drawn from a permanent data bank of descriptions and dimensions for standard components such as flanges, fittings and valves. Each component has a unique part of "code" number. Another permanent data bank which is automatically accessed contains graphical symbols for each part -- these symbols appear on the computer generated isometrics. And finally, a third data bank contains material specifications or classes which contain the lists of all acceptable parts within each class. These three data banks can be updated, as necessary, without difficulty.

In operation, the program not only accesses the three data banks based upon coded input, it also checks the validity of the input. For example, two different pipe sizes will not be "connected" without a reducer being specified. An isometric

and bill of material is produced only if all input is found valid.

As the basic program described above proved successful, additional capabilities added with time included:

- \*summary bill of material for an entire project
- \*summary of insulation requirements based on component type, temperature range and length of pipe
- \*summaries of heat tracing materials, including insulation requirements
- \*summaries of surfaces requiring painting
- \*weld summaries
- \*material unit costs for use in estimating or budget control
- \*fabrication labor costs
- \*erection manhours for each isometric

APPENDIX B

GLOSSARY OF TERMS

The following glossary of terms has been prepared specifically for this report. Accordingly, many definitions are presented in the context in which the words or phrases were used in the body of this report and may not be entirely general.

|                              |                                                                                                                                                                                                                                                                                                                                       |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Analytical                   | to arrive at a result by mathematical calculation.                                                                                                                                                                                                                                                                                    |
| Analytical<br>Photogrammetry | the method in which images of specific points of interest within a scene are measured on photographs -- these measurements are then computer processed to form a three dimensional digital model of the scene which, in turn, may be further processed by digital means for final presentation of numerical and/or graphical results. |
| Attribute                    | specific identifying information belonging to any part of a piping system; for example, a branch may have attributes which further define that it is an extruded branch of diameter 2-inches.                                                                                                                                         |
| CRT                          | abbreviation for cathode ray tube.                                                                                                                                                                                                                                                                                                    |
| Camera Station               | see exposure station.                                                                                                                                                                                                                                                                                                                 |
| Cathode Ray Tube             | a television-like device used for fast display of numerical or graphical computer input and output when a hard-copy record is not immediately required.                                                                                                                                                                               |
| Comparator                   | see monocomparator.                                                                                                                                                                                                                                                                                                                   |
| Computer-aided               | to be partially assisted by computer action; for example, the calculation of pipe bending data based on pipe geometry input to the computer by a user.                                                                                                                                                                                |
| Convergence                  | tilting of the optical axes of adjacent photographs so that the axes tend to intersect rather than remain parallel or diverge.                                                                                                                                                                                                        |
| Design Model                 | a model whose final form is based largely upon engineering design decisions exercised throughout construction of the model; decisions are guided initially by ship or plant specifications and general diagrammatic traditional design at the drafting board is not performed.                                                        |
| Digital                      | numerical; expressed in terms of numbers usually in the context of a computer environment.                                                                                                                                                                                                                                            |

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| Digital Model    | a scaled three dimensional rendition of a scene photographed, generated by computer processing of comparator measurements of images of specific points within the scene or through point-by-point digitizing of an optical model in a stereoplotter; the digital model consists only of those points of the scene whose images are measured. |
| Digitizer        | an instrument for recording relative locations of points - digitizing tables such as used in mold lofts record only in two dimensions whereas a stereoplotter can record in three dimensions.                                                                                                                                                |
| Encoder          | a device for continual monitoring of the position of a measuring reticle along an axis of a digitizer.                                                                                                                                                                                                                                       |
| Event            | an occurrence along a run of pipe such as its starting point, ending point and intervening fittings, valves, branches, etc.                                                                                                                                                                                                                  |
| Exposure Station | the location from which a photograph is taken.                                                                                                                                                                                                                                                                                               |
| Format           | a defined order in which data are collected together and presented to a computer program or are output from a computer program.                                                                                                                                                                                                              |
| Geometry         | an unambiguous and complete numerical description of the locations of pipes and their fittings, etc. in three dimensional space.                                                                                                                                                                                                             |
| Graphical        | a presentation of data in the form of a line drawing such as a map.                                                                                                                                                                                                                                                                          |
| Hard-copy        | a presentation of data on a reproducible medium; for example, output from a computer printed on paper.                                                                                                                                                                                                                                       |
| Hardware         | tangible equipment such as a computer, camera or digitizer.                                                                                                                                                                                                                                                                                  |
| Identifier       | see attribute.                                                                                                                                                                                                                                                                                                                               |
| Interactive      | a dynamic man/computer operation where in the-user sits at a terminal and "converses" with the computer; either may ask pre-programmed questions of the other and provide answers to the same.                                                                                                                                               |

|                   |   |                                                                                                                                                                                                                                                                                                  |
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| Measuring Reticle | - | a dot or cross-hair within a stereoplotter or comparator used to sight upon specific points of interest or to trace features for the purpose of digitizing or producing graphical product.                                                                                                       |
| Mechanize         |   | automate.                                                                                                                                                                                                                                                                                        |
| Mini-computer     |   | a physically small computer primarily intended to monitor and control operation of equipment on an instantaneous basis.                                                                                                                                                                          |
| Model Base        |   | a rigid table upon which a model or portion thereof is constructed.                                                                                                                                                                                                                              |
| Monocomparator    |   | a device for measuring relative locations of images of points on a photograph; the instrument consists of an x-axis, a y-axis, a stage upon which the photograph is lain, a measuring reticle and viewing optics.                                                                                |
| Monoscopic        |   | a two dimensional perception.                                                                                                                                                                                                                                                                    |
| Off-line          |   | to perform a function as a second step usually at a point in time removed from an initial action and oftentimes in a different place; for example, to computer generate data for plotting an isometric and recording the data on magnetic tape for subsequent input to a plotting machine.       |
| On-line           |   | to perform a function just as soon as it can be executed and usually in the same location at which the function became ready for execution; for example, to computer-generate data for plotting an isometric with the plotting proceeding on a plotting machine wired to the computer.           |
| Optical Axis      |   | that line which passes through the optical center of the lens and is perpendicular to the focal plane of the camera.                                                                                                                                                                             |
| Optical Model     |   | a three dimensional rendition of a scene photographed, created in a stereoplotter by projecting light through the original negatives or transparent copies thereof; the separately projected images are viewed with special optics so as to fuse like images and create the perception of depth. |

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|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Orthographic           | a pictorial or graphical presentation of an object which is of equal scale over the entire presentation.                                                                                                                                                                                                                                                                                                                                          |
| Photogrammetry         | the science of extracting reliable two or three dimensional measurements of a scene from one or more photographs of the scene.                                                                                                                                                                                                                                                                                                                    |
| Ray                    | a pencil of light or a mathematical line between a point on an object, its image on a photograph and which passes through the camera lens.                                                                                                                                                                                                                                                                                                        |
| Relative Orientation - | the geometrical relationship of one photograph to another at the times at which they were taken; expressed mathematically in terms of the angular relation of the optical axes and coordinate locations of the exposure stations.                                                                                                                                                                                                                 |
| Reticle                | a dot or cross-hair used to sight upon points of interest in a measuring instrument.                                                                                                                                                                                                                                                                                                                                                              |
| Signalize              | to place an identifying mark such as a target on an object.                                                                                                                                                                                                                                                                                                                                                                                       |
| Software               | computer programs.                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Standard Deviation -   | a statistical measure of the probable accuracy of a number whose value is the result of more than one independent measurement or calculation; a one-standard deviation accuracy figure means that the difference between the measured or computed value and the true value will probably be less than or equal to the standard deviation 67 out of 100 times; as a practical matter, tolerance is equal to 2 to 2.5 times the standard deviation. |
| Stereometric           | three dimensional in nature or having the capacity to produce a three dimensional result.                                                                                                                                                                                                                                                                                                                                                         |
| Stereoplotter          | a projection instrument used to create a three dimensional optical model from a pair of overlapping photographs; see optical model.                                                                                                                                                                                                                                                                                                               |
| Stereoscopic           | a three dimensional perception.                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Tag                    | an adhesive label upon which identifying information is placed and which is attached to a component within a model.                                                                                                                                                                                                                                                                                                                               |

|               |                                                                                                                                                                                                 |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Target        | a mark such as a dot or cross which is used to unmistakably identify a location upon which a sighting is to be made by a measuring instrument.                                                  |
| Terminal      | a device through which a user can enter and/or receive information, usually in connection with computer processing.                                                                             |
| Triangulate   | in analytical photogrammetry, the process of digitally projecting rays from corresponding images of the same point on two or more photographs to their intersection at that point in the scene. |
| Wire and Disc | a model building technique wherein pipes are represented with thin wires and pipe diameters are represented by discs attached to the wires; diameters of the discs are true-to-scale.           |

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