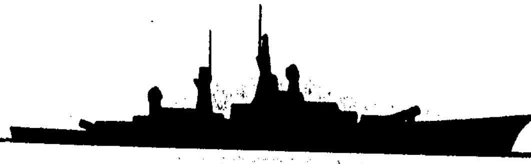

MATHEMATICAL SHIP LOFTING, Part I. Theory.

ART 1. THEORY

Technical Report 1.0.0.1
Volume 2 of Final Report
Contract NObs-4427

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TODD SHIPYARDS CORPORATION

LOS ANGELES DIVISION SAN PEDRO CALIFORNIA

FORWARD

This publication is one of six volumes of the final report on Mathematical Ship Lofting and Numerical Control of Shipyard Fabricating Equipment. The work reported on herein was performed under Bureau of Ships Contract No. NObs-4427, Code 770, during the period from April 1961 to March 1963.

The volumes of this final report have the following titles:

Vol. 1. Project Summary Report (Technical Report 9.0.0)

Vol. 2. Mathematical Ship Lofting -
Part 1. - Theory (Technical Report 1.0.0-1)
Part 2. - Operating Manual (Technical Report 1.0.0-2)

Vol. 3. Mathematical Ship Lofting - Summary Report (Technical Report 1.5.0)

Vol. 4. Programming System for Numerically Controlled Flame Cutting of Ships Parts - Operating Manual (Technical Report 5.0.0)

Vol. 5. Development and Testing of Programming System for Numerically Controlled Flame Cutting of Ships Parts - Summary Report (Technical Report 5.5.0)

Vol. 6. Numerically Controlled Shipyard Fabricating Equipment - Summary Report (Technical Report 3.0.0)

The work was accomplished by the Research and Development Group of the Los Angeles Division of Todd Shipyards Corporation, San Pedro, California. Mr. Thomas G. Smith was Project Manager for the work, and Dr. Henry A. Schade of the University of California, Berkeley, was Principal Consultant.

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ABSTRACT

This report summarizes the work performed by Todd Shipyards Corporation under Bureau of Ships Contract NObs-4427, during the ~~period from April 1961, to March 1963, in~~ the development of a mathematical lofting system, a parts programming system for numerically controlled flame cutting, and numerically controlled shipyard fabricating equipment, is described.

Program accomplishments, conclusions, and recommendations are ~~have been~~ summarized.

CONTENTS

Section I

INTRODUCTION

BACKGROUND

In March 1961, the Todd Shipyards Corporation was awarded Contract NObs-4427 for the purpose of developing a system for Mathematical Ship Lofting and Numerical Control of Shipyard Fabrication Equipment.

Much work had been done throughout the world in an effort to mathematically fair ships hulls, but no one had developed a method which satisfactorily met the requirements of the Bureau of Ships, nor had any method been expanded into a full mathematical lofting system capable of meeting the production needs of a shipyard.

In the area of numerical control of fabrication equipment, several numerically controlled flame cutting machines were under development and/or test in Europe, and one was being constructed in the United States. A production-oriented, economical method for programming these machines to cut ships parts had not been demonstrated.

Little work was under way to develop other numerically controlled fabricating equipment for shipyard use.

Upon award of a contract, Todd organized the project and immediately undertook to determine the state-of-the-art. Foreign shipyards and research centers known to be working on the problems were visited by a Research Team. Some shipyards, universities, and other industries in the United States were also contacted. These visitations, reported in Reference 1, provided the Project with necessary knowledge of the state-of-the-art.

The next step was to establish criteria for the proposed mathematical lofting and numerical control systems. The only difficulties encountered were in reducing the subjective word, "fairness" to a mathematical definition. The Bureau of Ships approved the criteria (Reference 2), on August 7, 1961.

A literature search for methods of defining ships' hulls and other surfaces was next undertaken. All known approaches were then reviewed, including those under development in Europe, and compared against the criteria. As a result of this investigative work, it was decided that Dr. Feodor Theilheimer's representation of the cubic equation offered a form of notation best meeting the criteria. Reference 3, submitted in March 1962, reported the results of this study.

Meanwhile, work had begun on two separate approaches to the problem of mathematically defining ships, investigations were started on determining the shipyard computer language requirements to define ships' parts, and investigations of various forming methods were undertaken.

In the area of mathematical lofting, and in order to meet the criteria, a method was developed for checking the naval architect's offsets for gross errors in measurements or transcription. This method, complete with computer routines, was submitted (Reference 4) on June 1, 1962.

By April 1962, work had progressed on the two methods of fairing to the point where it was necessary to make the decision to drop one and put all the effort on a single method. The first method of fitting individual plane curves to waterlines and stations and combining them by an iterative routine, was discontinued in favor of the method of fitting a surface equation to waterlines and stations. The surface fitting method not only offered a potential capability of meeting all of the requirements of the criteria as established, but also provided a method capable of accepting the further constraints which would have to be imposed in order to define end conditions. It was also decided that a surface equation offered a greater potential for other uses than did equations describing only waterlines and stations.

The method finally selected and the mathematical theory developed was reported in Reference 5, submitted June 11, 1962. Work then proceeded on writing the computer programs to apply this theory to the problems of fairing ships hulls.

While the work was proceeding on the development of the mathematical fairing concept, a state-of-the-art study on various forming methods was undertaken. This study was submitted (Reference 6) on June 8, 1962. From this study it was determined that the stretch forming process held the potential for forming ship frames and plates by numerical control. This method of forming does not employ the principles inherent in present methods which make them so difficult to control numerically.

Work then proceeded on the conceptual design of stretch presses for forming ships' frames and plates. A unique method for controlling an adjustable die was conceived and submitted to the Bureau as an Invention Disclosure (Reference 7).

In order to form plate by the stretch press process, excess material must be left on the plate for the gripping jaws. This imposed the requirement that the shell be cut after forming rather than before forming, as is done by conventional methods. To overcome this problem, a special-purpose burning machine was conceived, together with a new method of defining the edges of shell plate. Two invention disclosures were submitted as a result of this work (References 8 and 9).

Paralleling the design effort was the development of a procedure for making a cost analysis and comparison of numerically controlled methods versus conventional methods. This procedure was submitted for Bureau comment and approval on June 11, 1962 (Reference 10).

In June 1962, the Bureau determined that the mechanical design and cost study work had been completed to the extent desired, except for final reporting. Work was then discontinued on this phase.

By this same time, the mathematical fairing theory had been implemented on the computer and was producing satisfactory surfaces defining hull areas of up to eight waterlines by ten stations. The Bureau then determined that efforts toward developing this portion of the lofting system into a production system were not as desirable as those aimed at adding capabilities to the overall lofting system. The direction of the effort was changed accordingly.

The work of increasing the capability of the mathematical lofting system proceeded, and on June 15, 1962 (revised August 24, 1962), a method for mathematically developing shell plate was submitted (Reference 11). In the following months, system capabilities were expanded to define bows and sterns, decks, sight edges of structural intersections with the hull, inner edges of web frames, and all of the other information produced by the conventional graphical loft.

Development work had been proceeding on a numerical control programming system with a study of all of the steel parts of a guided missile frigate and a C-4 class cargo ship. This study determined what geometric description capabilities a programmer would require in order to describe all of the ships parts to a computer to produce numerical control tapes. Other system requirements, such as methods for checking parts programs and for nesting multiple parts on a single plate, were established. The requirements for the System, together with the specifications for a programming language, were presented as a technical report on September 10, 1962 (Reference 12).

Work had proceeded on the development and testing of the Parts Programming System employing the IBM Corporation's "AUTOMAP" programming language. This language had been augmented, within the capacity of an IBM-1620-60K computer, to meet the shipyard specifications previously established.

The final months of the program were spent in production testing the numerical control parts programming system by cutting parts for the DLG-33 and in documenting the mathematical lofting system for use and evaluation by others.

Section II

ACCOMPLISHMENTS

MATHEMATICAL LOFTING

A full mathematical lofting system has been developed and presented as Volume No. 2 of this final report.

Starting with the naval architect's preliminary lines and offsets, the System has the capabilities for:

- Smoothing the original offsets, relocating points which have been measured or recorded erroneously
- Fitting a mathematically fair surface to those points
- Defining sight edges of shell plate, longitudinal frames and stringers, deck edges and knuckles
- Defining waterlines, stations, buttocks lines or diagonals at any intervals
- Preparing numerical control data
- Plotting lines drawings
- Developing shell plate and stringers
- Determining frame and plate bending offsets
- Determining inner hull and deck camber offsets
- Defining the inner edges of web frames

Part 1 of Volume 2 contains the mathematical theory upon which the System is based, and Part 2 is the Operating Manual for the System. In addition to operating instructions, Part 2 contains the computer programs, flow diagrams, and listings, and sample problems for each program.

The System capabilities and deficiencies, tests, and economies are discussed in Volume 3. This volume also presents certain conclusions about the System and makes recommendations for its use and improvement.

NUMERICAL CONTROL PROGRAMMING

A complete production programming system for numerically controlled flame cutting of ships parts has also been developed and is presented as Volume 4 of this final report. A companion document to Volume 4 - the IBM Corporation Parts Programming Language, AUTOMAP II Manual - has also been submitted. AUTOMAP, IBM's general purpose, small computer language, was expanded to meet the needs of the shipyards by IBM personnel working directly with Project personnel.

With this programming system, employing the AUTOMAP II language, a parts programmer has all of the capabilities necessary to produce tapes for cutting multiple ship parts from single plates. He has this capability whether he receives his original data as offsets from a conventional graphical loft or as equations provided by the mathematical lofting system developed under this contract.

Though this system has, of necessity, been implemented for use on a specific set of equipments, it will serve as a useful, cost-saving guide in the development of other systems for any combination of other equipments.

A discussion of the programming system, its production use and costs, together with a study of available parts programming languages, is presented in Volume 5 of this final report.

NUMERICALLY CONTROLLED FABRICATING EQUIPMENT

Volume 6 of this final report presents the results of all mechanical design work accomplished under this contract to June 1962. The discussion contained in this report indicates the feasibility of replacing all conventional hull fabricating equipment now requiring graphical templates in their non-automatic operation, with numerically controlled equipment. This work was not carried to the extent of demonstrating feasibility.

In addition to the discussion, this volume contains

- Preliminary specifications for numerically controlled flame and plasma arc cutting machines
- Design concepts and specifications for digitally controlled frame and plate stretch forming presses
- A method and machine design concepts for cutting shell plates after forming
- A procedure for making a cost analysis and comparison between various production methods and equipments

Section III

SUMMARY OF CONCLUSIONS

MATHEMATICAL LOFTING

The mathematical lofting system, as implemented to date, has adequately demonstrated the feasibility of the mathematical theory employed. Not only has the feasibility been demonstrated, but it has also been demonstrated that it is a practical, economical approach, capable of providing any shipyard with all of the general information provided by conventional lofts. It is not a "black box" system. That is, the method has not been implemented with sufficient computer programs to permit complete lofting without manual intervention and decisions. The Bureau determined in June 1962, that such further implementation would come after feasibility has been demonstrated, and when the decision is made to use the system productively.

In addition, the latter months of the contract were spent developing the methods for defining bow and stern surfaces and for producing other loft information, with the result that the system was tested by trying to fully define only one ship. This single test showed that the system was lacking in completeness. It did not satisfactorily join faired surfaces, nor was it reliable in defining flat bottoms. It is apparent there is a need for additional work before the system is complete and ready for use by production forces.

The method employed in meeting the established criteria has overcome the basic problems in mathematical lofting which heretofore appeared insurmountable. It offers to the shipbuilding industry a greater potential for economical use of numerically controlled fabrication processes. If used early in the design phase, it offers the architect the potential for employing automated drawing machines in his daily work.

PROGRAMMING FOR NUMERICALLY CONTROLLED FLAME CUTTING

Production testing demonstrated that the numerical control parts programming system is capable of producing tapes for cutting the most complex of ships parts. Programming costs appeared to be economically competitive with the conventional templating process.

One must not expect to obtain immediate cost reductions through the use of the system alone. Other changes must also be made, particularly in the area of design and drawing dimensioning, before significant cost savings will be realized. Also, the system is more economical when mathematical lofting is employed, and the more parts are mathematically defined, the more efficient the system will become. For example, it is within the state-of-the-art to automate numerical control programming of similar, though not identical parts.

Conventional templating methods have about reached their full cost cutting potential, whereas numerical control programming, in its infancy, is economically competitive today and has a good cost-reducing potential - the limit of which is still unknown.

NUMERICALLY CONTROLLED FABRICATING EQUIPMENT

It has been demonstrated that mathematical lofting and numerically controlled flame cutting is economically feasible. A question still remains as to the feasibility of numerically controlling other fabricating equipment now requiring templates in their operation.

The equipments conceived under this contract appear to offer feasible means of forming frames and shell plates by numerical control. Much work remains to be accomplished to determine the mechanical feasibility of the methods before cost determinations can be made.

The equipments conceived are high-production tools requiring a good volume of work to justify their acquisition cost. It is conceivable that cost reductions will come through the use of this equipment only to larger yards having high-volume production, or to smaller yards through the use of central forming facilities serving several yards. The central forming facility will be made possible through the use of precise mathematical definition of hull form.

Section IV

SUMMARY OF RECOMMENDATIONS

MATHEMATICAL LOFTING

Though the method employing linear programming to fit a fair surface to the naval architect's offets has been demonstrated as practical and economically feasible, the only full ship test which time permitted to be made, proved that the system had certain technical deficiencies which remain to be corrected to improve its reliability and to make it a workable production system.

Overcoming these deficiencies does not require any state-of-the-art breakthroughs, but is generally a matter of straightforward application of mathematics and computer programming. This work should be accomplished before the system is placed in full production usage. Efforts can then proceed on improving the economy of the system itself.

PROGRAMMING FOR NUMERICALLY CONTROLLED FLAME CUTTING

Numerical control and the new techniques made possible thereby, offer the Navy and the shipbuilding industry new tools with the potential for reducing the cost of designing and constructing ships. The Programming System (Volume 4) offers a means for taking the initial step toward exploiting the potential of these new tools.

Tests accomplished under this Project were limited to producing random complex parts to test the capabilities rather than the economies of the System. It is therefore recommended that the economies of a mathematical lofting/numerically controlled flame cutting process be determined. This can be accomplished by a pilot installation where the lofting and programming group is given full responsibility for producing all of the parts for a large section of a ship.

It has been determined that the greatest potential for cost savings through numerical control will come through designing ship structure (and identifying it on the working plans) for cutting by numerical control. For example, the designer can strive to design hull structural parts in such a manner that as many parts as possible can be described by standard symbolic parts programs, thus eliminating the need to write separate programs for similar parts.

Further, it is within the state-of-the-art to design certain ship structures with the aid of a computer and have the computer produce drawings and/or numerical control tapes directly, eliminating a substantial portion of the drawing and programming costs.

It is in these areas that the "tools" developed under Contract NObs-4427 can be exploited to effect substantial cost savings in the design and construction of ships.

In expanding the use of computers and numerical control in design and cutting of ships parts (and in other hull fabrication applications) care must be taken to avoid developing a computer system which is too sophisticated for the needs. Cost and simplicity must be given first consideration.

NUMERICALLY CONTROLLED SHIPYARD FABRICATING EQUIPMENT

No further effort need be expended on determining the mechanical feasibility of numerically controlled flame cutting. The economies of a full production system, though appearing favorable, are as yet unknown.

A pilot installation in a shipyard could provide this necessary information.

The mechanical and economical feasibility of other numerically controlled fabrication processes should be determined to the extent necessary to demonstrate the advantages or disadvantages of such processes.

Section V

REFERENCES

Reports submitted to BuShips by Todd Shipyards Corporation, under Contract NObs-4427:

Reference Number	Technical Report No.	
1		Summary of Progress to June 1, 1962
2	1.1.0	Proposed Criteria, July 17, 1961
3	1.1.1	Evaluation of Mathematical Lofting Methods in Current Use, and Comparison with Developed Criteria, March 1, 1962
4	1.2.1a	Mathematical Lofting - Point Smoothing - Method of Second Differences, June 1, 1962
5	1.2.3	A Method for Mathematically Defining and Fairing Ships' Form Using Linear Programming, June 11, 1962
6	3.1.0	State-of-the-Art Studies on Processes Considered for the Fabrication of Ships Parts Under Digital Control, June 8, 1962
7	3.4.3	Disclosure of Invention: Simplified Method of Cutting Contours of Shell Plates after Forming, March 26, 1962
8	ID-3	Disclosure of Invention: Control Device for Angular Movement of X-Y Slides, May 10, 1962
9	3.4.1/ 3.4.2	Disclosure of Invention: Position Control for Multiple Tools, Feb. 20, 1962
10	7.1.0	Procedure to Establish a Cost Analysis and Comparison Between Different Production Methods, June 11, 1962
11	1.2.4ga	System for Mathematically Developing Shell Plate for Ships' Hulls, June 15, 1962 (Rev. Aug 24, 1962)
12	5.4.0	A Programming System for Numerically Controlled Flame Cutting of Ships' Parts, September 10, 1962