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FUNCTIONAL REQUIREMENTS OF A TARGET DESCRIPTION SYSTEM FOR VULNERABILITY ANALYSIS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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This paper defines the functional requirements of a target description (geometric modeling) system for vulnerability analysis. Included are discussions of one philosophy of a new target description system in the context of present computer technology and the intended use of the target description system, required outputs, and new methods of generating and modifying target descriptions.

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I. INTRODUCTION

One of the required steps for performing a vulnerability analysis of a vehicle is to obtain a set of data that describes the vehicle in terms which the various vulnerability models can use. Briefly, this process involves generating a computer model of the target (the target description), then operating upon the model with various application codes which produce the desired target data in the proper format. The target description method presently used by the Ballistic Research Laboratory (BRL) is based upon combinatorial geometry and is called COMGEOM. The application codes which produce the various outputs are collectively called GIFT.[1,2] Together the COMGEOM description model and GIFT codes make up the BRL's target description system. The significance of a target description system is explained in the Vehicle Descriptions Section of "Plans for Updating the Armored Vehicle Lethality/Vulnerability Methodology and Data Base," BRL, 22 August 1977. That section discusses the BRL's present target description system and the types of features that would be desired in an improved system. It is suggested that Task 46 in that document be reviewed also.

Computer technology has advanced to the point where computer graphics and target description models can be coupled with integrated data-base systems to provide a wider range of decision-making information than was formerly feasible. Such systems can be developed to yield the following payoffs: a reduction in data redundancy, improvement in the utilization of storage space, an aid in servicing requests for ad hoc information, minimization of program development costs, and a tool which fosters user/data-base interaction.

The purpose of this paper is to define the functional requirements of a target description system (TDS) and to provide a very limited tutorial on computer technology. The underlying philosophy of a new target description system in the context of present computer technology and the intended use of the target description system are discussed; the required outputs of a TDS are defined; and new methods of generating and modifying target descriptions are described.

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[1] Lawrence W. Bain, Jr. and Mathew J. Reisinger, "The GIFT Code User Manual; Volume 1, Introduction and Input Requirements (U)," Ballistic Research Laboratory Report No. 1802, July 1975. (AD #B006037L)

[2] Gary G. Kuehl and Lawrence W. Bain, Jr., "The GIFT Code User Manual; Volume II, The Output Options," unpublished draft of BRL report.

II. UNDERLYING PHILOSOPHY

The BRL has a computer processing system, the CDC CYBER System, that reflects modern computer technology. It is a flexible, multiprocessing, time-shared system that supports interactive and batch computing. It has an online file system, remote terminals - both hardwired and dial-up, interactive graphics (including direct-view storage tube, raster scan, and refreshed vector generating types), an offline plotting facility, and various software packages, including a number of data-base management systems. Furthermore, some of the system's components offer impressive capabilities in their own right; each Vector General Graphics terminal, for example, is driven by a modern midi-computer with 96K words of semiconductor memory, floating point and memory management hardware, disk storage, card reader, line printer/plotter, and console terminal. In addition, it can run in a stand-alone mode, i.e., not connected to the CYBER, and, via a multi-user disk operating system, supports an extended FORTRAN, extensive file-handling packages, an editor (much better than the CYBER editor!), and a program overlay function.

We now have the tools at hand to apply advanced technology and computer science to vulnerability analysis. We should make these tools work for us and not cling to old methods unless reevaluation indicates potential adaptation to the new direction that vulnerability analysis is taking.

Software is evolving as a tool for the vulnerability analyst just as it did for the programmers many years ago. Then everyone had to write programs in actual machine instructions. Contrary to popular belief, coding in machine instructions is easy; however, using machine language takes too much time! Also, the process is loaded with pitfalls; one little "0" where there should be a "1" can create chaos. Someone came along with the idea of letting the computer do most of the bookkeeping involved with programming - calculating addresses, offsets, and the like - and assemblers and assembly languages were born. Then all one had to do was write programs with mnemonics like "mov" to indicate a "move" instruction and "addr" to indicate an address (which the computer calculated so it automatically substituted the actual address whenever it encountered "addr" in the program). Of course the programmer still had to keep track of scaling factors (many computers only worked with numbers between zero and one), make sure that words were allocated for variables and constants, and ensure that programs didn't inadvertently wipe out instructions by overflowing a data area. Even so, the change to assemblers was an improvement of an order of magnitude over the old way. Many people were happy with that; but fortunately, other people who thought the computer was a tool for its own use developed high-level languages (FORTRAN, for one) and operating systems. Now we store a program or output onto a file without worrying about how or where to transfer the patterns of 1's and 0's to a disk pack. And, if we take the trouble to properly protect those files, we don't even have to worry about wiping them away because of a slip of the finger at the keyboard.

The present CYBER system comprises vast, shareable resources such as central processing units, peripheral processing units, communications processors, memories, disk storage units, magnetic tape units, line printers, card readers, card punches, terminals, and many others. The NOS/BE-SCOPE operating systems manage those resources for us. In the same manner, a computerized target description system can be thought of as a large system of resources - such as the ability to produce illustrations of a vehicle, simulated engineering drawings of a component, presented areas and shotlines; the ability to warn us when we've tried to make two components occupy the same space; or the ability to make changes in a target description almost with the same ease as cutting and pasting with paper. What we need is a system to manage those resources so it will be easy to exploit the tools that we have available. We need to break away from the present necessity of keeping track of where each card goes in the "solids" table when we want to modify a target description.

As an example, using COMGEOM/GIFT, consider the simple exercise of modifying an already existing target (described by someone else). Assume that the modification is limited to replacing a tank's fire control system with another system different in both shape and position in/on the vehicle. Further assume that a person experienced in generating a COMGEOM description (a "COMGEOMer")is available to advise which shapes (solids) to select from the library of shapes and how to combine them to best approximate the shape of the new component. The user must determine the vehicle's coordinate system and define each solid, its size and position in that vehicle, and specify the combination of solids to make up the component. After that, all that remains to be done is to remove the old component from the description and insert the new. This last "step" is a non-COMGEOMer's headache! The process is as follows:

1. All solids which form the component to be deleted must be replaced by "dummy" solids to keep the sequence of the table of solids intact. (It may be possible to "reuse" some of the old positions in the table, but that is a little more complicated.) The proper sequence must be maintained because all specifications for combinations of solids in the region table refer to actual order of occurence in the solids table; the COMGEOMer cannot assign a numbering scheme. If the original sequence of solids is not conserved, the whole region table must be redone.

2. The new solids are added to the end of the solids table, and their actual place (numeric order) in the table is noted.

3. The specification for the old component's combination of solids in the region table is replaced with the new specifications, based upon the numerical order of the solids in the solids table.

4. The region identification table is altered to show the changes.

Although it is no longer necessary to sort through boxes of cards to make these types of changes, a similar action must be performed on the CYBER system via UPDATE directives.

Let us now consider a similar situation in which we have a new and "magic" target description system at our service. Assume that the new fire control system has been described (generating descriptions in this system is fast and easy) and is denoted by "XFC-A3"; the one being replaced is denoted by "FCA1." The user must modify a copy of the file that defines the tank; for example:

```
 1   Title, TANK, US, Model M60A3, VMT v3.5
 2   Description history:  DHfile
 3   Define, M60A3X
 4   HULL:  M60front-hull
 5          M60left-hull
 6          M60right-hull
 .                .
 .                .
 .                .
27  TURRET
 .                .
 .                .
32  FIRE CONTROL:  FCA1
 .                .
41  TAILPIPE
<end of file>
```

All the user has to do is replace "FCA1" with "XFC-A3."

Let us look into a possible interpretation of that file:

Line 1: Any operation or subsequent processing which uses or produces an identification, or title, will use the characters "TANK, US, Model M60A3, VMT v3.5."

Line 2: "DHfile" is a file that contains, in narrative form, comments, assumptions, or information, which relates to why, how, what, or who produced the various parts of the description. The DHfile is analogous to program documentation (FORTRAN "comment" cards).

Line 3: Any reference to "M60A3X" in any associated interactive or batch mode will mean that this target definition is to be used.

Line 4: The tank's hull is an assembly made up of the pieces M60front-hull, M60left-hull, etc., and any reference to "HULL" will include those subassemblies M60front-hull, M60left-hull, etc.

Line 27: The file "TURRET" contains specifications for the turret assembly. That file can have the same type of definitions as the tank definition file:

```
 1   Title, TURRET, M60A3 fitted with XM1001 Gun
```

```
2  Define. TURRET-XM1001
3  Position. X=0., Y=0., Z=2.75; inches
4  Orientation. Az=0, El=0.: degrees
.              .
.              .
.              .
11  TURRET-ARMOR:  M60A3turrent-top
12              .
.              .
<end of file>
```

Line 32: The component of interest in this example.

Although the above set of files is an imaginary example, the concept is valid. Command files, indirect files, and the like are common modi operandi in data processing.

The feature that will tie all the target description resources together into a very efficient system will be a data-base management system (DBMS) that will create, organize, maintain, modify, and interrogate those files which make up target descriptions. A few years ago, the use and implementations of DBMSs left a lot to be desired. As a result, there are still those who have a bad opinion of their utility. However, that state-of-the-art has progressed such that today there are numerous (over 25 DBMS software packages are commercially available) DBMSs that are very efficient. They differ mainly in the services they offer. With a DBMS, we do not have to be concerned about where the positional data for a component are stored (unless we want to know). For example, when we sit at the graphics console and rearrange the components in a vehicle in an effort to reduce the vehicle's vulnerability, it is the DBMS that keeps track of the actual positional data of the components. If we want to know what those data are, they can be displayed immediately. The possiblities are almost endless.

One principal advantage of using a DBMS is that once a component is described, it is available for inclusion (or modification) into any target description. For example, the component might be a "standardized" piece of communications gear used in tanks, trucks, etc. Such a system would allow the user to optionally replace all the gear's flat slotted screws with oval-headed phillips screws at runtime. This is a ridiculous example but it emphasizes the power of the system. The attractive feature of a DBMS is that only data that are needed for a particular application, or input, need be processed--not the whole target description. Finally, a DBMS is flexible; instead of casting in concrete all formats for all data storage, as is the case now, the DBMS offers the capability to easily change data, descriptions, even formats. For example, after a target description system is developed and implemented, suppose that the component vulnerability models need data that are not in the descriptions. A good DBMS will allow redefinition of the target description structures and modification of all existing descriptions to include the new parameters.

III. OUTPUTS

Although this section is entitled "outputs," do not be misled into thinking that all of these "outputs" are conventional, either printed on the line printer or plotted. On the contrary, because the target description system is envisioned as a system and not just a collection of codes, the modules which make up the system are expected to work in concert; one module's output may be another module's input - indeed, the user may never even see some of the "output"!

As a minimum, any or all of the following are required services - broadly classified as output - which must be available either in an interactive mode, batch mode, or both:

A. Illustrations of the target or its components from the front, top, side, or any view or section through the target. These illustrations (and all illustrations referred to below) must be able to be displayed on all of the BRL's graphics devices, such as the Vector General Graphics terminals, the hard copy devices attached to these terminals, Tektronix storage tube terminals like the 4014-1, and the Calcomp plotting facility. This output will close the loop in the interactive generation/modification phase of the description process, thereby giving the analyst immediate visual feedback.

B. Simulated engineering drawings of the target or its components. Also, there should be available an automatic dimensioning capability.

C. A method to give warnings whenever an analyst attempts to construct components or targets in ways which are physically impossible. For example, functions which check for interference of components (two or more components attempting to occupy the same space) or for voids (gaps existing where two components should meet) are required.

D. Projected areas of the target or its components from the front, top, side, or any view.

E. Perimeter of the target or components, and centroids of the area from any view.

F. Volume of the components.

G. Angular and spatial values between the components of the target and between components and specified patterns, such as cones which represent spall spaces. Values must include (but are not limited to) all those types currently available with the GRID and RIP routines in GIFT. Additionally, methods for obtaining these types of values must be able to account for the dimensions of projectiles and not represent them only by "shotlines." Problems in fusing and ricochet will require these dimensional considerations. Hence, dynamic interference detection will be required.

H. Intermediate results (quite possibly in internal binary form) for operations which are suspended for some reason but which will be resumed.

Finally, given that components' densities or types of material are available:

I. The moment(s) of inertia of the target or components from any view.

J. The center of gravity of the target or its components.

K. The weight of the target or its components.

It is expected that all of the outputs above which correspond to those that are currently available and used as input to vulnerability programs will be available, optionally, in the same formats that are produced by the GIFT codes.

IV. GENERATING AND MODIFYING TARGET DESCRIPTIONS

The target description system should be structured to aid in building and correcting ("editing") target descriptions as they are generated. Its man/machine interface must permit rapid entry of vehicle data from engineering drawings, measurements, design-stage specifications, etc. Numerous interactive, automated approaches for generating descriptions should be available. It is likely that the Vector General Graphics systems will be the primary tool for this phase. Automated procedures for transforming measurements taken directly from engineering drawings (when they exist!) via the data tablet are required. For example, algorithms exist for the reconstruction of objects from their orthographic views (of course these algorithms are limited in scope and not foolproof for the general case). An implementation of this type of algorithm, coupled with the "editing" feature above, will greatly speed the generation of descriptions when drawings are available.

Sometimes actual components (or a complete vehicle, perhaps delivered by a defector) are at hand and descriptions are needed of them. The present method involves a lengthy process of measurement-taking, the making of drawings, and the conversion to target description format. What is needed is a method to automatically produce a description from the actual object, say by scanning some form of images of the object and mathematically reconstructing the object from the scanning data. Although the solution to this problem has not been attempted, to the author's knowledge, he believes that it is theoretically feasible to develop such a capability. (Methods exist for mechanically, or opto-mechanically, "feeling" the surface of an object, but these methods do not lend themselves to map the exterior of a tank easily.)

A surface generation and manipulation package is needed where a low-detail, design-stage vehicle must be described, possibly when only specifications, a narrative description, or just an artist's rendering is available. This will allow the user to "sculpt" shapes at will and then transform those shapes into a target description. Most surface generation packages define shapes with some sort of grid or mesh technique which typically produces contours in space. Indeed, perhaps the inverse, producing a mesh or grid network from a completed description, will be a requirement of a component vulnerability code which simulates the effects of blast using a finite-element analysis. An excerpt from a paper by Wu, Abel, and Greenberg, of Cornell University, presented at the 1977 ACM Conference on Computer Graphics and Interactive Techniques, is included in the appendix to illustrate this sort of practicality. The complete paper is available from the author of this report. In addition, a book, Interactive Graphics for Computer Aided Design, 1971, by Prince, is a good reference for the capabilities of interactive graphics.

Briefly, interactive graphics will give us the capability not only to describe targets quickly, but to modify them in ways which are impossible with the present COMGEOM system. For example, we will be able to increase easily the thickness of the armor on a vehicle, or to increase the case thickness of components and immediately see what it will cost in terms of weight gain.

Finally, the question must be asked, "Is it worth it?" If we are content with the status quo (COMGEOM/GIFT), and think that these systems will be suffcient for the needs of vulnerability analysis in the future, then the answer is probably "No." However, if we feel that vulnerability analysis will use target descriptions in new ways and that advanced technology will be needed to generate them, then the answer must be "Yes!" The utility of the target description system proposed here far exceeds the ability to produce shotlines for the compartment and point-burst (component level) models. If BRL is to continue to be the lead laboratory for vulnerability analysis, in production as well as research, new techniques need to be employed.

APPENDIX

Excerpt from "An Interactive Computer Graphics Approach to Surface Representation". Copyright 1977, published October 1977, reprinted by permission of The Associations for Computing Machinery.

Graphics and Image Processing
J. Foley Editor

An Interactive Computer Graphics Approach to Surface Representation

Sheng-Chuan Wu, John F. Abel, and Donald P. Greenberg
Cornell University

An interactive computer graphics method has been developed for the rapid generation of arbitrary shaped three-dimensional surfaces. The method is a synthesis of spline theory and algorithms, an interactive means for man-machine communication, and software for static or dynamic graphics display. The basic technique employed is a modified lofting method in which sectional curves are represented by uniform B-splines and the surface is interpolated between sections by Cardinal splines. Among the features of this method are algorithms which enable interactive modification of the B-spline representation of the sectional curves. At all stages of the process, the spatial information is graphically displayed to the user. Complex surfaces can be created by the combination of a number of shapes that have been separately generated and automatically joined. The system has been successfully interfaced to a variety of analytical routines for structural, medical and graphical applications.

Key Words and Phrases: computer graphics, three-dimensional surface representation, splines, lofting, finite element input methods

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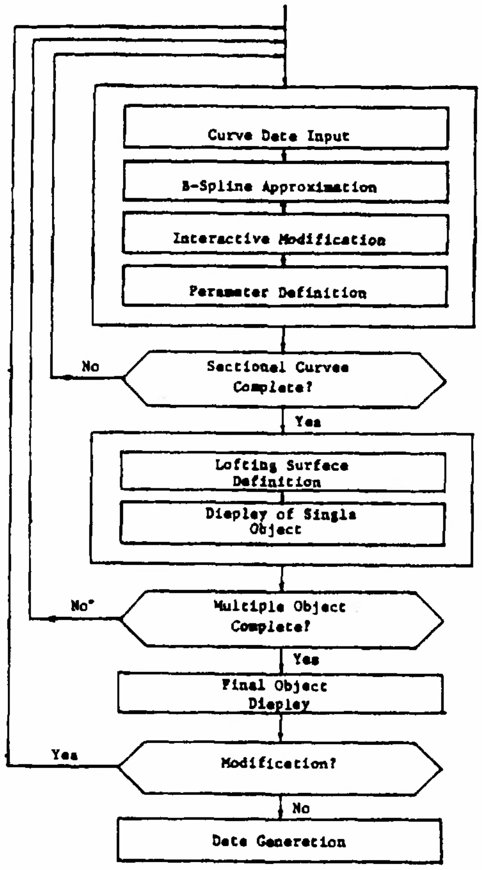
Program Description

The following brief description of the operation of the program demonstrates the ease and flexibility of the interactive graphics routines. The sequence of steps describes the creation of a complex, arbitrary three-dimensional form. For purposes of illustration, it is assumed that the original cross-sectional information is known and that this information can be traced on the digitizer. The entire sequence of operations takes several minutes for the complete input description. A flow chart of the program organization is shown in Figure 6. The equipment and facilities of the laboratory are described by Greenberg in [7].

1. The first step in the process is to specify the cross-sectional contour which is to be interpolated. For arbitrary shapes this can be created by using standard inking routines and tracing the original photographic material (Figure 7). Conic curve generation routines are used when geometrical contours are desired.

Fig. 6. Flowchart of program organization.



2. With the inversion techniques previously described, a B-spline curve is computed which closely represents the original contour (Figure 8). The user can select any number of nodes (typically between 20 and 40) at equal arc length intervals to determine the B-spline. When the interpolation is complete, the original curve, the resulting B-spline, and the defining polygon vertices are simultaneously displayed.

3. By using graphical zooming functions, any region can be effectively magnified, and the user can interactively adjust the polygon vertices so that the spline representation can more closely approximate the original curve (Figures 9 and 10).

4. At this stage, the scale and the location and orientation of the plane containing the digitized information are input to the computer and stored.

5. The process described in steps 1-4 is repeated for each cross-sectional level until all the sectional curves belonging to one object are defined. To illustrate the flexibility of the program, an open contour with cusps is input at mid-height (Figure 11).

6. When all cross-sections have been defined, Cardinal splines are then generated in the other direction, so that the resulting surface contains all of the originally digitized contours. The user is allowed to specify the surface mesh size. A set of intermediate contours is automatically generated at appropriate intervals.

7. The complex object is dynamically displayed in three-dimensional perspective views, providing the opportunity to view the object from any direction (Figure 12). Interactive graphic functions provide user control of all rotations and translations. Significantly, the dynamic display combined with depth cueing through intensity variations enables a complete three-dimensional perception of the object.

8. When the object has been completely defined, it can be stored and used for the creation of multiple objects. Figures 13 and 14 show how several geometric shapes have been specified and combined with these techniques. At any step of the process, the user can modify any contour or any object. The process is not necessarily sequential, and the user may intervene at any stage.

Once the geometric surface is completely specified mathematically, information can be automatically obtained for use in a variety of analytical routines. For example, this process of surface generation has already been successfully interfaced with finite element stress analysis procedures which require coordinate, slope, or curvature information at each mesh point. Furthermore, once the object definition has been completed, it is possible to use the basic surface information to generate color displays. Figures 15 and 16 show the color images of the objects depicted in Figures 12 and 14, respectively.

Summary

An interactive computer graphics method has been developed for the rapid generation of arbitrarily shaped three-dimensional surfaces. The method is a synthesis

Fig. 7. Arbitrary contour: The contour was digitized from original photographic material.

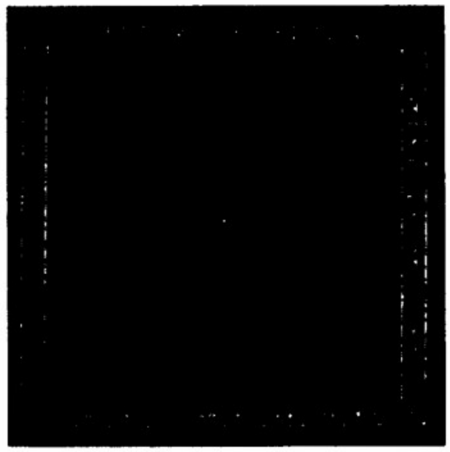


Fig. 8. B-spline curve and original contour: The B-spline interpolation closely represents the original shape ($m = 19$).

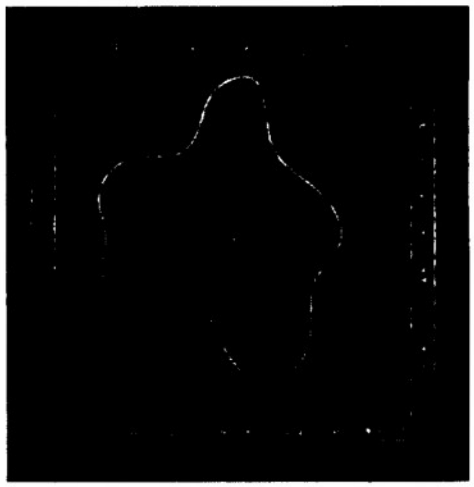


Fig. 9. Enlarged view of original contour, B-spline and control polygon: The B-spline deviates slightly from the dotted original curve.

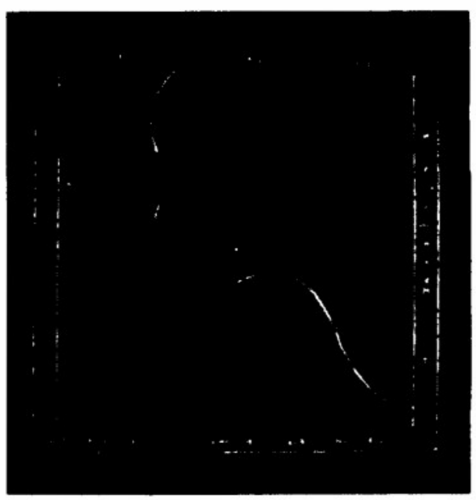


Fig. 10. Adjusted B-spline, original curve and control polygon: By interactively positioning the polygon vertex locations, a very accurate representation can be obtained.

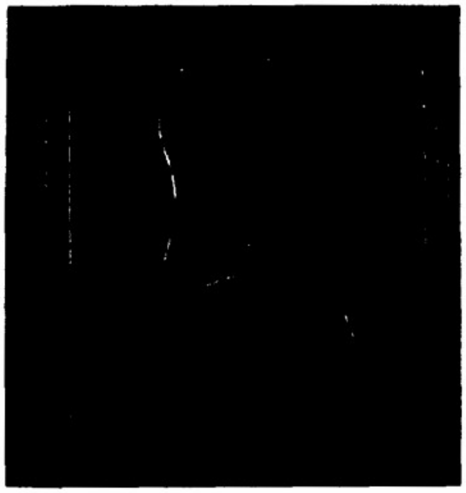


Fig. 11. Open B-spline with cusp ($m = 19$).

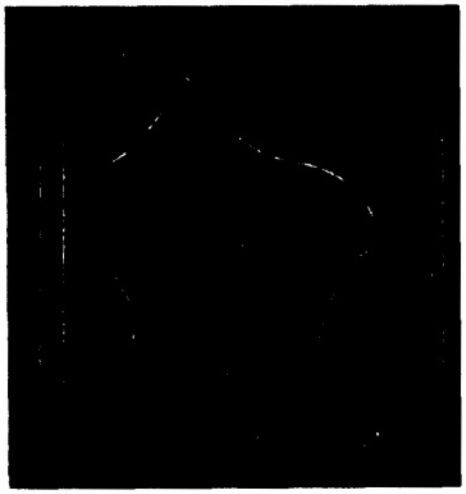


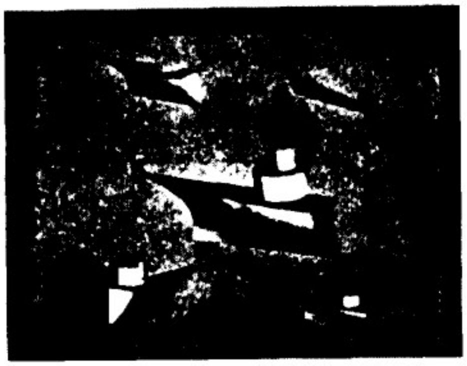
Fig. 12. Perspective view of three-dimensional object ($n = 2$): The surface was created by using two closed contours for the top and bottom and an open contour at mid-height.

Fig. 13. Separate objects for creating ship geometry: Each of the individual components has been defined by using the lofting techniques described.

Fig. 14. Perspective view of combined geometric objects: Shapes have been combined to represent a portion of a ship's hull. The resulting description can be used for input to finite element analysis routines.

Fig. 15. Smooth shaded perspective image of amorphous shape shown in Figure 12 (shading program by Doug Kay).

Fig. 16. Smooth shaded perspective images of ship geometry shown in Figure 14 (shading program by Doug Kay).



of spline theory and algorithms, an interactive means for man-machine communication, and software for static or dynamic graphics display.

The basic technique employed is a modified lofting method in which sectional curves are represented by uniform *B*-splines and the surface is interpolated between sections by Cardinal splines. The sectional curves need not be parallel and may consist of any combination of open or closed curves. A convenient method is included for introducing and controlling cusps. An inversion procedure is incorporated which enables a *B*-spline curve to be automatically generated which closely approximates a digitized or predefined curve.

Among the features of this system are algorithms which enable interactive modifications of the *B*-spline representation of the sectional curves. Standard editing routines for manipulation are included. Thus both the flexibility for initial shape design and the adjustment capability to match existing forms are provided.

At all stages of the process, the spatial information is graphically displayed to the user. The efficiencies necessary for this interaction are obtained by the use of difference equations which enhance the speed of the repetitive calculations.

Complex surfaces can be created by the combination of a number of shapes that have been separately generated and automatically joined. The system has been successfully interfaced to a variety of analytical routines for structural, medical, and graphical applications.

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