

SIKORSKY INTERACTIVE GRAPHICS SURFACE DESIGN/  
MANUFACTURING SYSTEM

Richard Robbins  
Sikorsky Aircraft

INTRODUCTION

The design, analysis, and manufacturing of aircraft components using free form surfaces is a complex task. In the late 1960's and early 1970's Sikorsky Aircraft Engineering Design and Manufacturing Engineering Branches were using APT FMILL in an attempt to accomplish this task. Limitations of APT FMILL, problems with transfer of data between departments, and the obvious problem of surface evaluation in a batch mode led to the development of Sikorsky's Interactive Graphics Surface Design/Manufacturing System.

In addition to the basic surface definition and viewing capabilities one would expect to see in a system such as this, numerous other features are present: surface editing, automated smoothing of control curves, variable milling patch boundary definitions, surface intersection definition and viewing, automatic creation of true offset surfaces, digitizer and drafting machine interface, and cutter path optimization. Documented costs and time savings of better than six to one are being realized using this system.

- This system was written in FORTRAN and GSP for use on IBM 2250 CRT's; Sikorsky currently has three 2250 mod III CRT's running on an IBM 370/158.

## SURFACE

The surface is defined from a rectangular array of points, each column and row of which describes a cubic control curve. The elementary surfaces, bounded by four intersecting control curves, are mathematically defined by the four corner points and the two tangents at each of those points.

In general, the control curves are 3-D space curves. However, in our experience it has been found for ease of surface development that the control curves in one of the parametric directions be in plane.

### SURFACE DESIGN DEVELOPMENT

#### Point Generation

The primary input to the surface system is a set of control points that define the surface control curves. The number of control points required and the spacing of these control points are the variables that the surface designer must work with to obtain a desired surface.

For example, if the curve spacing is uneven, the resultant surface may have glitches, making the surface unacceptable when milled. It is therefore important from the designer's point of view that the control curves can easily be generated or modified, and the surface checked.

The Surface Design System provides several algorithmic tools in the designers behalf for generating control points. The methods used to generate the 3-D control points are:

- (1) A skeleton set of 2-D points obtained from digitizing known contours or by APT programming is read into the Surface Design System. The points are curve fitted using a composite of straight lines, conics, and splines. These planar lines now become the basic reference curves for the surface. 2-D points are generated from these curves (by intersecting with planar curves or by using the equally spaced point generating algorithm for a curve) and then transformed to 3-D space to obtain the control points.

- (2) Projecting control curves onto coordinate planes and interpolating the projected curves at a specified value to obtain new control points.
- (3) Intersecting the control curves of a surface with a plane.

All points may be observed visually in the Surface System and may be modified as required. For instance,

- (1) Points may be deleted
- (2) Coordinates of points read out
- (3) New points keyed in
- (4) Multiple points may be defined at a coordinate location
- (5) Surface points may be replaced
- (6) Points may be transformed

### Tangent Generation

At the heart of the surface generation section of the program are algorithms to define and edit tangent vectors at control points. The algorithms may be applied to all points on individual curves, or at all points on all curves, within a section of the surface, in either or both parametric directions.

Tangent generation algorithms may be selected from -

- (1) Algorithms based on segment chordal distance.
- (2) Algorithms based on 2nd derivative continuity between segments of control curve.
- (3) Algorithms based on matching a 2-D spline through a set of control points. The control curve is projected onto a working plane. This projected curve is then matched, if possible, against a 2-D spline fitted through the set of projected control points. For example, the tangent vector direction of the control curve is matched against the tangent vector direction of the spline. The magnitude is matched, where possible; otherwise, it is averaged.

## Surface Checking

A major problem with developing a surface is in checking the validity of the surface. Procedures to help solve this problem are

- (1) New planar control curves may be checked automatically by projecting them onto a working plane and comparing with 2-D splines through the sets of projected control points
  - (a) Checking may be done visually by comparing the overlaid curves
  - (b) Automatic checking may be done by an algorithm which indicates those segments that are out of tolerance by more than a specified amount. Tangents at the segment end points can then be edited individually until segments are within tolerance
- (2) Displaying and plotting plane intersections of the surface
- (3) Magnifying control curves in one direction in order to detect curve irregularities
- (4) Surface continuity may be checked by displaying a parametric distribution of connected points in either of the surface directions. Since the parametric distribution simulates the cutter path when the surface is milled, it can be used to identify possible problem areas in surface definition.

## MILLING DESIGN

One of the problems in the past with milling the surface - a batch postprocessing operation - was limiting the milling boundaries to the input geometric control curves. The problem for the user was introducing control curves into his model often with adverse results, solely for the purpose of defining milling boundaries.

The graphics program allows user to define milling boundaries after the surface has been defined. The boundaries can be defined from

- (1) Any parametric curves including control curves
- (2) Plane/surface intersections
- (3) 2-D projections of straight lines, conics, splines onto surface

The post-graphics processing performs

- (1) Chord and scallop height analysis on the milling patch to determine the optimum number of cutter paths and point to point moves required for a specified tolerance
- (2) Cutter location data generation
- (3) Machine dynamics and paper tape generation.

## APPLICATIONS

### Helicopter Blades

The primary use of this system has been in the design of helicopter blades and manufacture of blade tooling. Contours which have been defined from aerodynamic considerations are used as a basis for defining surface control curves. Intersecting the developed blade surface with planes and comparing the intersection contours with known cross sections is used as a measure of blade acceptability. Key features of the Surface System in blade design and milling are

- (1) True surface offset capability which is frequently required in blade development
- (2) Independent construction of milling patches for blades. This frees the blade designer from milling considerations during surface modeling of blade.

## NASTRAN Grid Point Generation

The surface System has been found useful in generating grid points for finite-element programs such as NASTRAN. Most of the nodal points required in modeling a helicopter fuselage, for instance, are found in the body or tail section - surfaces of constant cross section, ruled surfaces, or transition surfaces between ruled surfaces. These are all points which can easily be defined. For example, contour points describing intermediate frames which may be canted are computed by the plane/surface intersection algorithm. The transition surfaces are defined by generating the body and tail sections separately and allowing the resultant boundary conditions to define the transition surface. (See figs. 1 to 3.)

### CONCLUDING REMARKS

Although there are disadvantages mathematically with this surface under certain conditions - zero twist vectors and triangular surface segments for example, and there are limits to the surface checking that can be performed interactively, the system has resulted in considerable cost savings for many applications.

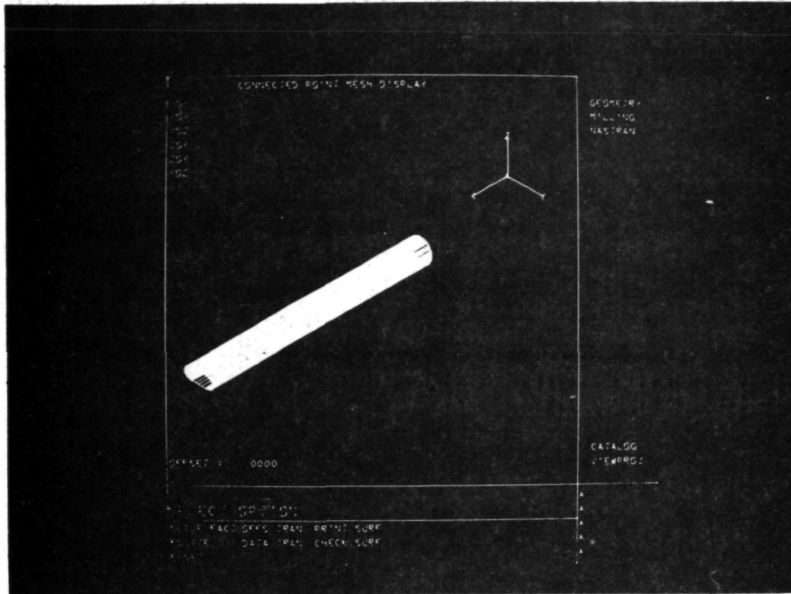


Figure 1.- Orthogonal view of blade spar.

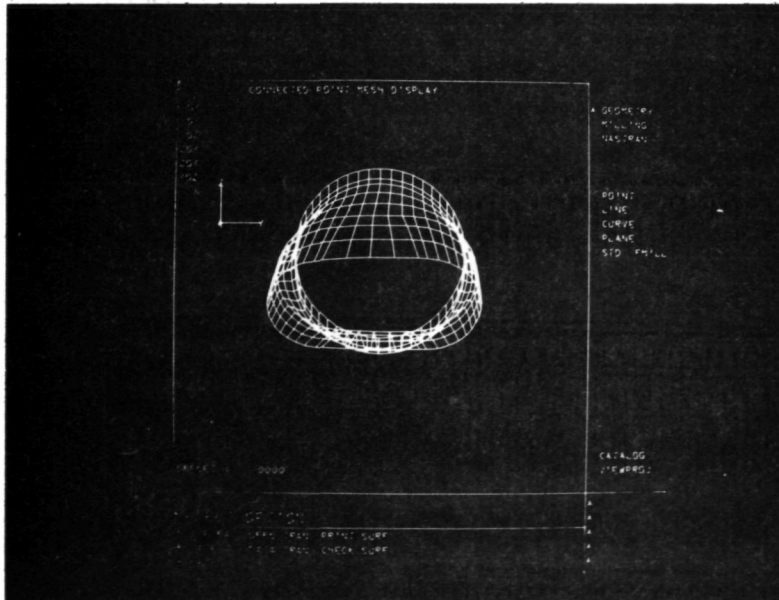


Figure 2.- Blade spar viewed end on.

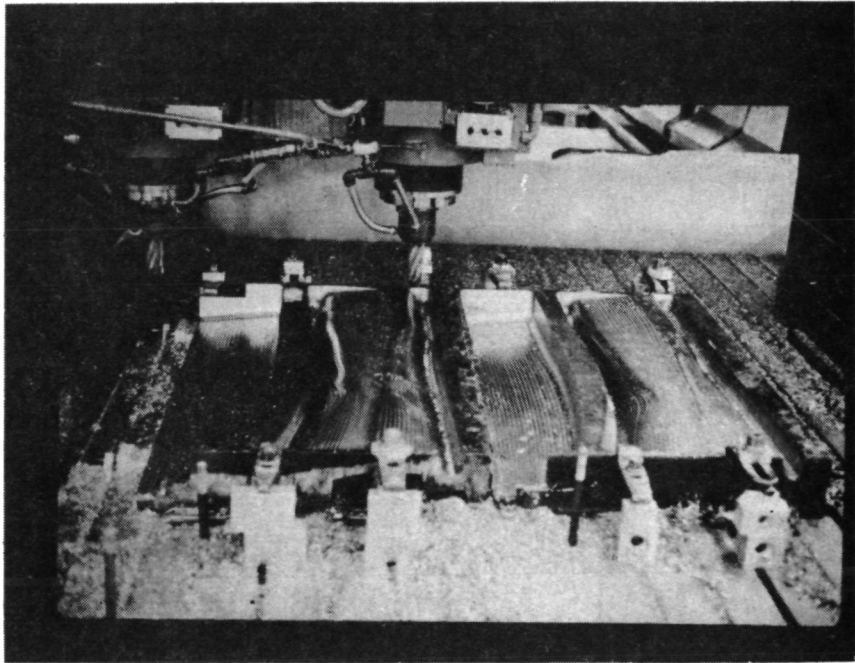


Figure 3.- Milling of blade surface tools.