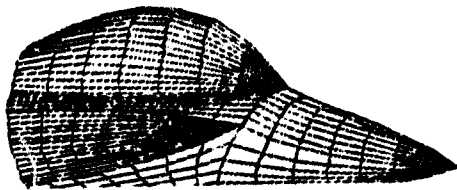


## N O T I C E

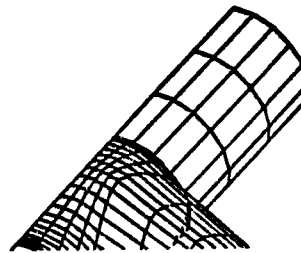
THIS DOCUMENT HAS BEEN REPRODUCED FROM  
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IN THE INTEREST OF MAKING AVAILABLE AS MUCH  
INFORMATION AS POSSIBLE

# Workshop on Aircraft Surface Representation for Aerodynamic Computation



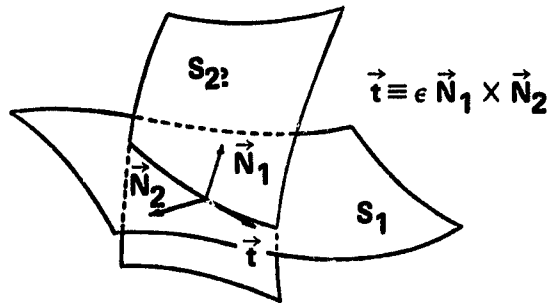
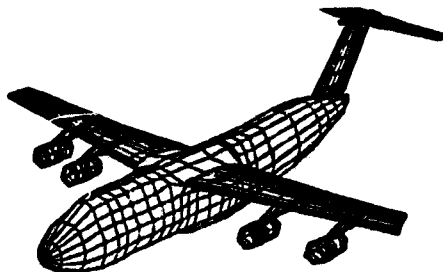
(NASA-TM-81170) WORKSHOP ON AIRCRAFT  
SURFACE REPRESENTATION FOR AERODYNAMIC  
COMPUTATION (NASA) 560 p HC A24/MF A01

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N80-19025

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G3/01 47489



February 1980

**NASA**

National Aeronautics and  
Space Administration



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# Workshop on Aircraft Surface Representation for Aerodynamic Computation

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Held at  
Ames Research Center  
Moffett Field, California  
March 1 & 2, 1978

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Edited by  
T. J. Gregory, Ames Research Center, Moffett Field, California  
John Ashbaugh, USAF, Ames Research Center, Moffett Field, California



National Aeronautics and  
Space Administration

Ames Research Center  
Moffett Field, California 94035

**WORKSHOP ON AIRCRAFT SURFACE REPRESENTATION FOR AERODYNAMIC COMPUTATION**

**CONTENTS**

- A. Program - March 1-2, 1978
- B. Workshop Objectives
- C. Presentation Material
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    - Panel Topics
  - Session 2 - Methods
    - Panel Topics
  - Session 3 - Systems in Use
    - Panel Topics
  - Session 4 - Workshop Summary
- D. Invitation Letters (3)
- E. Attendees and Mailing List

# WORKSHOP ON AIRCRAFT SURFACE REPRESENTATION FOR AERODYNAMIC COMPUTATION

## PROGRAM

March 1, 1978

8:30	Welcome	I. Roberts/Ames
8:40	Workshop Details and Overview	J. Ashbaugh/Ames
8:55	Workshop Objectives	T. J. Gregory/Ames

### REQUIREMENTS IN AIRCRAFT SURFACE REPRESENTATION

9:15	"Geometric Modeling in Conceptual Design"	P. E. Divan/Rockwell
9:35	"Airplane Surface Descriptive Geometry Requirements"	R. Wallace/Boeing
10:10	"Aircraft Configuration Modeling"	D. R. Clark/Analytical Methods
10:30	"Geometric Effect on Internal Flow Computations"	H. Kao/Lewis
10:50	"Geometry Requirements for Unsteady Aerodynamics"	C. Yates/Langley
11:10	"Flow Field Grids"	J. L. Steger/Ames
11:30	"Numerical Aerodynamic Simulation Facility"	R. L. Carmichael/Ames
11:50	"Machine Shop and Wind Tunnel Model Requirements"	W. R. Mann/Ames
1:10	"Graphics & Geometry Considerations in IPAD"	R. E. Miller/Boeing
1:30	Panel	

### METHODS OF SURFACE REPRESENTATION

2:30	"Mathematical Techniques for Surface Definition"	S. M. Staley/Univ. of Conn.
2:50	"Visual 3D Interaction with Parabolic Blending"	D. Anderson/Purdue
3:30	"Point Thinning for Graphical Representation"	T. R. Rau/Langley
3:50	"Parametric Cubic Surface Representation"	D. P. Roland/Informatics
4:10	"A Solution to the Surface Intersection Problem"	H. Timmer/McDonnell-Douglas
4:30	"Generation of Geometric Input for 3D Potential Flow Programs"	J. L. Hess & D. Halsey/ McDonnell-Douglas
4:50	Adjourn	

March 2, 1978

8:30	"Body Oriented Mesh Generation for 3-D Flow Fields"	I. C. Bhatel/General Dynamics
8:50	"Boundary Fitted Coordinate System Using Tension Splines"	L. L. Presley/Ames
9:10	"Tchebycheff Approximations for Surface Definition"	R. E. Smith/Langley
		H. Hoy/Ames

GEOMETRY SYSTEMS IN USE

10:50	"IPEGS-Interactive Parametric Equation System"	J. Ashbaugh/Ames
11:10	"ICAD-Interactive Computer Aided Design"	E. J. Brown/USAF-ASD
11:30	"QUICK GEOMETRY Representation of Surfaces"	A. Vachris/Grumman
11:50	"Interactive Input for QUICK GEOMETRY"	J. C. Townsend/Langley
1:10	"Lockheed Georgia Aerodynamic Paneling Program"	L. Haverly/Lockheed-GA.
1:30	"Interactive Surface Design"	M. A. Dincau/Lockheed-CA.
1:50	"ACAD-Advanced Configuration Analysis and Design"	T. Weir/Northrop
2:10	"Interfacing Aerodynamic Programs to AVID"	A. W. Wilhite/Langley
2:50	Panel	
3:50	Summary	T. J. Gregory/Ames
4:10	Adjourn	

**This discussion will describe the Workshop objectives, some of the reasons for holding the Workshop, and the emphasis that we'd like to maintain throughout the program.**

**T. J. Gregory  
Vugraph #1**

**NASA-AMES WORKSHOP ON  
AIRCRAFT SURFACE REPRESENTATION  
FOR  
AERODYNAMIC COMPUTATION"**

**WORKSHOP OBJECTIVES**

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**TOM GREGORY  
NASA-AMES RES. CTR.**



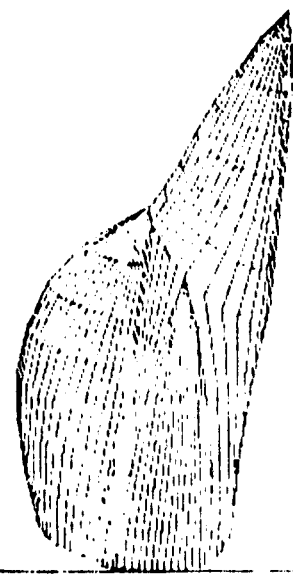
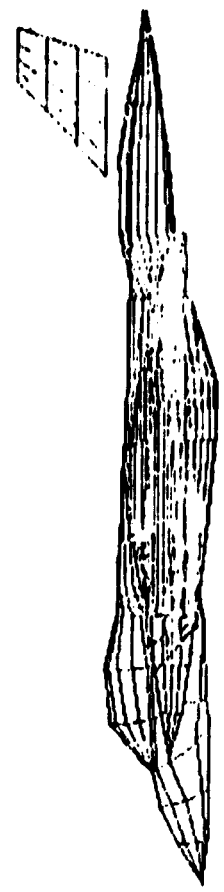
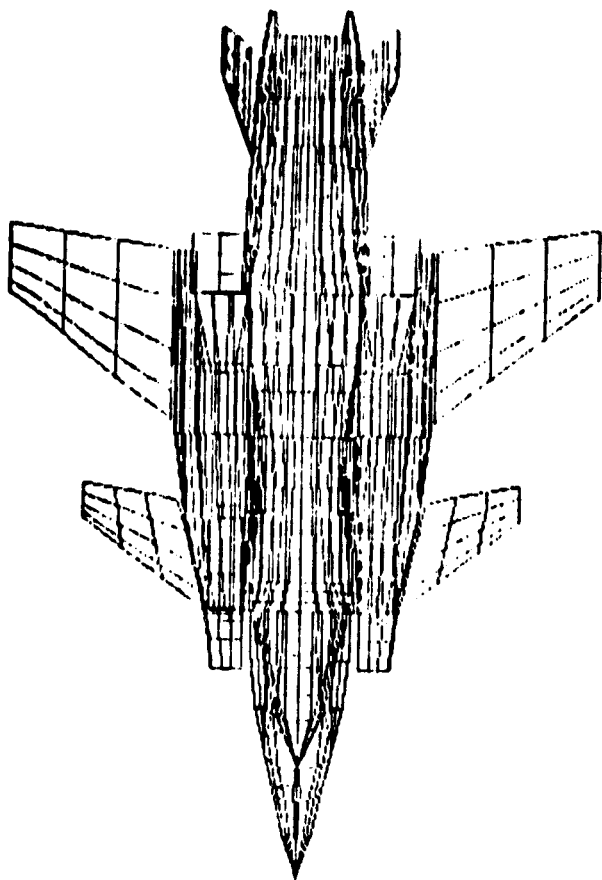
The Workshop origins began about a year ago and became clearer last September in a meeting of NASA, Air Force and Navy representatives in Washington. At this meeting, the planning for the new aerodynamic paneling technique embodied in a system called PAN AIR (Paneling aerodynamics) was becoming finalized. Basically, it was recognized by those involved that the new aerodynamics techniques could use more detailed surface definition beyond that which was typically used. The next slide indicates that a realistic and complex aircraft configuration can be defined in terms of small quadrilateral panels that are the basis for the new paneling techniques. This technique is based on the fact that pressure on each panel can be computed as a function of the free stream flow conditions and the inclination of the panel as well as the inclination of the surrounding panels. The result is a large linear algebra problem that is solvable by the more powerful computers. Referring back to the last slide, it was apparent that significant resources were going into geometry definition and that, in fact, more resources were planned and being requested. Also, there were many alternatives in the proposed approaches and the extensions and enhancements to these alternatives provided a wide variety of options. At this point the picture was unclear with regard to selecting particular options and it was felt that it was time to stop and survey the whole activity. Hence, the interest in holding this Workshop.

T. J. Gregory  
Vugraph #2

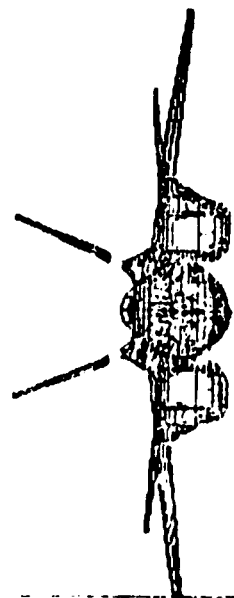
# **WORKSHOP ORIGINS**

## **AERODYNAMICISTS AND MANAGERS REALIZED**

- **NEW AERODYNAMICS NEEDED  
DETAILED GEOMETRY**
- **SIGNIFICANT RESOURCES GOING  
TO GEOMETRY**
- **MORE PLANNED/REQUESTED**
- **MANY ALTERNATIVES AND  
EXTENSIONS**
- **OVERALL PICTURE UNCLEAR**



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*TOM GREGORY  
NASA-AMES RES. CTR. 3*

The specific objectives of NASA Headquarters were that the Workshop would help coordinate the activity, that is, exchange information between all of the participants involved in surface representation for aerodynamic computation, and to possibly gain a consensus as to preferred approaches or a tentative point of view regarding commonality between the approaches. If possible the Workshop could initiate discussions of standardization that the aerospace community may desire. Again, we wanted industry participating in defining any consensus point of view with regard to preferred approaches or standardization. Secondly, we felt the Workshop would help us understand the elements and issues surrounding the technical activities and this would aid NASA in preparing a reasonable funding plan for further development of surface representation technology.

T. J. Gregory  
Vugraph #4

# WORKSHOP OBJECTIVES

NASA HQ:

- COORDINATE ACTIVITY
- UNDERSTAND ELEMENTS AND ISSUES
- REASONABLE FUNDING PLAN

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The Workshop objectives at NASA Ames include those just discussed and additional ones. First, our primary function is to develop new technology in aerodynamics and if this involves geometry or surface representation then that is an area of interest and activity for us. We'd also like to have the aerodynamic and geometry technology used by the aerospace community and that means having their opinions and ideas included at the early stages of this development process. Finally, I think the key motivation for the Ames aerodynamicists is to have a "painless" geometry package which we can use for technology development in aerodynamics. Certainly if the Workshop can provide us with new ideas, direction, and approaches that would lead to accomplishing this latter objective, then the Workshop would be most beneficial for us.

T. J. Gregory  
Vugraph #5

# WORKSHOP OBJECTIVES

## NASA-AMES

- DEVELOP NEW TECHNOLOGY
- HAVE IT USED
- "PAINLESS" GEOMETRY PKG.

The next slide suggests that all the attendees at the Workshop would benefit from a survey of the field and would provide an opportunity to show the capability in each organization. Both of these are important for those interested in participating in NASA sponsored development of the technology. In general, probably the most direct benefit for all attendees at the Workshop will be to gain information or even software that may be of immediate value to their own efforts in aircraft surface definition.

T. J. Gregory  
Vugraph #16



# **WORKSHOP OBJECTIVES**

## **OF ATTENDEES:**

- **SURVEY FIELD**
- **SHOW CAPABILITY**
- **GAIN INFORMATION**

**TOM GREGORY  
NASA-AMES RES. CTR. 6**

Prior to starting the first panel session, I'd like to describe some terminology that will be used throughout the next two days and emphasize what we mean by aircraft surface representation. There are two types of surfaces of interest, aircraft surfaces and surfaces within the flow field. Aircraft surfaces can be defined by a hierarchy of elements. The first element is a component such as a wing, body, nacelle, etc. that in turn can be described by surface patches. These are described by either systems of equations, points, or functions. The patches can be further subdivided into panels as indicated on the earlier vugraph of a complete aircraft configuration. These panels and the patches can be described in terms of the edges or curves along the boundaries, but the panels are sufficiently described, for aerodynamic paneling computations, in terms of points at the intersections of their edges.

Flow field surfaces are needed to define such items as shock waves, vortex sheets, separation bubble areas, etc. These are of major importance to the aerodynamists and will become more important as we get further into this technology. The same hierarchy of elements mentioned above can apply to flow field surfaces.

T. J. Gregory  
Vugraph #47

# **TERMINOLOGY**

**(1) AIRCRAFT SURFACE**

**COMPONENTS**

**PATCHES**

**PANELS**

**EDGES**

**POINTS**

**(2) FLOW FIELD SURFACE**

**VORTEX SHEET**

**SEPARATION BUBBLE**

There is another field of major importance to computational aerodynamics and that is the definition of a flow field volume (i.e. solid). This is usually done by means of grids and meshes in the flow field that are divided by either uniform spacing in the simplest case, or by streamlines or other distributions. These are used to make finite difference computations using the fundamental partial differential equations in aerodynamics. These finite differences computations are an emerging field in aerodynamics and generating significant interest within NASA. Again, the emphasis in this Workshop is on surface definition and not on flow field volume (solid) definition. Perhaps the specialists in this latter field will generate a workshop in the future.

T. J. Gregory  
Vugraph #18

# **TERMINOLOGY (CONT.)**

## **(3) FLOW FIELD VOLUME**

- **GRIDS OR MESH**
- **UNIFORM SPACING**
- **STREAMLINES**
- **OTHER**

To reiterate, the Workshop emphasis is on surface representation and its integration with aerodynamics, computers, graphics and wind tunnel model fabrication as well as flow field grid generation, but none of these items per se. It's our intention to try and focus the discussions and papers at the Workshop on surface representation and to defer detailed discussions of these other items to other workshops or conferences.

T. J. Gregory  
Vugraph #109

# **WORKSHOP EMPHASIS**

## **IS SURFACE REPRESENTATION AND INTEGRATION WITH**

- **AERODYNAMICS**
- **COMPUTERS**
- **GRAPHICS**
- **W.T. MODEL FABRICATION**

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**TOM GREGORY**  
**NASA-AMES RES. CTR.**

GEOMETRIC  
MODELING  
IN  
CONCEPTUAL  
DESIGN

P. E. DIVAN III 1



# CONCEPTUAL DESIGN

NEW PRODUCT DEVELOPMENT

OLD PRODUCT MODIFICATIONS

PHILOSOPHICAL RATHER THAN CORPOREAL

## CHARACTERISTICS

RAPID TURN AROUND

RAPID EVOLUTION OF IDEAS

AT LEAST ONE COMPLETE RE-START

SPENDS RATHER THAN MAKES MONEY

# SYSTEM CAPABILITY

## GEOMETRY

ARBITRARY PLANFORMS

NONPLANAR

MULTIPLE SURFACES

ARBITRARY CAMBER AND TWIST

CONTROL SURFACES

OPEN / CLOSED BODY

ARBITRARY CROSS - SECTION

CENTERLINE AND OFFSET BODIES

## ANALYSIS

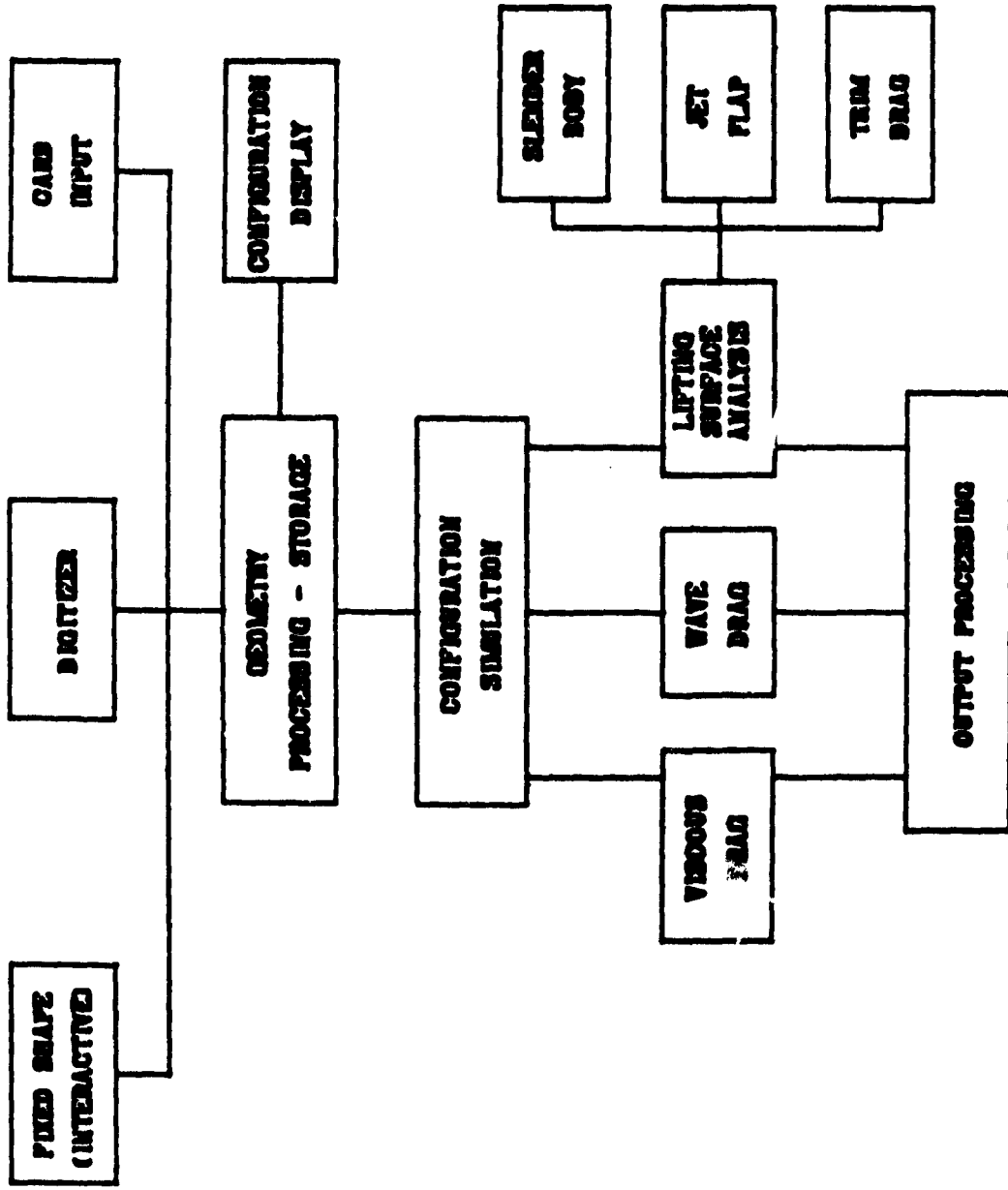
SUBSONIC AND SUPERSONIC SPEEDS

PRESSURES - FORCES - MOMENTS

STATIC AND ROTARY DERIVATIVES ( PITCH - YAW )

TRIMMED DRAG USING CONTROL SURFACES

# CONCEPTUAL DESIGN ANALYSIS SYSTEM



# REQUIREMENTS



ONE MODEL

INTERACTIVE INPUT AND EDITING

REDUCE COST

REDUCE TIME

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# MODELING METHODS

## DIGITIZING

INPUT CROSS SECTIONS OF COMPONENTS

USING DIGITIZING PEN AND TABLET

## KEY INPUT

KEY IN SELECTED GEOMETRIC DESCRIPTIONS

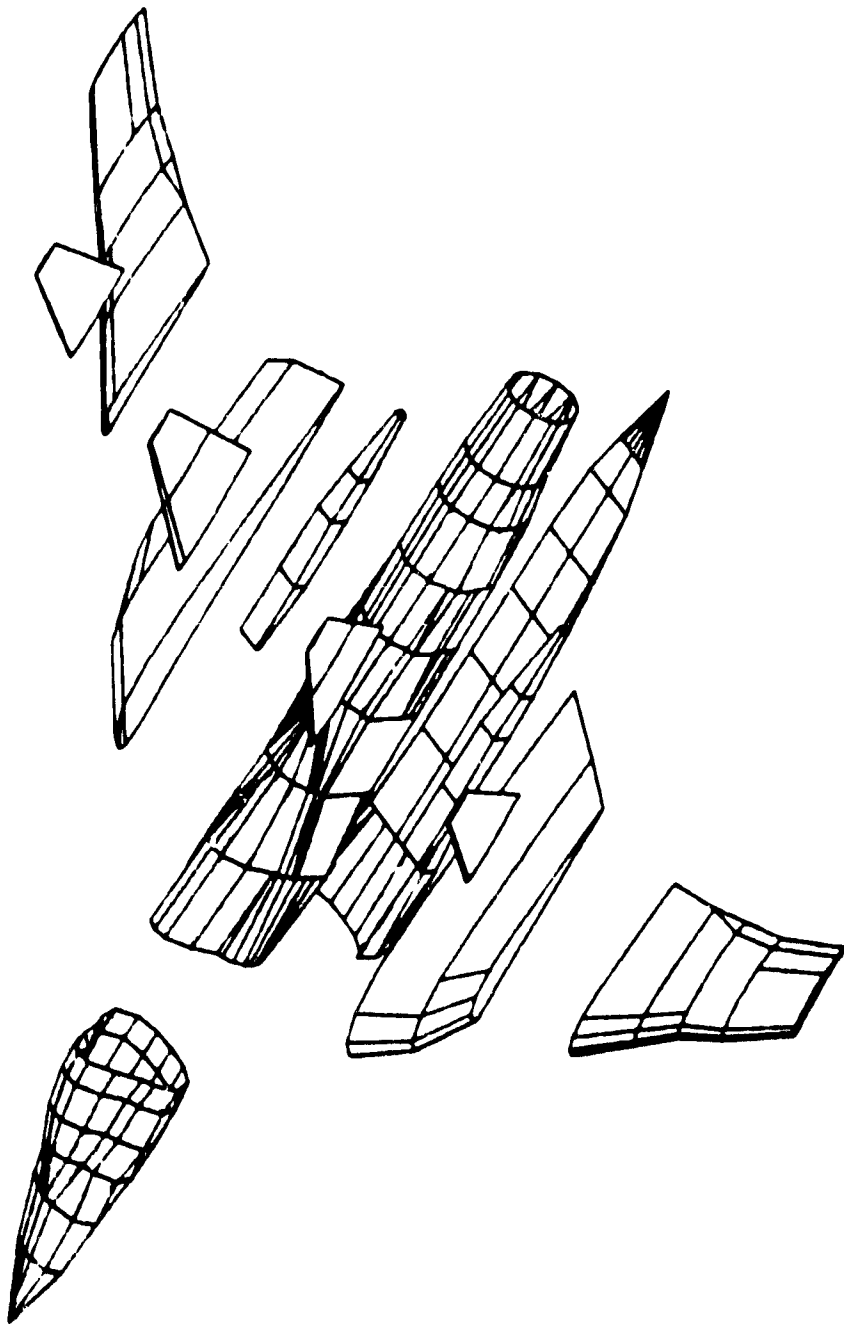
SURFACES - AR. SW. TAPER. SWEEP. DIHEDRAL THICKENING

BODIES - CROSS SECTION AREA. X-STATION. SHAPE

# MODELING SCHEME



## STACKED CROSS SECTIONS COMPONENTS



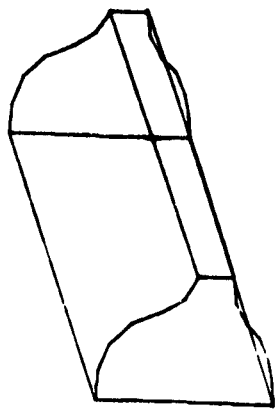
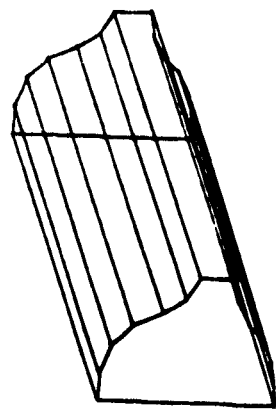
# STACKED CROSS SECTIONS



EACH CROSS SECTION

SAME NUMBER OF POINTS

SAME NUMBER OF SEGMENTS



# COMPONENTS



## CLASSIFY COMPONENTS

BODIES OR SURFACES

SYMMETRIC OR ANTI-SYMMETRIC

COMPONENT AXIS

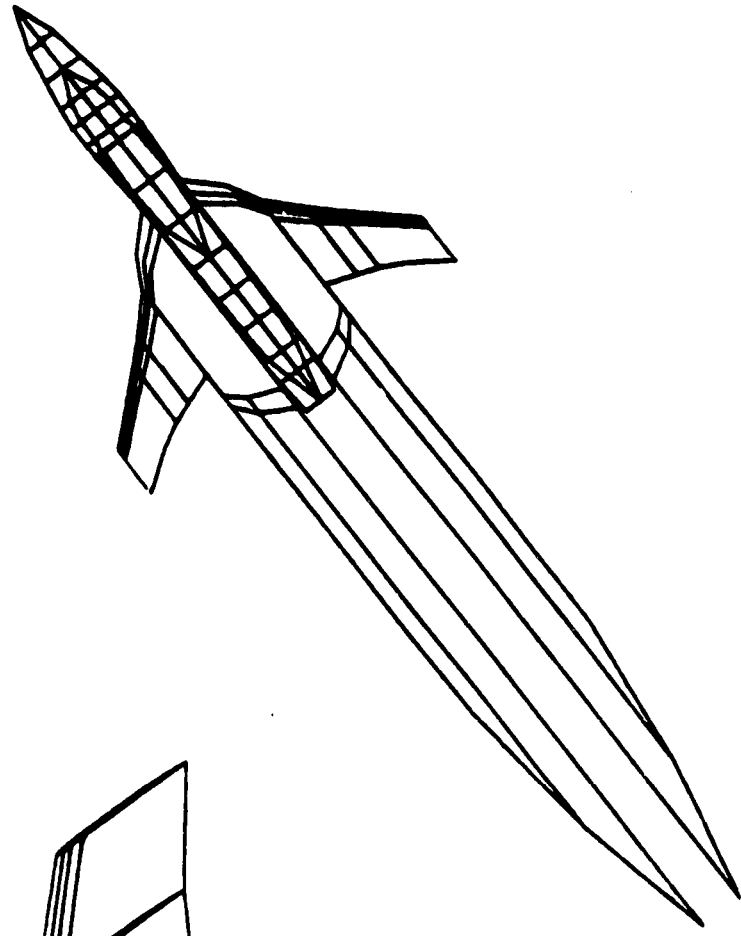
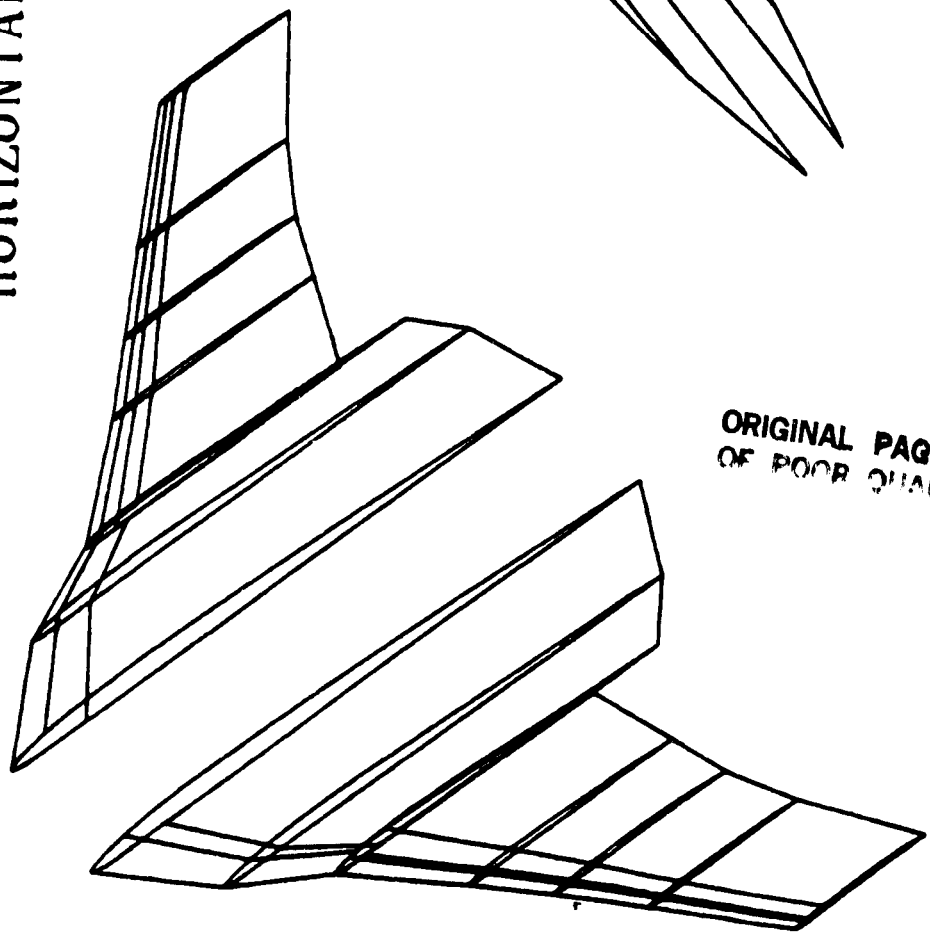
VEHICLE AXIS



# SURFACE COMPONENTS



WINGS - VERTICALS -- CANARDS  
HORIZONTALS

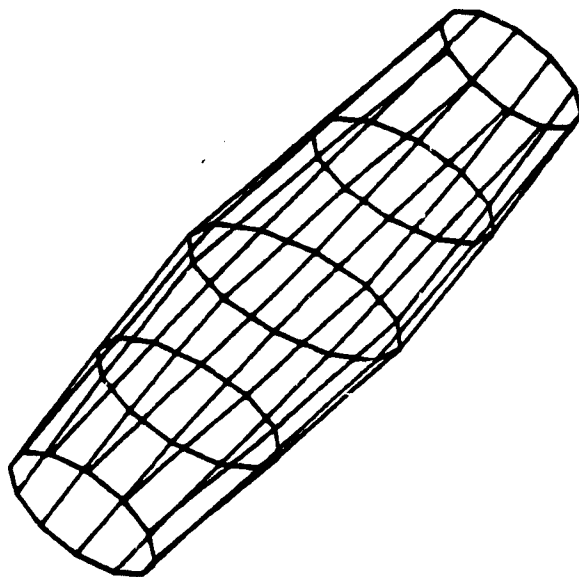
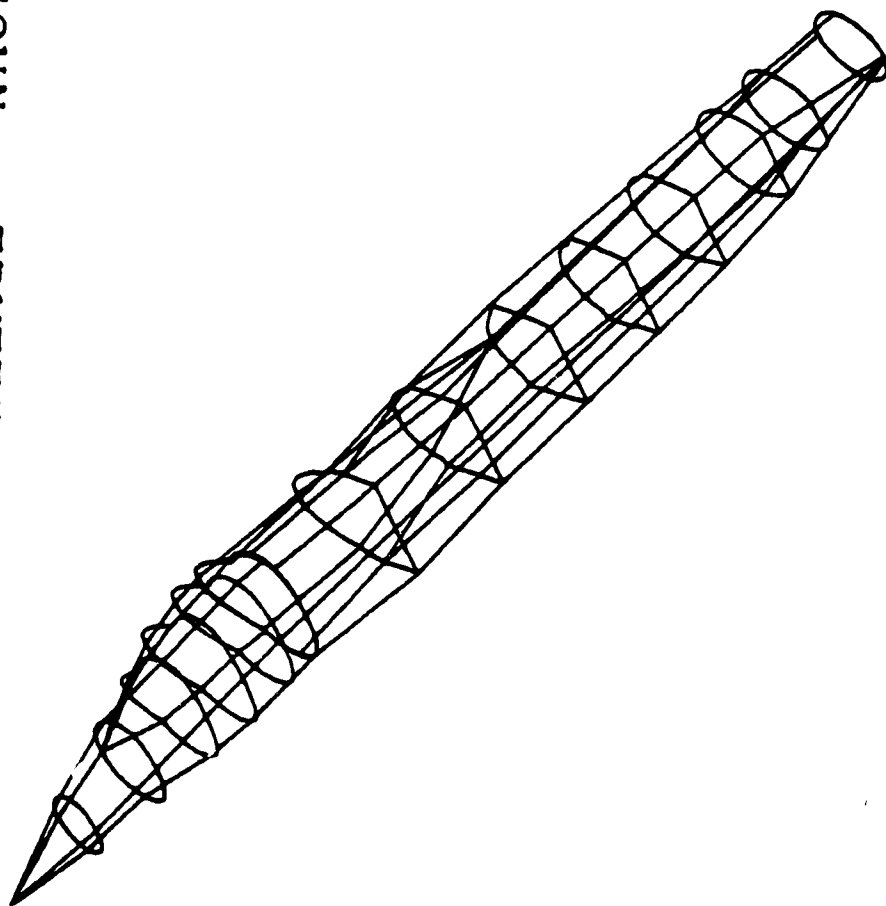


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# BODY COMPONENTS



FUSELAGE - NACELLES - PODS



# INTERPOLATE SECTION

INTERMEDIATE

USE BROKEN SPLINE ROUTINE

FINDS BREAKS IN LONGITUDINAL LINES  
INTERPOLATES INDEPENDENTLY BETWEEN BREAKS

BODY COMPONENTS

INTERPOLATES TO SPECIFIED X-STATION

SURFACE COMPONENTS

INTERPOLATES TO SPECIFIED 2Y/B

# CURVE FIT SECTION SEGMENTS

## LEAST SQUARES SMOOTHING

2-10TH ORDER SMOOTHING

L. E. RADIUS POLYNOMIAL FOR AIRFOILS

## THIRD ORDER SPLINE FIT

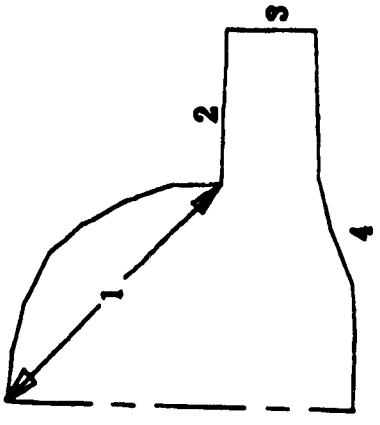
CONTROLLED AND UNCONTROLLED END SLOPES

## SEGMENTS CURVE FITTED INDEPENDENTLY

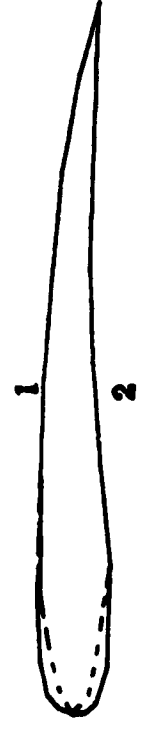
## WEIGHTED POINT SPACING

BASED ON FIRST DERIVATIVE

**BODY SEGMENT CURVE FITS**

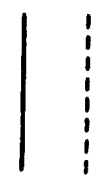


**SURFACE SEGMENT CURVE FITS**

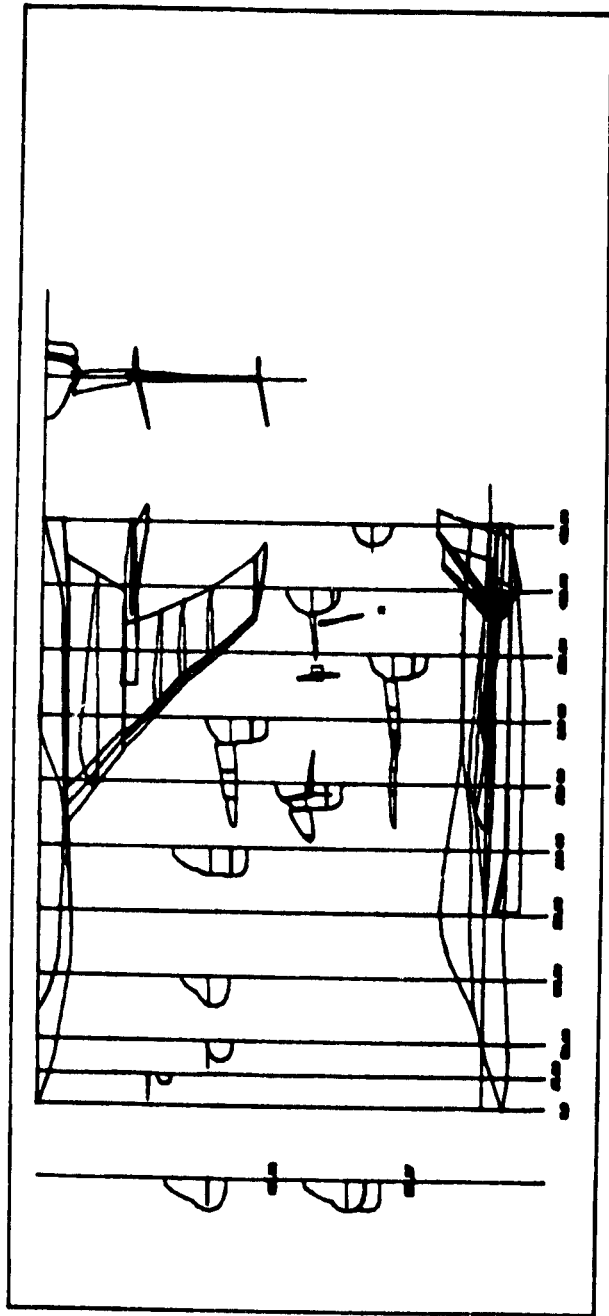


— WITH L. E. RADIUS POLYNOMIAL

- - - WITHOUT L. E. RADIUS



COMPLETED VEHICLE DESCRIPTION



ANALYSIS



LIFTING SURFACE

WAVE DRAG

VISCOUS DRAG

# GENERAL APPROACH

## LINEARIZED POTENTIAL THEORY

BODY SURFACE SOURCE SEGMENTS

WING CHORD PLANE DISTRIBUTED SOURCE/VORTEX FINITE ELEMENTS

BODY VORTEX PANEL INTERFERENCE SHELL

## FLAT PLATE STRIP SKIN FRICTION

## NEAR AND FAR FIELD DRAG ANALYSIS



# **LIFTING SURFACE SOLUTIONS**

## **UNIFIED DISTRIBUTED PANEL SOLUTION**

### **REQUIRES**

**PANEL DEFINITIONS**

**CORNER POINTS**

**CONTROL POINTS**

**PANEL CENTROIDS**

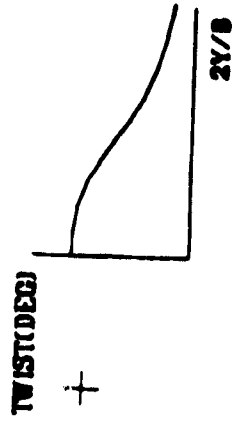
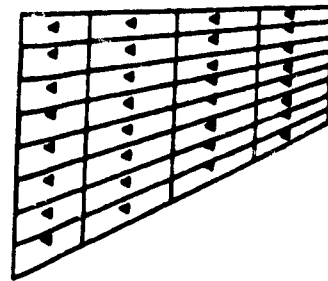
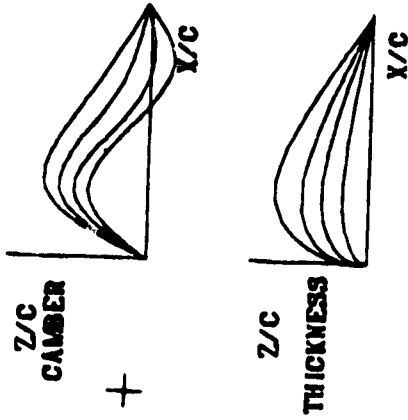
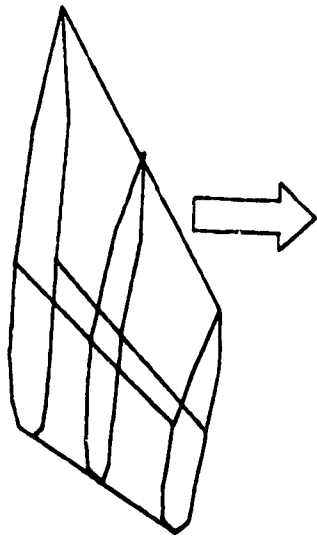
**PANEL AREAS**

**SPANWISE TWIST DISTRIBUTIONS**

**CAMBER AT EACH CONTROL POINT**

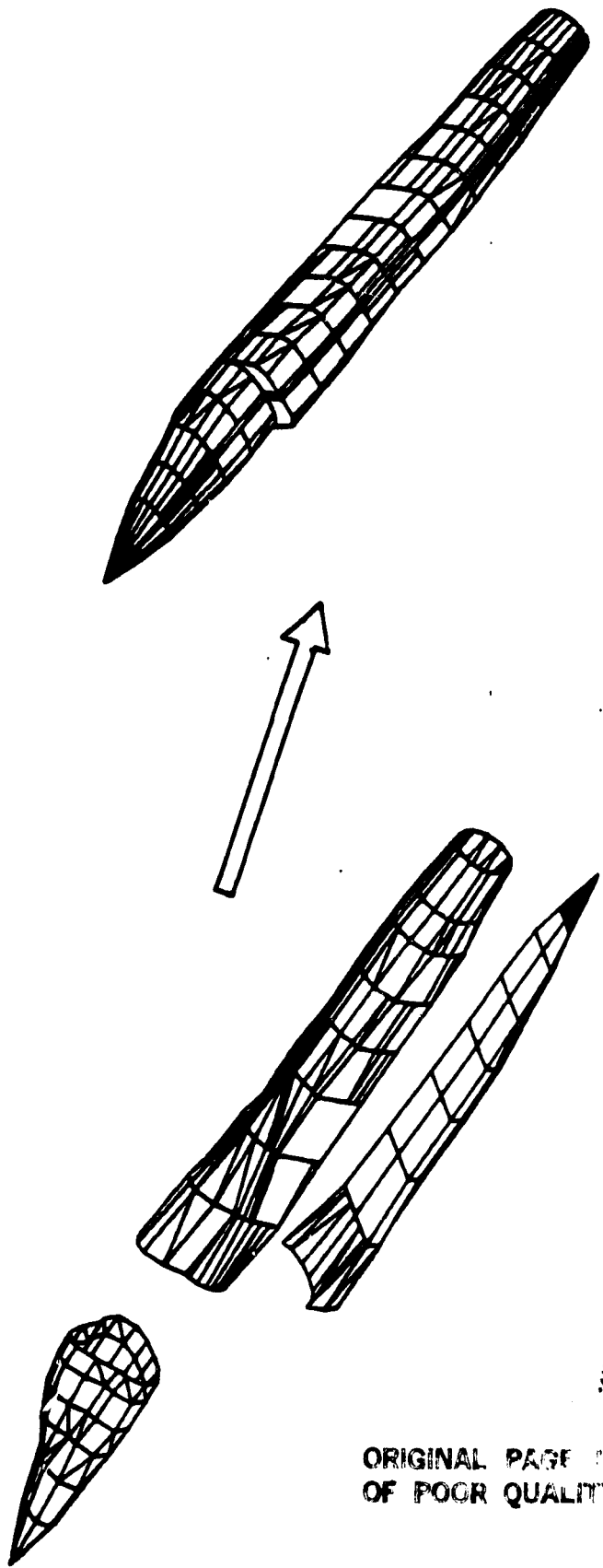
**THICKNESS AT SPECIFIED CONTROL LOCATION**

# SURFACE COMPONENT BREAKDOWN



# BODY COMPONENTS IN LIFT

CONVERT COMBINATIONS OF BODIES TO SINGLE ISOLATED BODY

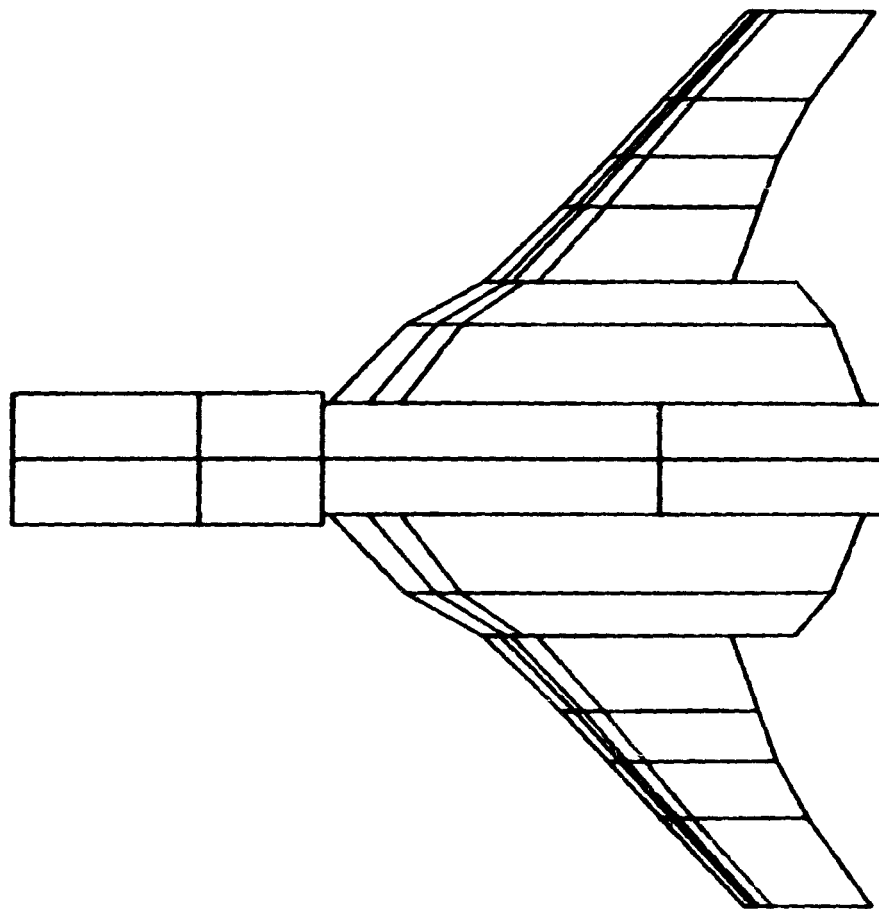


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# INTERFERENCE SHELL BUILDUP

ACCOUNT FOR INFLUENCE OF SURFACES ON BODY

CONSTRUCTED BY USER WITH AUTOMATIC SURFACE ATTACHMENT



# WAVE DRAG



USE SURFACE AND BODY GEOMETRY DIRECTLY

DISPLAY AREA DISTRIBUTIONS AS A FUNCTION OF ROLL ANGLE

DISPLAY DRAG VERSES ROLL ANGLE AND MACH NUMBER

# VISCOUS DRAG

INTEGRATE WETTED AREA FROM SURFACE AND BODY GEOMETRY

PRINT DRAG AS A FUNCTION OF COMPONENT

DISPLAY DRAG VERSES MACH NUMBERS FOR INPUT CONDITIONS

PRESSURE AND TEMPERATURE OR ALTITUDE

SURFACE ROUGHNESS

# RESULTS AND CONCLUSIONS

50% SAVINGS IN COSTS (REDUCED MAN HOURS)

60% SAVINGS IN TIME PER ANALYSIS ITERATION

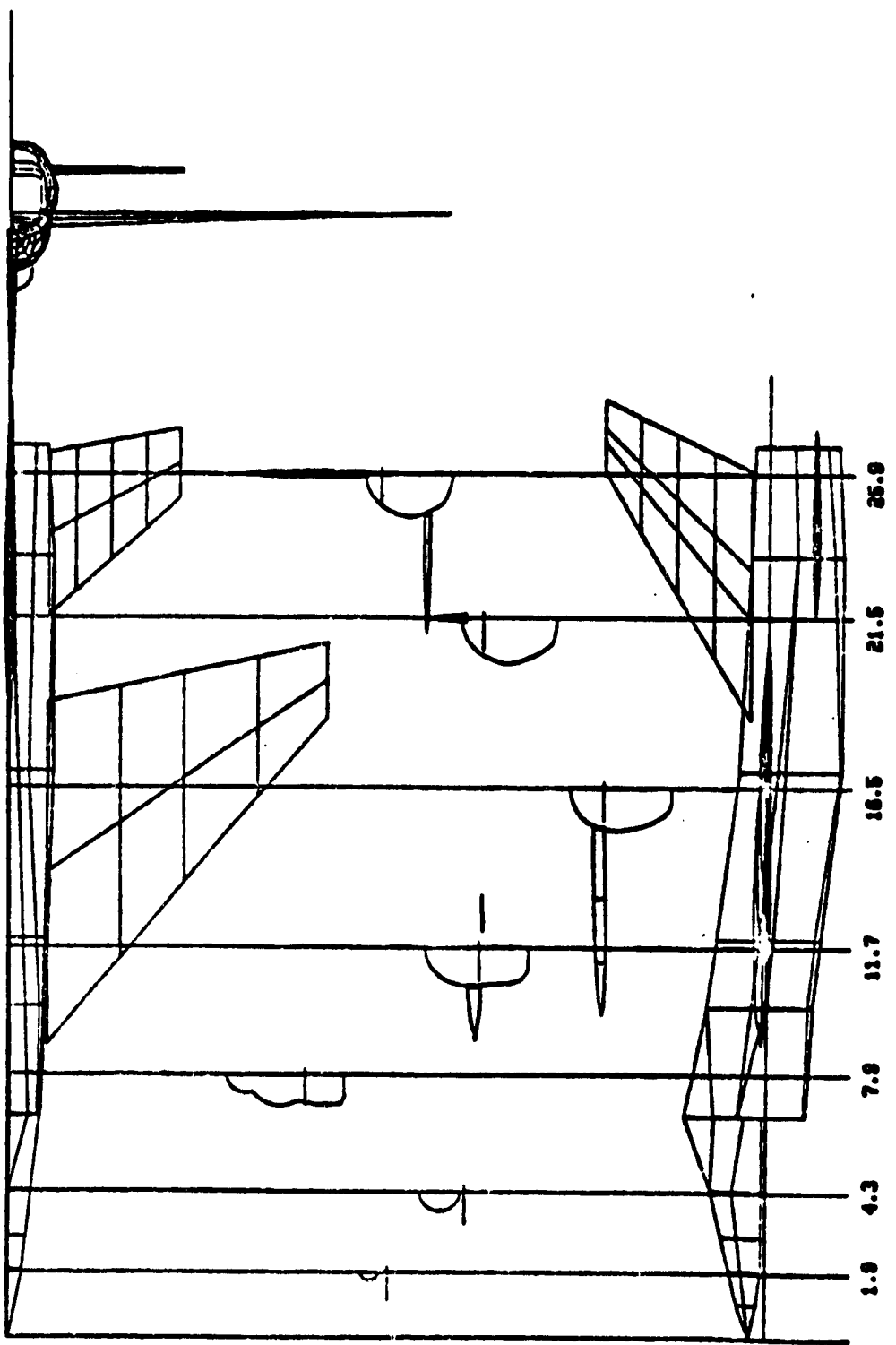
GEOMETRY INPUT WITH ONE MODEL

INPUT AND OUTPUT FULLY INTERACTIVE





SCIP-1 GEOMETRY INPUT MODEL



3 TRANSLATE 1 3 CROSS SECTIONS 2 3 DD 0 3

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11/07/77

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 SPAN 17.93 IN  
 YCG 0.0 IN  
 CBAR 7.466  
 ZCG 0.0

VISCOUS SOLUTION CASES

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2		521.0	2759.0	
3		521.4	2759.0	
4		610.0	3432.0	
5		610.2	4388.0	

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 1.00 2.00 2.16

RDD (IF APPLICABLE): 0.000

SOLUTIONS WHICH ARE AVAILABLE:

VISCOUS DRAG  
 VALUE ILL.0  
 LIFTING SURFACE

MACH NUMBERS IN SOLUTION:  
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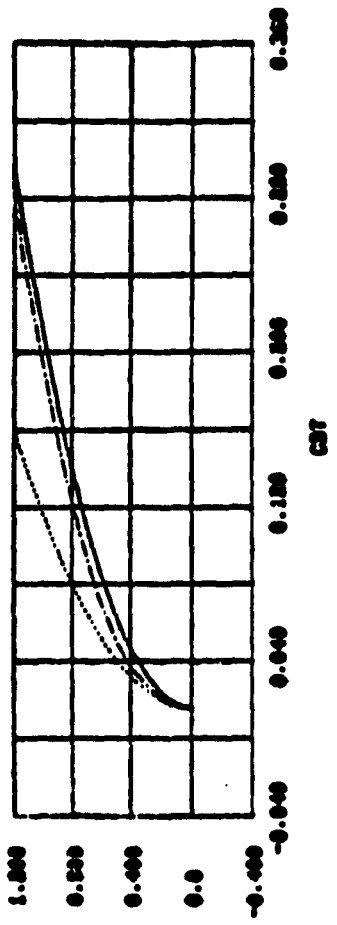
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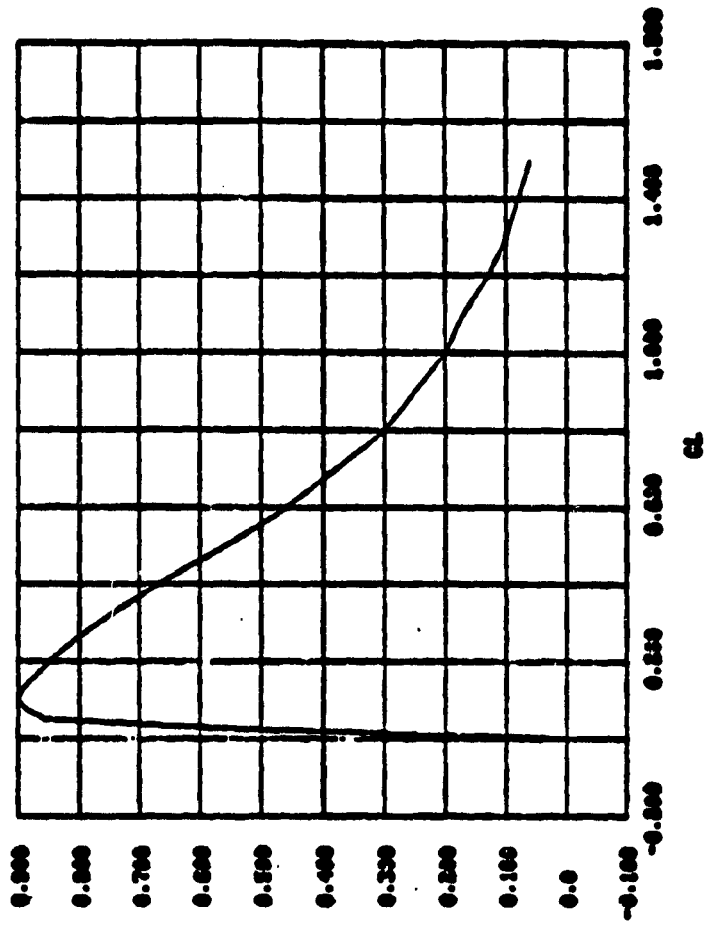
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SUCTION

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SUCTION CURVE

INCH NUMBER 10.00



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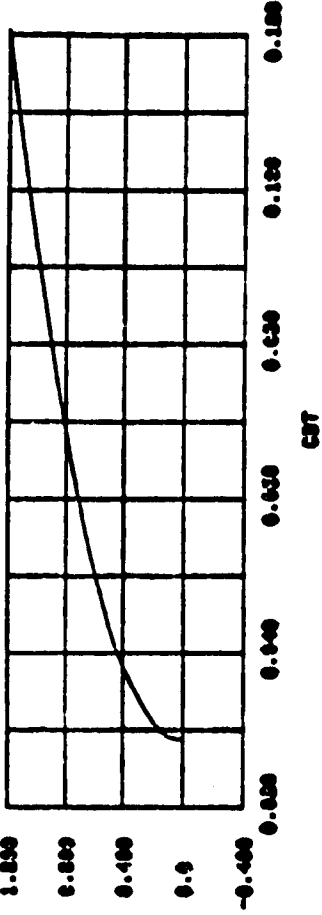
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BEAR DATA UNTRIMMED

INCH NUMBERS 1.00



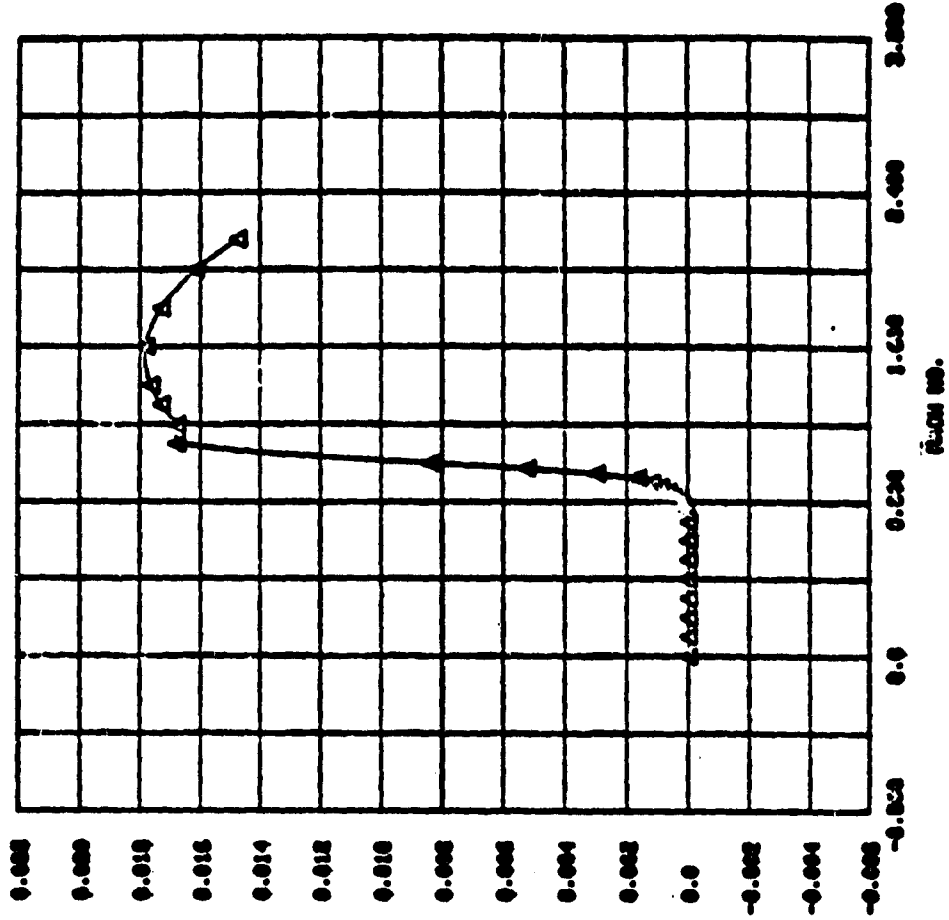
SCIP-1 GEOMETRY INPUT MODEL

11/07/77

REF. AREA  
 118.64 IN<sup>2</sup>  
 X<sub>CG</sub>  
 13.00 IN

SPAN  
 17.070 IN  
 Y<sub>CG</sub>  
 0.0 IN

CHORD  
 9.408 IN  
 Z<sub>CG</sub>  
 0.0 IN



SCIF-3 GEOMETRY INPUT MODEL

REF. AREA 18.00 IN  
 116.54 IN<sup>2</sup>  
 250  
 18.00 IN

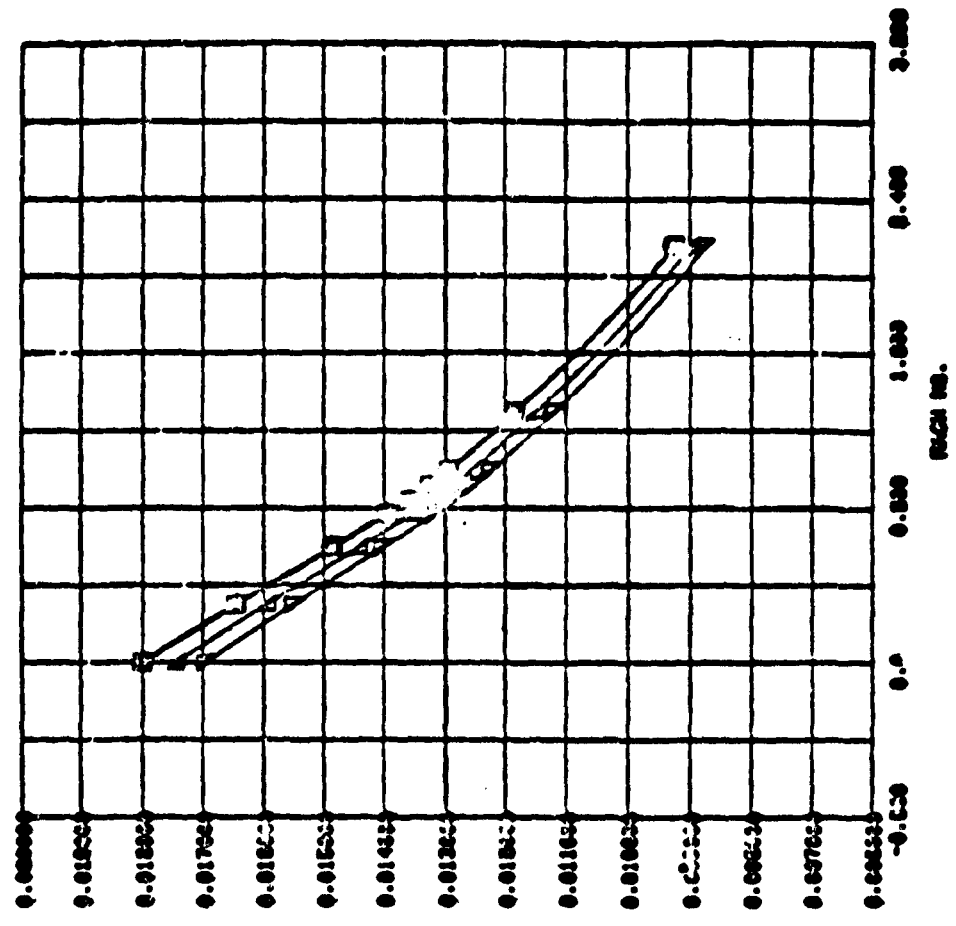
SPAN 17.035 IN  
 7.485 IN  
 250  
 0.0 IN

CHAS 7.485 IN  
 250  
 0.0 IN

CRP

SYM	TEMP (IN)	PCSS (LBS/FT <sup>2</sup> )
△	578.0	873.0
□	618.0	883.0
○	618.0	883.0
△	618.0	883.0
▽	618.0	883.0

BASE GRAIN HEIGHT: 0.0 FT.



# **FUTURE PLANS**

**INTERFACE WITH HYPERSONIC CODING (GENTRY)**

**INTERFACE WITH TRANSONIC CODING**

**IMPLIMENT REALISTIC STRUCTURAL AND PACKAGING CONSTRAINTS  
TO COMPLEMENT GEOMETRIC OPTIMIZATION**

**OPTIMIZE USE OF MINI AND MAIN FRAME COMPUTERS**

*DIVAN 32*

AIRPLANE SURFACE DESCRIPTIVE GEOMETRY  
REQUIREMENTS

**BOEING**

R. WALLACE  
MARCH 1978

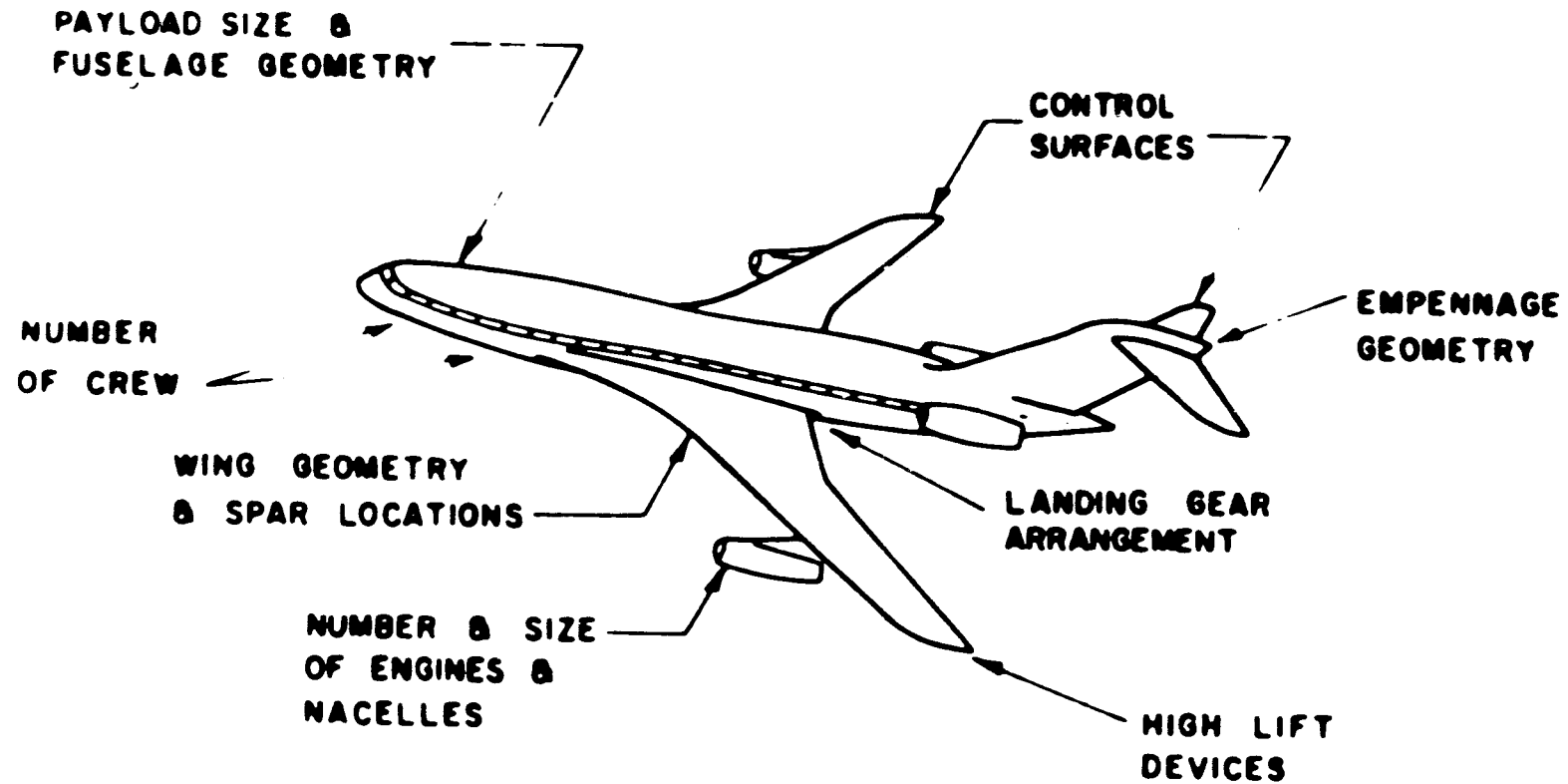
/



The geometric description of an airplane usually starts with a characterization of the configuration. There are only a few elements of a configuration, such as the payload, number of crew, number of engines, engine location, which are fixed. The remainder of the configuration characteristics, including fuselage geometry, wing geometry, control surfaces, empennage geometry, landing gear arrangement, wing high-lift devices, etc., are all variables that get perturbed during design evolution. Therefore, the first requirement on any airplane configuration geometry description system is flexibility. Easy modifications to geometry of a component, or the relations of components with respect to each other is essential.

Z Wallace

# CONFIGURATION DEFINITION



**BOEING**

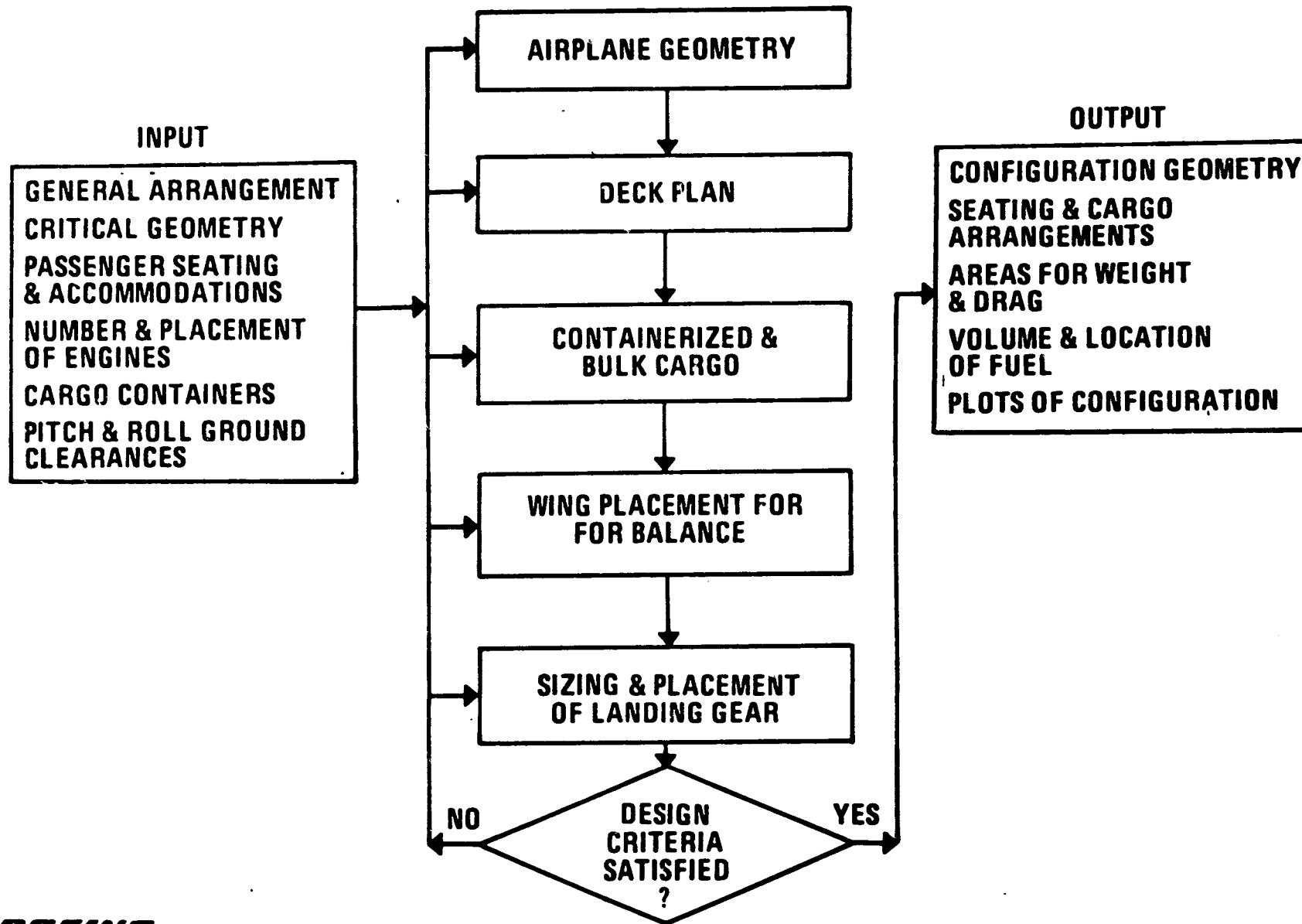
3 Wallace

WALLACE 2

Once the inputs are determined for an airplane design, the descriptive geometry process can begin. The payload can be accommodated, the wing can be placed properly for weight balance, the sizing and placement of the landing gear can be computed, and the myriad of design criteria to be satisfied by this configuration can be evaluated. The principal output from an airplane design includes the configuration geometry and the related geometrical information such as the payload accommodation, areas, volumes, and graphic portrayal of the design process results. The areas, volumes, and geometrical arrangement of a configuration are essential for determining performance and handling characteristics by analysis and experiment.

4 Wallace

# AIRPLANE DESIGN

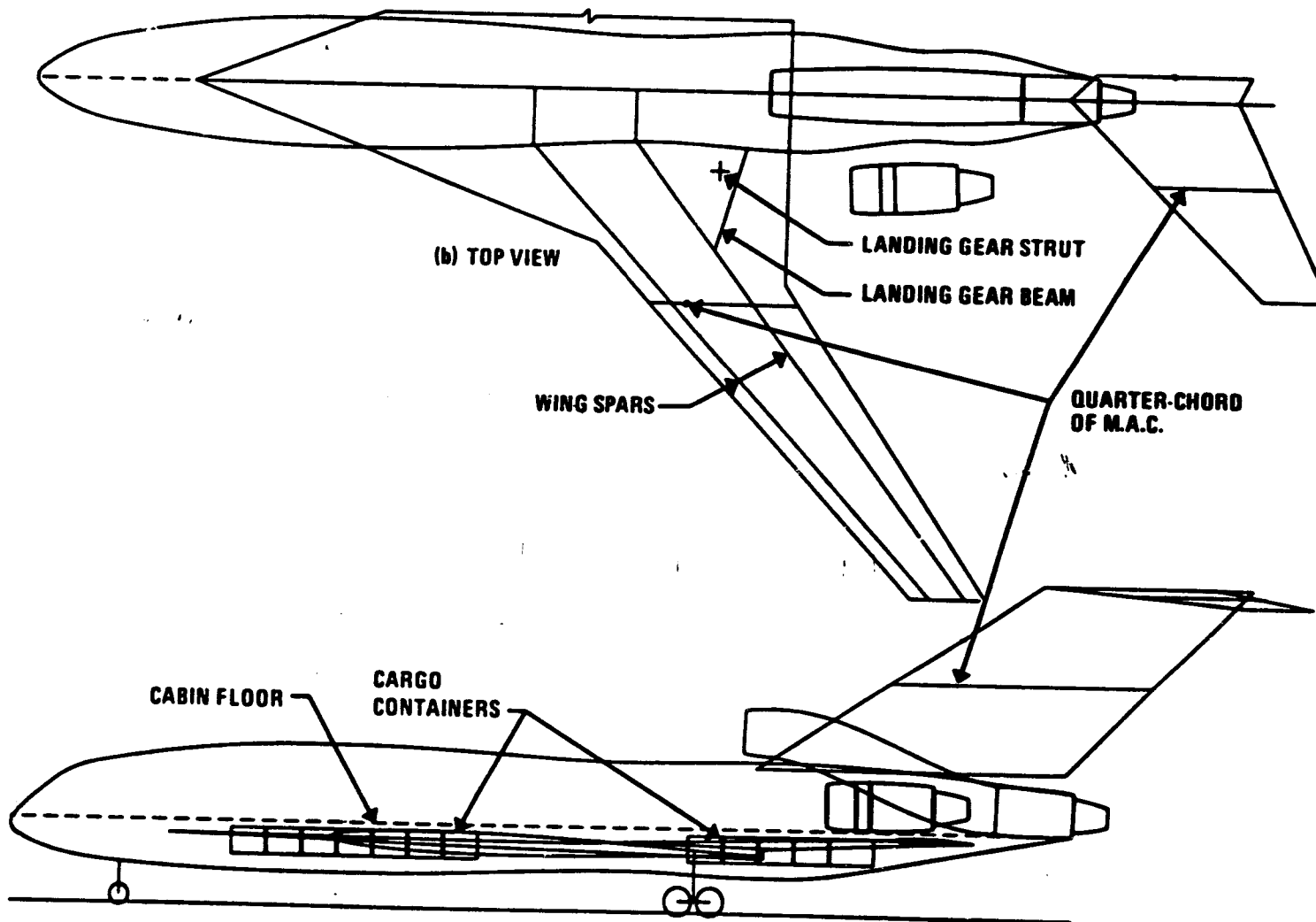
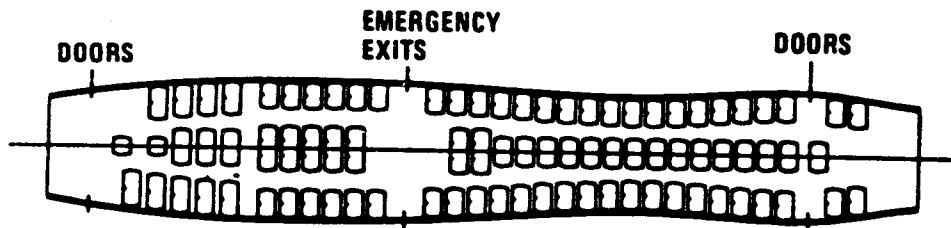


**BOEING**

This result of a preliminary design exercise for a transonic airplane configuration shows many of the elements described by the prior charts. A transonic airplane, typified by this NASA contract study configuration, has the added complex requirement of satisfying an area rule distribution. Therefore, any relatively minor modification such as wing area, nacelle placement, etc. has major significance to the total design compatibility. Simultaneous satisfaction of all design requirements and performance criteria demands very sophisticated and efficient geometry processing. This figure illustrates many of the variables that have a first order constraining effect on airplane geometry description.

6 Wallace

# TRANSONIC AIRPLANE CONFIGURATION

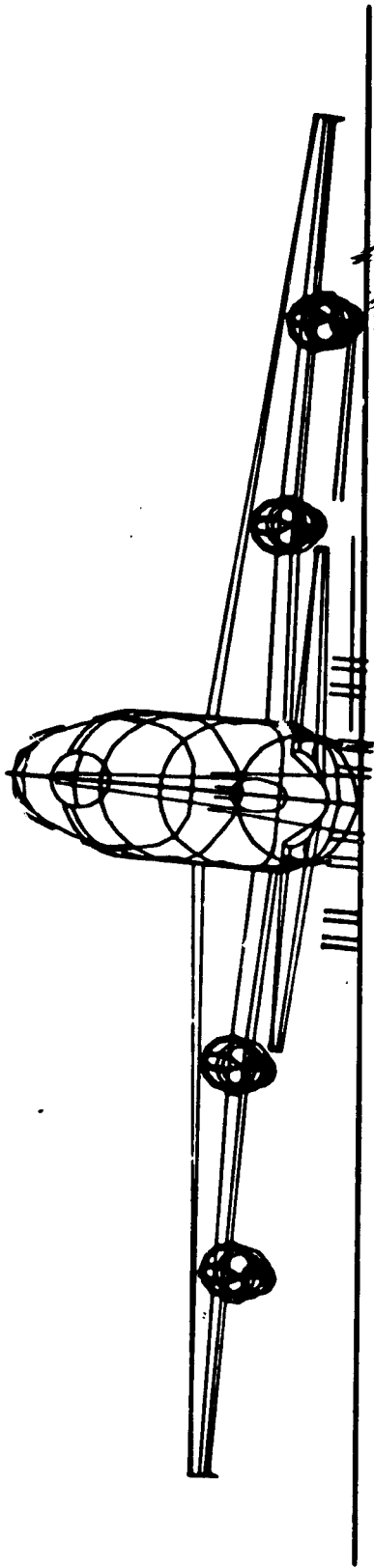


**BOEING**  
T Wallace

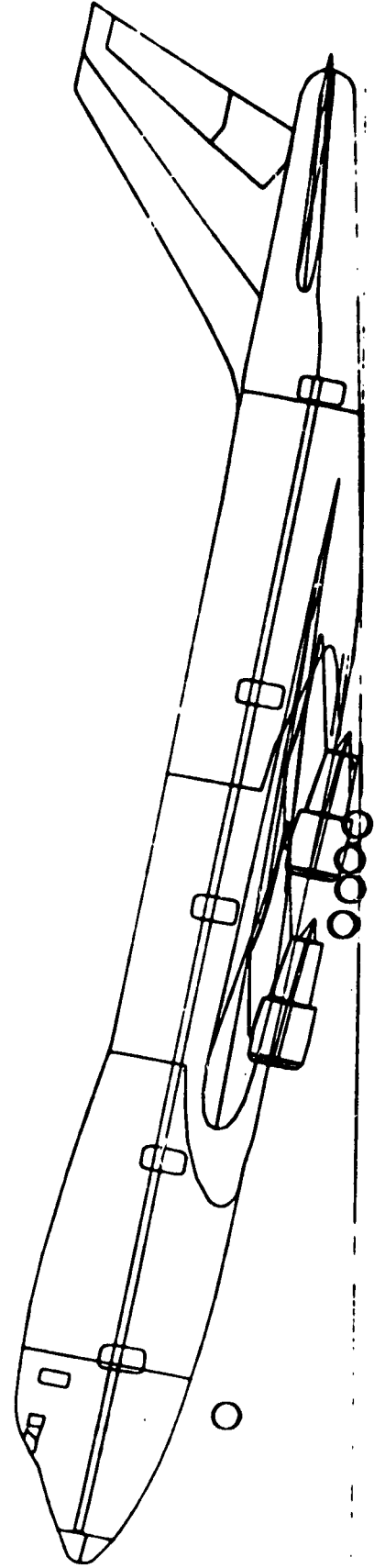
(e) SIDE VIEW

As indicated earlier by the airplane design block diagram, one of the geometry requirements on the complete configuration are the pitch and roll ground clearances as shown by this line drawing of the 747. These geometric conditions are necessary for flight control evaluations, damage determination studies, and pilot vision polars. Again, if any of these critical conditions are not met by the airplane configuration, then the geometry must be changed.

**COMPUTER GRAPHICS ILLUSTRATION OF CONTACT  
POINTS IN ROLLED, TAIL BUMP ATTITUDE**



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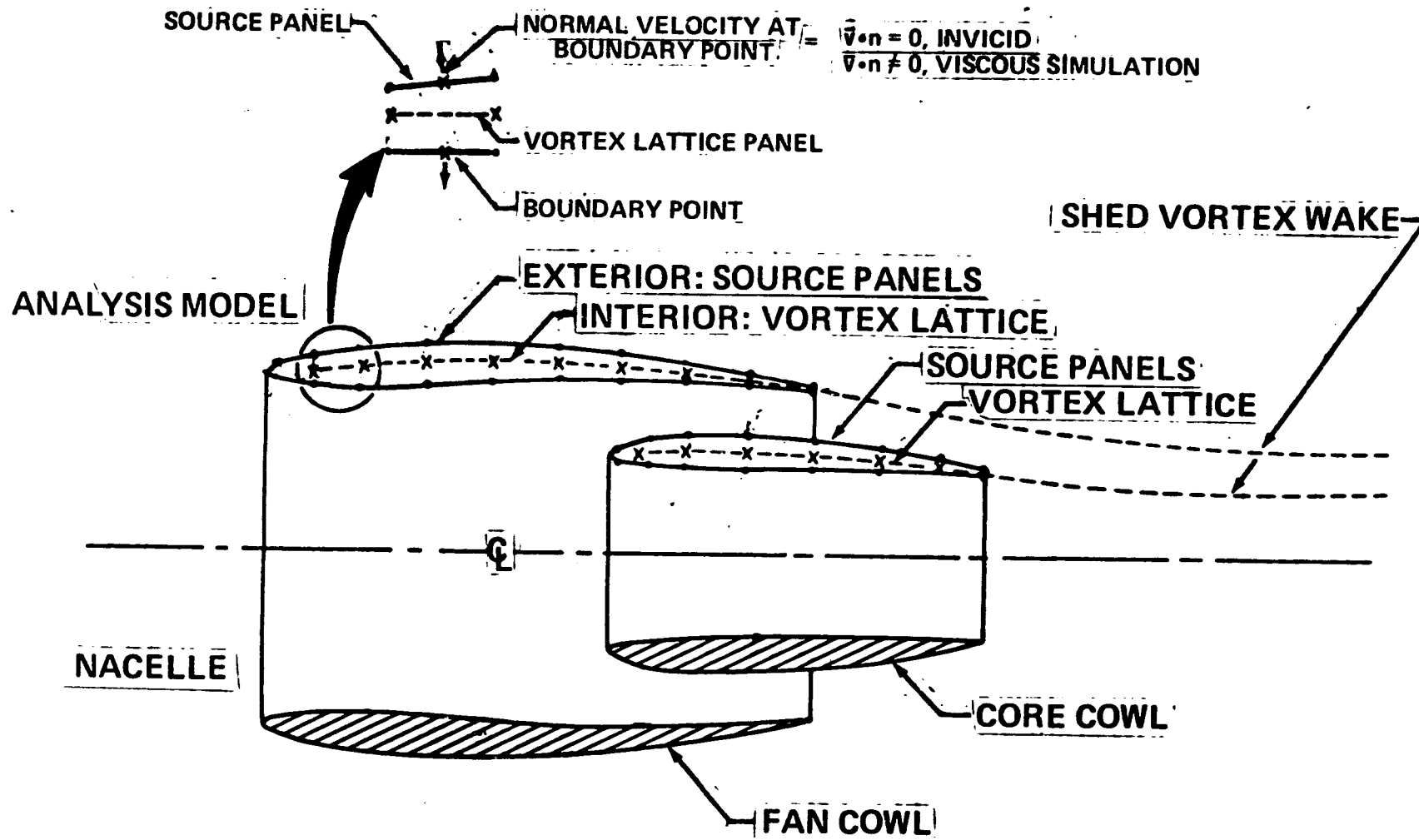
**BOEING**

9 Wallace



During configuration design or analysis, it is necessary to perform extensive analytical and experimental studies. Ideally, the same geometry is used for generating mathematical representation of an airplane configuration and its corresponding flow fields as is used to generate wind tunnel models for testing. This figure shows one kind of mathematical representation of an engine nacelle and its associated exhaust flow. This representation is typical of analyses used to determine nacelle interference with wing air flow properties.

# PANEL AERODYNAMICS SINGULARITY REPRESENTATION OF DUAL-BARREL FLOW NACELLE



**BOEING**

W Wallace

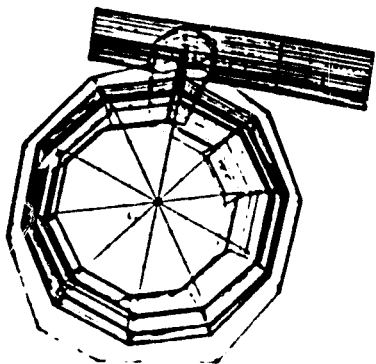
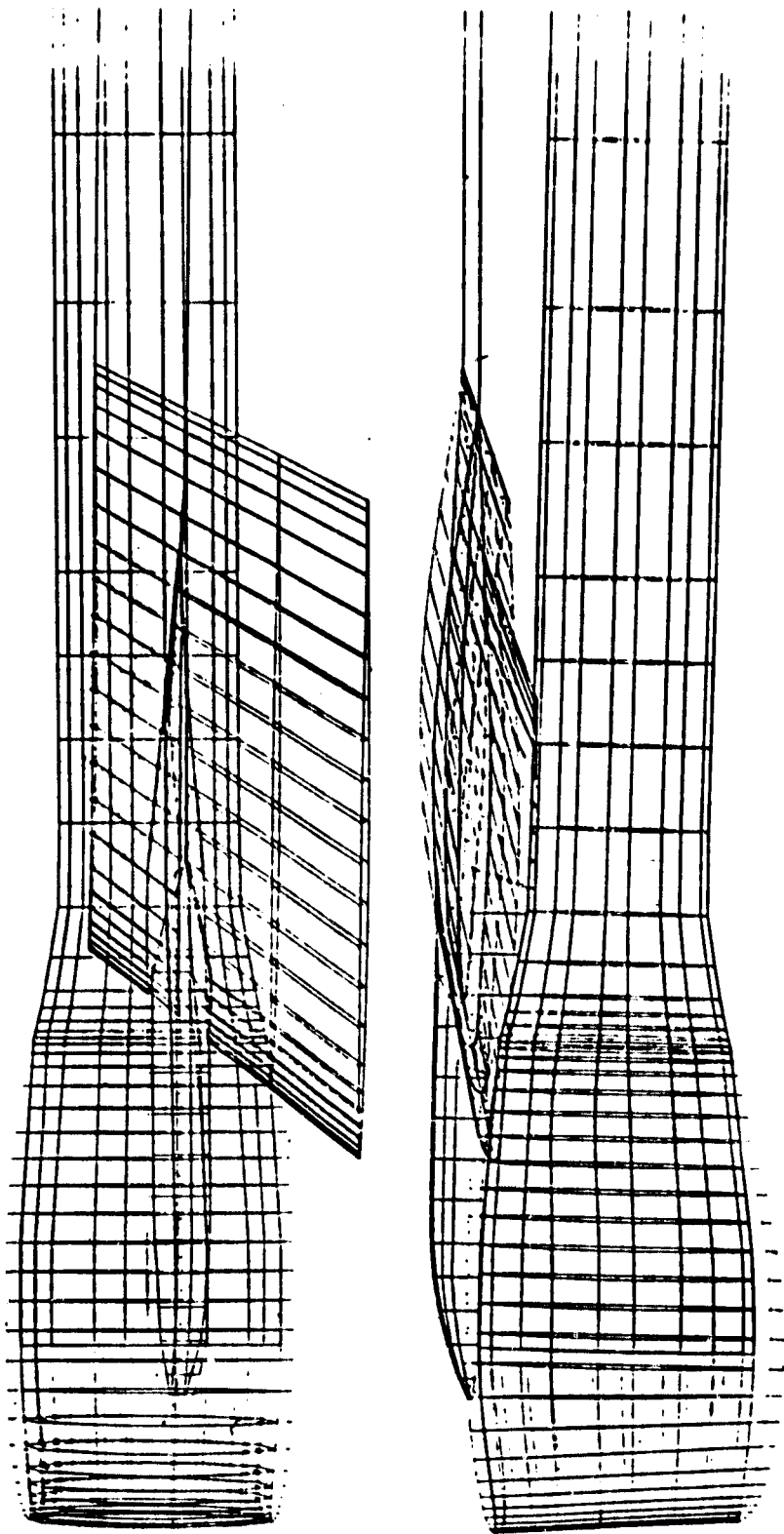
16

11

Once the nacelle geometry details have been adequately modeled, with suitably dense singularity arrays, then there is a gradual buildup to the complete configuration. This figure shows the addition of the nacelle strut and adjacent wing to the nacelle. This three-view layout illustrates the complex local tailoring associating with a close coupled nacelle. The nacelle is canted with respect to the strut and the wing and the strut is tailored to minimize local interference. This complexity is readily seen in these orthogonal views.

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12 Wallace



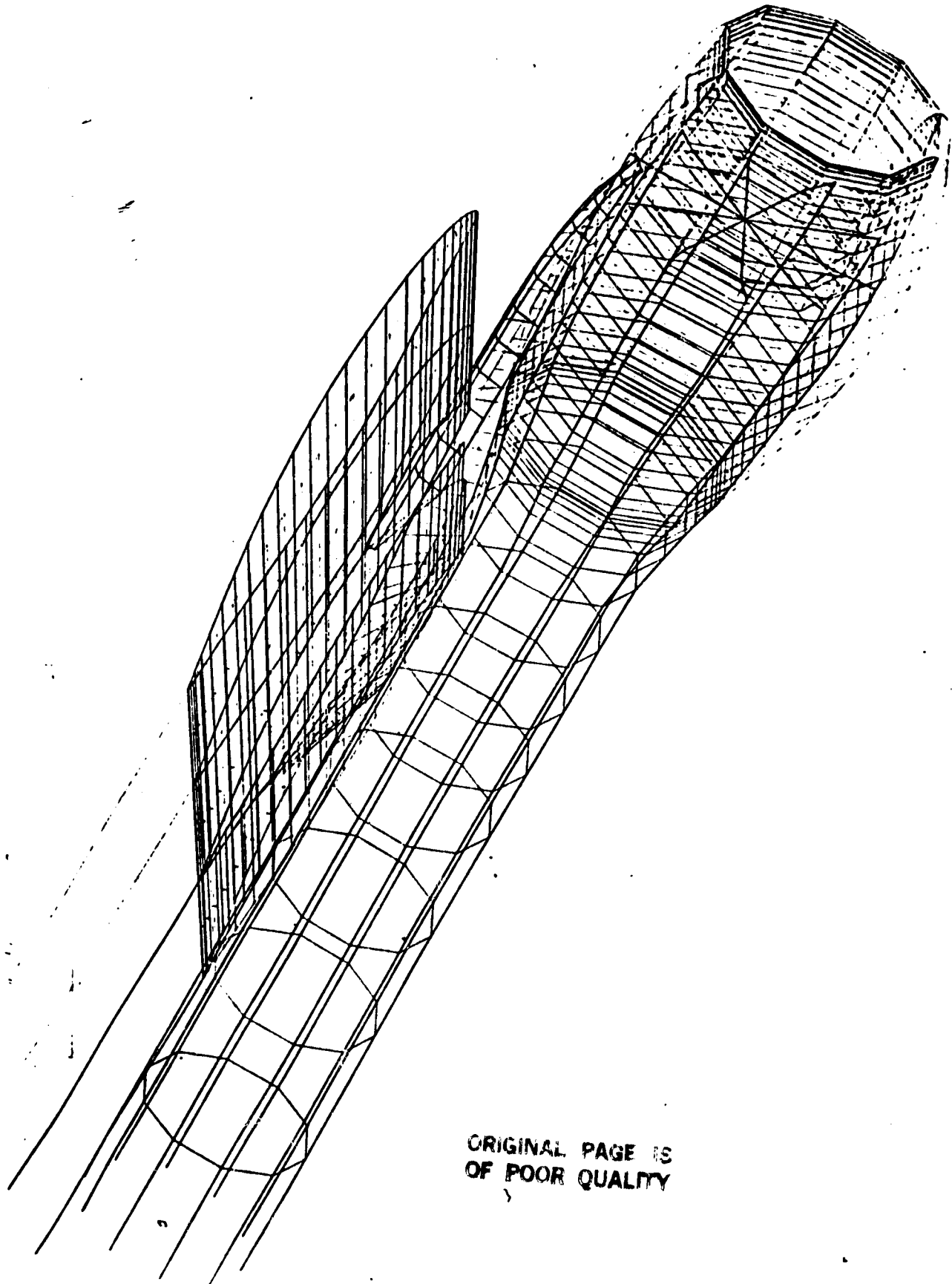
**BOEING**

13 Wallace

13

A perspective view of the wing segment, nacelle strut, nacelle and its associated flow control surfaces is the best way to appreciate its geometric intricacy. Notice that the exhaust flow tube is controlled well past the wing trailing edge and there is an intake flow control surface located within the nacelle under the leading edge of the nacelle strut. All of these singularity surfaces are necessary to accurately evaluate the engine installation interference flow phenomena.

14 Wallace



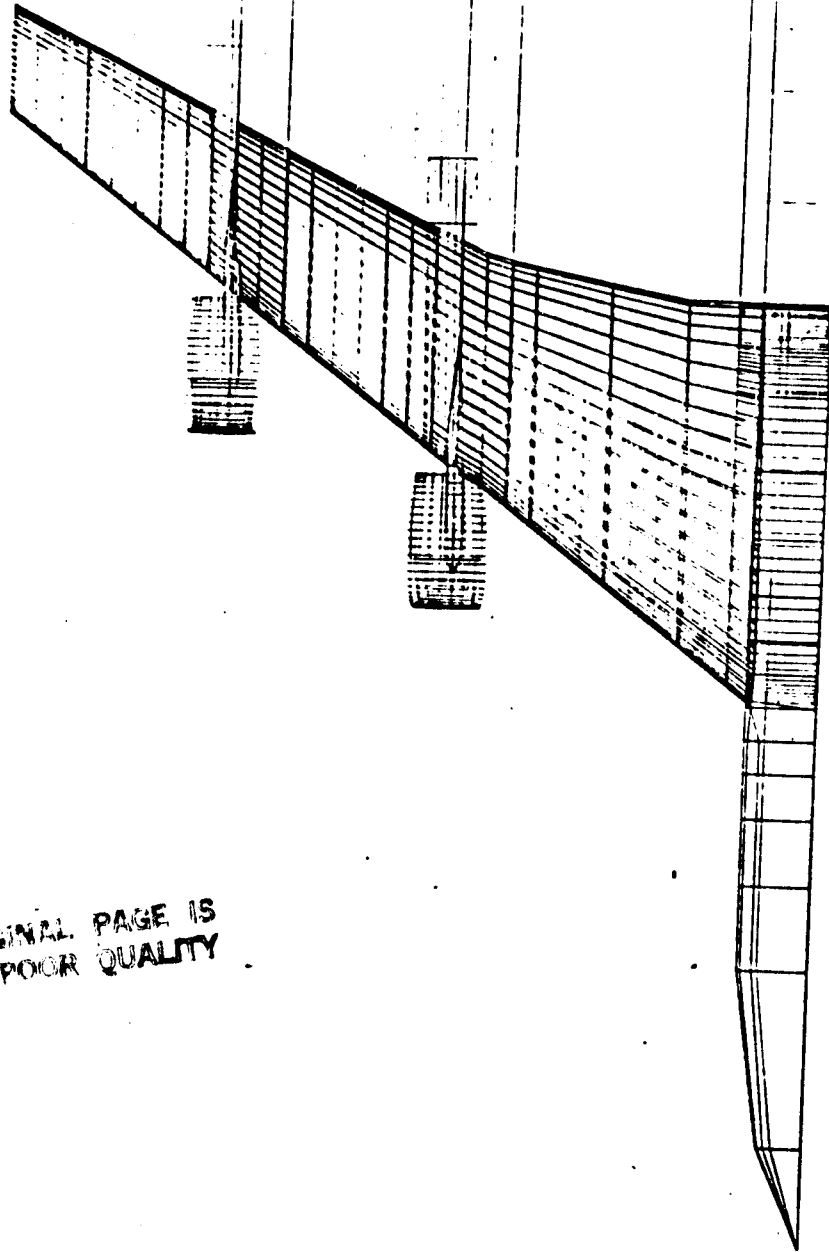
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**BOEING**

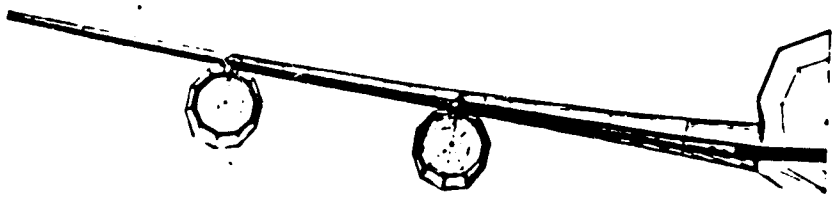
15 Wingcase

This two view drawing shows the complete model used for the study. The body was simplified, because of its remote distance from the region of interest. There are approximately 2700 singularities associated with the analytical model, which produces a like number of simultaneous equations for solution. Therefore, the computing cost of such a complex mathematical problem requires very accurate geometrical modeling with adequate visibility of that geometry prior to committing to the computing process. One set of computed solutions can cost as much as many wind tunnel model test runs.

16 Wallace



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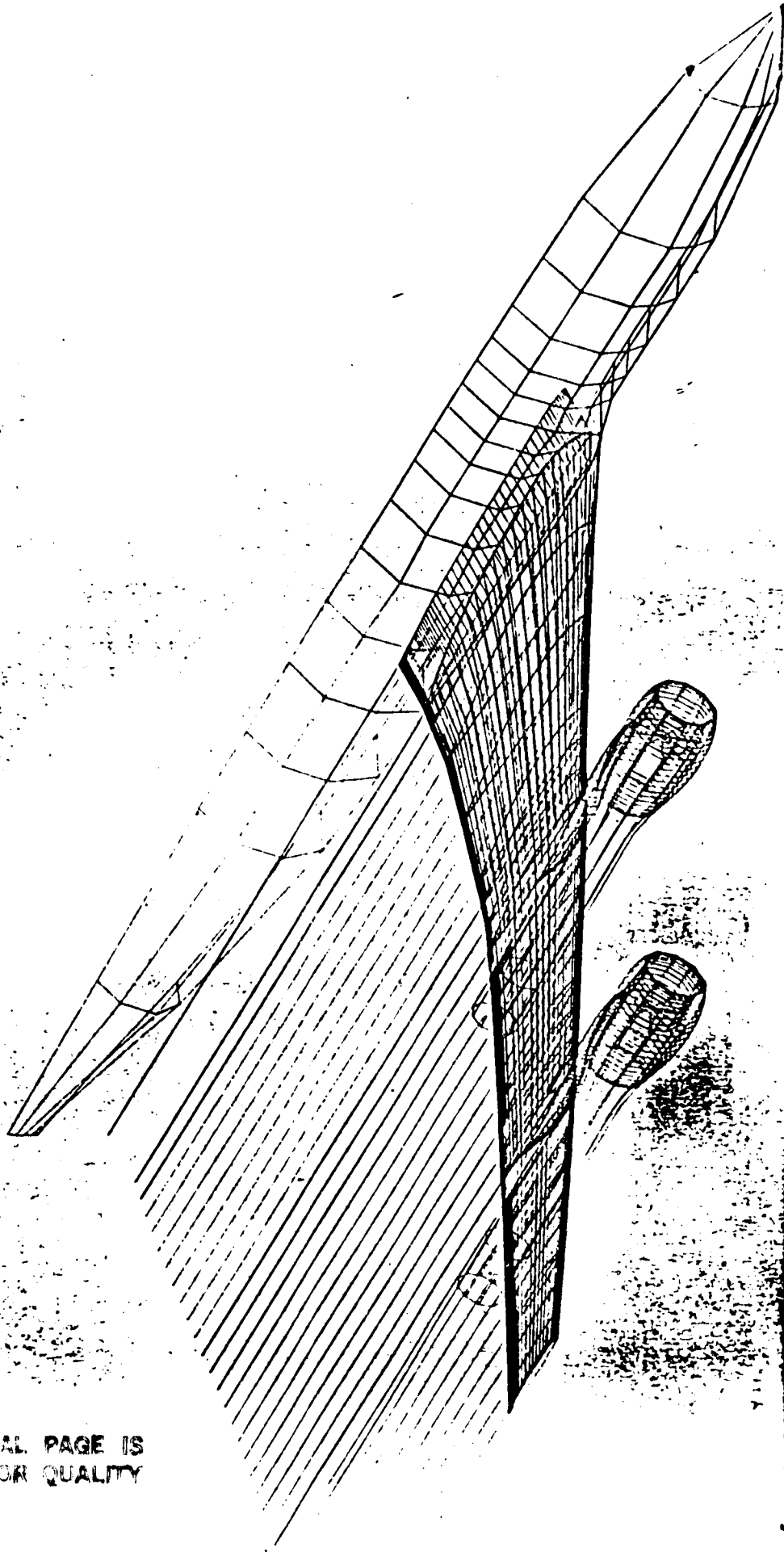
**BOEING**

17 Wallace



This perspective view illustrates more clearly the regions of sparse and dense singularities for representing a complete three-dimensional configuration.

18 Wallace



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**BOEING**

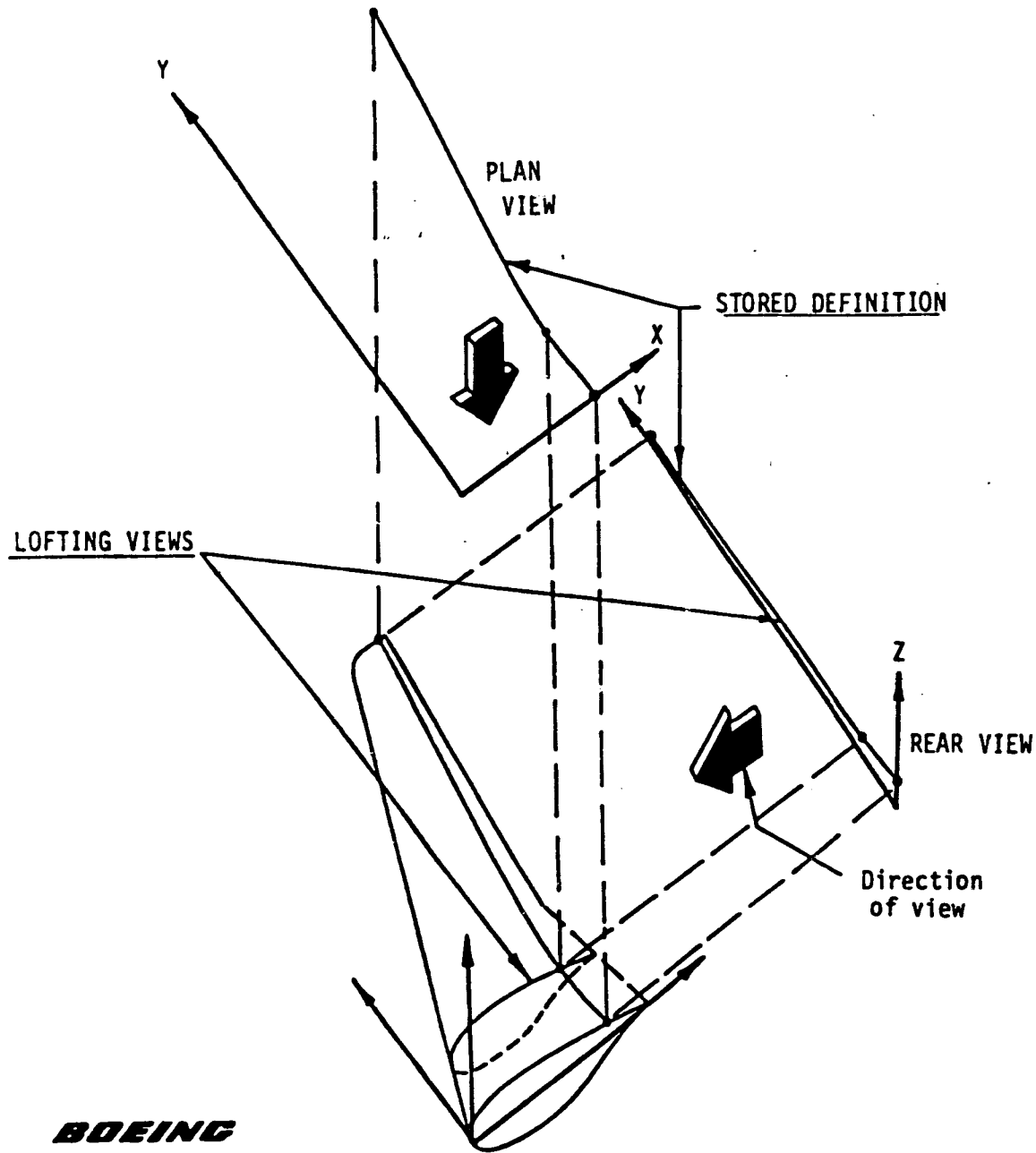
19 Wallace

Before describing geometry system requirements as they are viewed today, it is well to understand current lofting practice of The Boeing Commercial Airplane Company. This wing perspective drawing shows the lofting views constructed for generating a stored definition in two views; plan view and rear view. This process, of course, has its heritage in the ship building industry. Two types of curves have been prevalent in this current practice: (1) conic chains, and (2) cubic chains. The conic chain has been the traditional favorite, because it is simple to generate by most mechanical drawing processes and to check by most manual computing methods. It is also easy to control inflection points. This curve type is used for the master definition of production configurations.

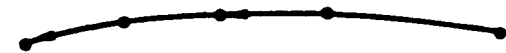
The cubic chain with its point, slope, and curvature continuity at given nodes has usually been best suited for design and development purposes. It is analagous to the process of using ducks and a spline on the drawing board. It is practical to embellish this mathematical representation with both point enrichment and smoothing processes. However, cubics have the disadvantage of causing ripples or inflection points for data sets that are not smooth initially. These traits make more complex algorithms necessary for generating good cubic chain curves.

20 Wallace

# CURRENT LOFTING PRACTICE



## CONIC CHAIN CURVE



- BEST FIT TO POINTS WITH SLOPE CONTINUITY
- MASTER DEFINITION

## CUBIC CHAIN CURVE



- POINT AND SLOPE CONTINUITY
- DESIGN AND DEVELOPMENT

**BOEING**

21 Wallace

Current practices using conic and cubic curves present significant limitations for the geometry description of an airplane configuration and its components. Multiple curve types cause difficulties with geometry automation and for the design user. The single-valued surfaces associated with current lofting practices are usually imposed by the extraction process which cannot adequately distinguish between multivalued components. Another difficulty encountered is mating surfaces of various components, because the surfaces are defined as projected control curves. This representation makes the definition (stored as equation coefficients) very expensive to uniquely transform between skewed coordinate systems.

All of these cited factors complicate the design and analysis processes, because they are not very flexible and are costly to use. In many cases, the systems are designed mostly for geometry extraction and provide little flexibility for geometry generation processes, which often require data enrichment and extensive three-dimensional smoothing.

22 Wallace

## LIMITATIONS OF CURRENT PRACTICES

### MULTIPLE CURVE TYPES

- COMPLICATES SMOOTHING
- COMPLEX DEFINITION STORAGE
- DIFFICULT DATA EXTRACTION

### SINGLE-VALUED SURFACES

- DIFFICULT JOINT SMOOTHING
- COMPLICATES MULTI-VALUED COMPONENTS

### SURFACE MATING

- DIFFERENT AXIS SYSTEMS
- PROJECTED CONTROL CURVES

### LIMITED TRANSFORMATIONS

- NO DIRECT TRANSFER BETWEEN SKEWED AXES
- REFIT EXTRACTED POINTS

### DESIGN AND ANALYSIS

- DESIGN REQUIRES ENRICHING AND SMOOTHING
- ANALYSIS DATA EXPENSIVE TO EXTRACT

Basic geometry system requirements contain two principal factors, the first of which is mathematical. The mathematical factors directly lead to the conclusion that surface representation is best accomplished with parametric, biquintic patches. This makes mathematical practice reasonably consistent with past cubic concepts, except that the higher order polynomial provides the essential element of local character. The parametric form provides the necessary capability for handling multivalued surfaces and performing smoothing and extraction processes with more consistency, since quintic equations are used over an entire surface. Where simple curve types, such as straight lines and circles become necessary, the quintic equations are perfectly adequate for defining these surface regions to well within data extraction computation accuracy.

## BASIC GEOMETRY SYSTEM REQUIREMENTS

MATHEMATICAL FACTORS ARE -

(1) ONE CURVE TYPE PATCHES

(2) CONTINUOUS CURVATURE SURFACES

(3) LOCAL CHARACTER PATCHES

(4) REAL, MULTIVALUED SURFACES

(5) ENRICHING, SMOOTHING & EXTRACTING

} BIQUINTIC

} PARAMETRIC FORM

**BOEING**

25 Wallace



The second major factor associated with basic geometry system requirements is the user working environment. The two primary innovations that have recently improved the geometry working environment are the minicomputer and its associated micro processors for use in interactive graphics devices. With th's hardware capability it is practical to provide excellent accuracy with low computing costs in a geometry system that can be used all the way from preliminary design through to detailed design activities. It is essential for all engineering technologies to have access to and influence the design geometry evolution to adequately reflect their responsibilities. Conversational interactive graphics gives the average user a reasonably acceptable working environment which will not overwhelm him with the necessity for training that makes him a computer expert. The last environmental requirement is communicating geometry with accuracy and speed between all involved developers as well as the ultimate users, who are charge with building the airplane.

## BASIC GEOMETRY SYSTEM REQUIREMENTS

ENVIRONMENTAL FACTORS ARE -

- (1) GOOD ACCURACY & LOW COMPUTING COST
- (2) ONE SYSTEM FOR PRELIMINARY & DETAILED DESIGN
- (3) EQUALLY USEFUL FOR ALL ENGINEERING TECHNOLOGIES
- (4) USE CONVERSATIONAL INTERACTIVE GRAPHICS
- (5) AUTOMATE GEOMETRY DATA BASE INTERFACES

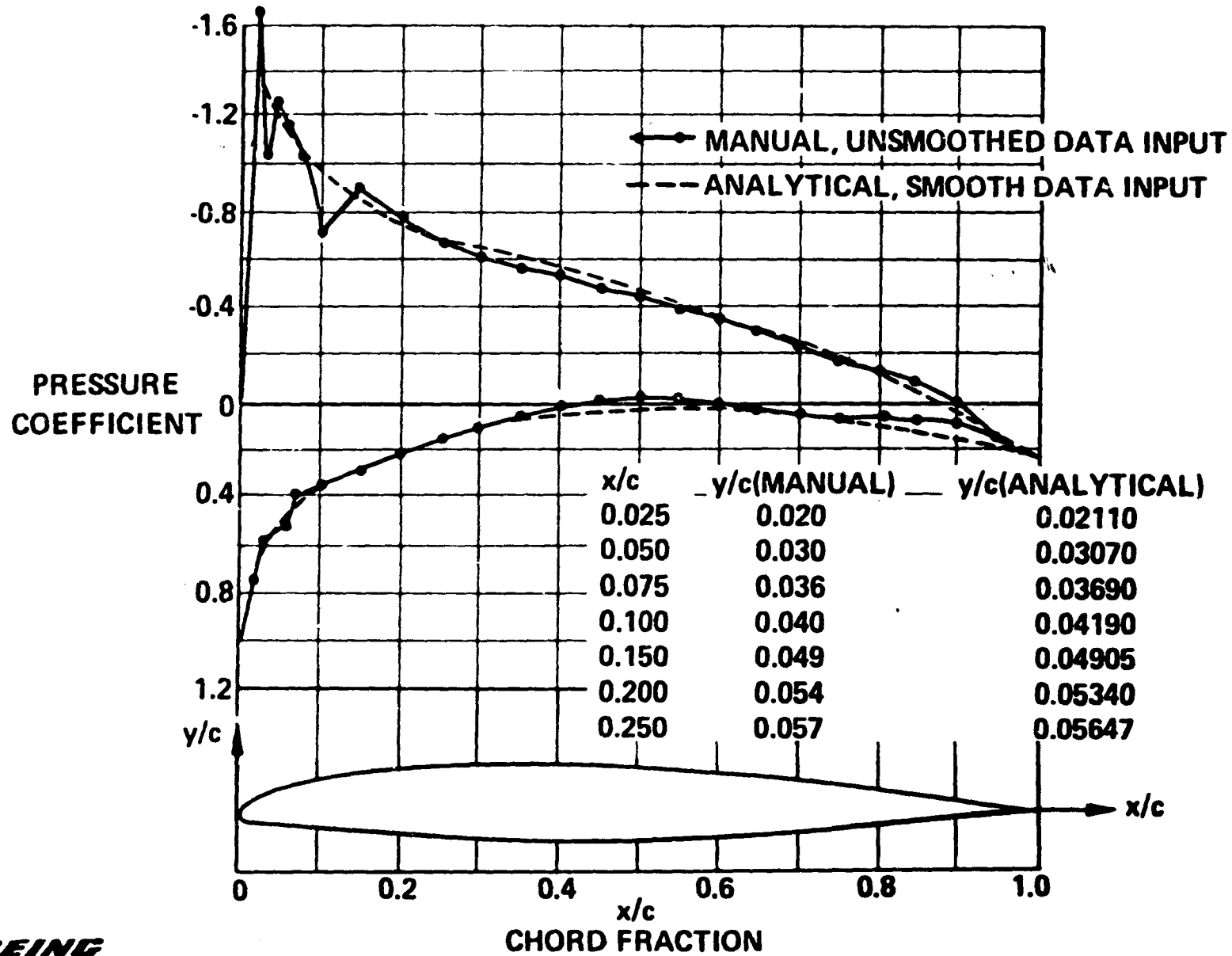
**BOEING**

27 Wallace

27

This figure shows the implications of smoothing on analytical results. A simple exercise was performed to manually record the coordinates of an airfoil to compute its pressure distribution. As seen from the pressure coefficient graph, the manual unsmoothed data caused severe adverse pressure gradients near the nose of the airfoil, which would probably lead to local adverse effects on the boundary layer, if not separation. Similarly, at the trailing edge there was an added adverse gradient due to the data irregularity. Simple two-dimensional analytical smoothing produced the smoother more satisfactory dashed line results. In all honesty, this was not a rigged case, but simply an illustration of an everyday event when accomplished without proper attention to geometric properties. The results cause poor aerodynamic performance.

# PRESSURE DISTRIBUTIONS COMPUTED FROM MANUAL & SMOOTHED ANALYTICAL DATA



**BOEING**

29 Wallace

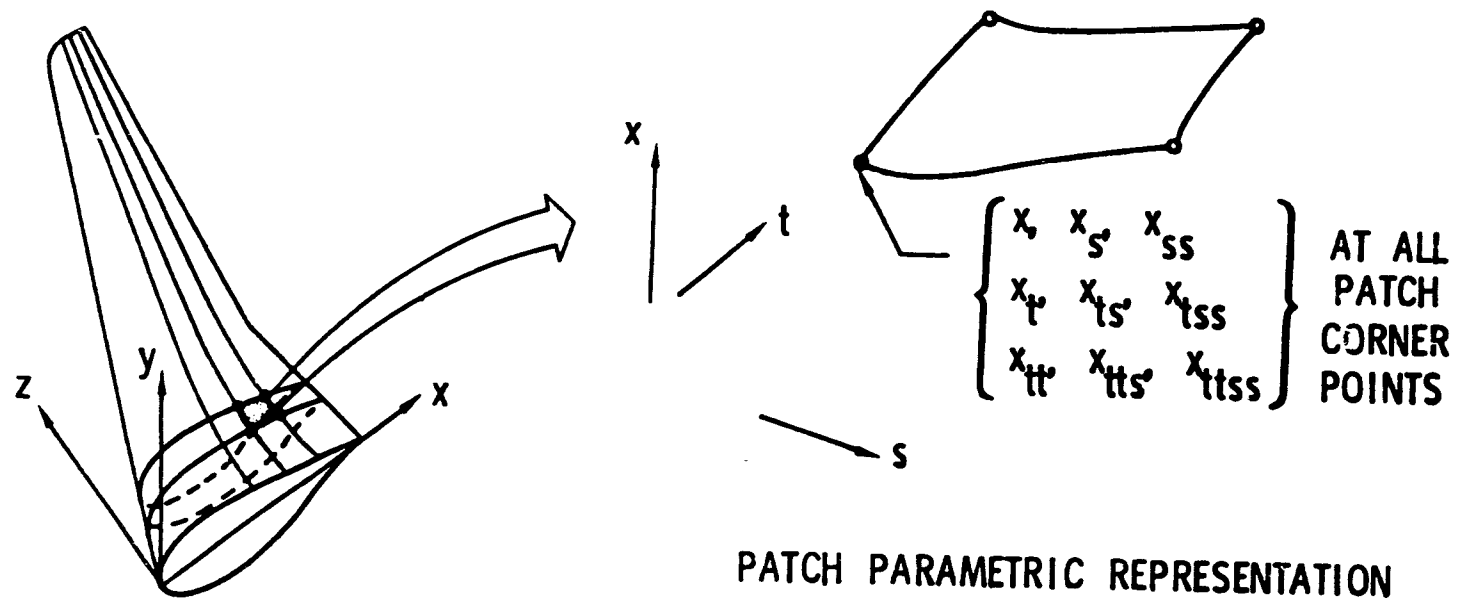
29

The two-parameter biquintic surface representation takes the equation form shown on this chart. Using the previous wing illustration, the patch shown in real geometry is mathematically handled in parametric form and the definition is stored as derivatives at the corner points rather than as coefficients of the respective bounding quintic lines. There are many advantages to this type of representation when put into practice as computerized methodology.

# TWO-PARAMETER SURFACES

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x(s, t) \\ y(s, t) \\ z(s, t) \end{pmatrix} \quad \text{WHERE} \quad x(s, t) = \sum_{i=0}^5 \sum_{j=0}^5 x_{ij} s^i t^j$$

PARAMETRIC BIQUINTIC EQUATIONS



PATCH REAL GEOMETRY

PATCH PARAMETRIC REPRESENTATION

**BOEING**

31 Wallace

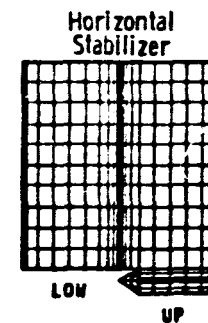
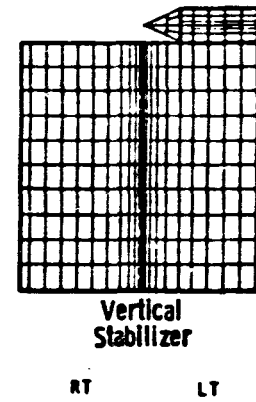
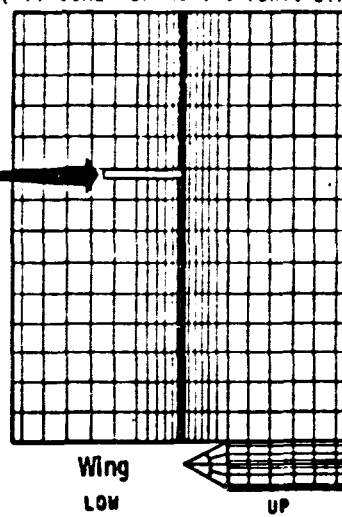
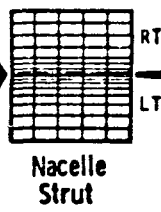
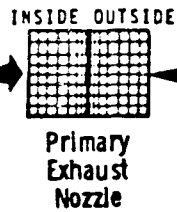
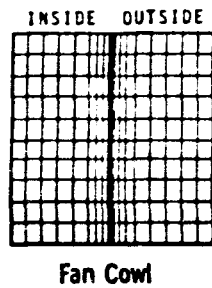
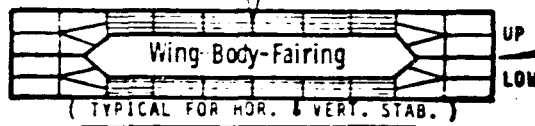
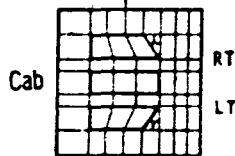
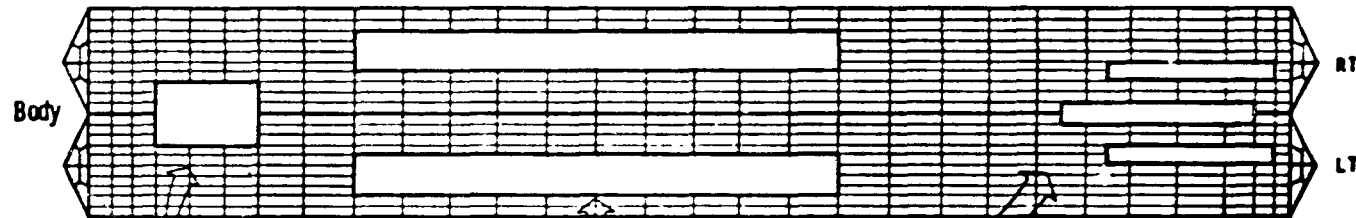
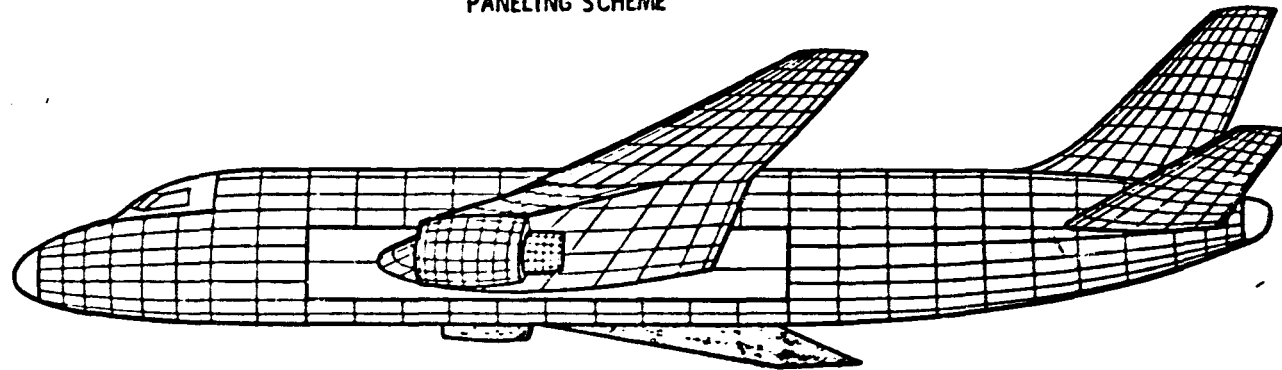
To illustrate the data for representing a typical airplane configuration these data array schematics are shown. At the juncture of every pair of lines there is a data set corresponding to that corner of the patch. Note that most of the data arrays are rectangular. Except for the cutout regions where spatial fairing properties are necessary, the configuration paneling is straightforward. Where intersections cause local need for fairing or irregular boundaries, then spatial handling techniques are required.

Developing the paneling representations of a configuration without considerable automation, is a very tedious and time-consuming task. It is not uncommon for an engineer to expend a man month in developing such extensive paneling schemes. Usually it is necessary to build these representations in an component-by-component fashion. By running simple evaluations of isolated components, it then becomes possible to develop confidence that the final results sought will be computed with good accuracy. It is very common to find that people have been unable to perform a satisfactory analytical evaluation of a configuration, simply because there was insufficient time to develop the geometry and its associated paneling scheme.

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PANELING SCHEME

Airplane Configuration



**BOEING**

33 Wallace

WALLACE 33



## SUMMARY

### 1 - BASIC REQUIREMENTS TOUGH TO SATISFY

- ONE CURVE TYPE WITH LOCAL CHARACTER
- MULTIVALUED, REAL SURFACES
- ENRICHING & SMOOTHING WITHOUT DISTORTION
- VERY ACCURATE, YET EASY TO CONTROL & CHEAP TO USE

### 2 - TECHNOLOGY IS AVAILABLE FOR SYSTEM DEVELOPMENT

- MATHEMATICS OF BIQUINTICS & TOPOLOGY
- MINICOMPUTER REFRESH GRAPHICS
- LARGE SCIENTIFIC COMPUTERS
- EXPERIENCE WITH LESS CAPABLE GEOMETRY SYSTEMS

**BOEING**

34 Wallace

WALLACE 34

AIRCRAFT CONFIGURATION MODELLING

ANALYTICAL METHODS INC

BELLEVUE , WASHINGTON.

D. CLARK AMI /

BASIC REQUIREMENTS

- SIMPLE ( TO USE )
- DIRECT
- ACCESSIBLE
- RESPONSIVE
- COMPACT

AMI CLARK  
2

INPUT OF THE CONFIGURATION

<u>PANEL BY PANEL</u>	CORNER POINTS	<u>ACCEPTABILITY</u> <u>UNACCEPTABLE</u>
<u>SECTION BY SECTION</u>	EACH POINT DEFINED. MACHINE CONNECTS ADJACENT SECTIONS TO MAKE PANELS	FAIR 1
	DEFINE CURVE. MACHINE DIVIDES AND CONNECTS.	GOOD 1
<u>BLOCK BY BLOCK</u>	DEFINE END CURVES. MACHINE DIVIDES AND CONNECTS FOR PANELS.	GOOD 1

\*\*\* DATA PREVIEW IS ESSENTIAL FOR EFFECTIVE MACHINE USE \*\*\*

1. USE OF A MACHINE DIGITISER RAISES THESE TO GOOD AND EXCELLENT.

AMI CLARK

INPUT

IDEAL INPUT SHOULD BE SIMPLE ENOUGH TO BE  
HANDLED BY A JUNIOR ENGINEER WITH MINIMUM  
SUPERVISION.

AMI CURK  
4

## DATA OUTPUT

### GEOMETRY

- + AERODYNAMICS ( AIRLOADS, VELOCITIES ETC. )
- + STREAMLINE BEHAVIOR
- + BOUNDARY LAYER BEHAVIOR
- + ETC.
- = LARGE VOLUMES OF PRINTOUT\*

CAPABILITY TO REVIEW OUTPUT DATA INTERACTIVELY IS ESSENTIAL.  
MACHINE PLOT AND PRINT ONLY REQUIRED DATA. ( SAVE THE REST )

\* MOST OF WHICH NEVER GETS READ.

OUTPUT

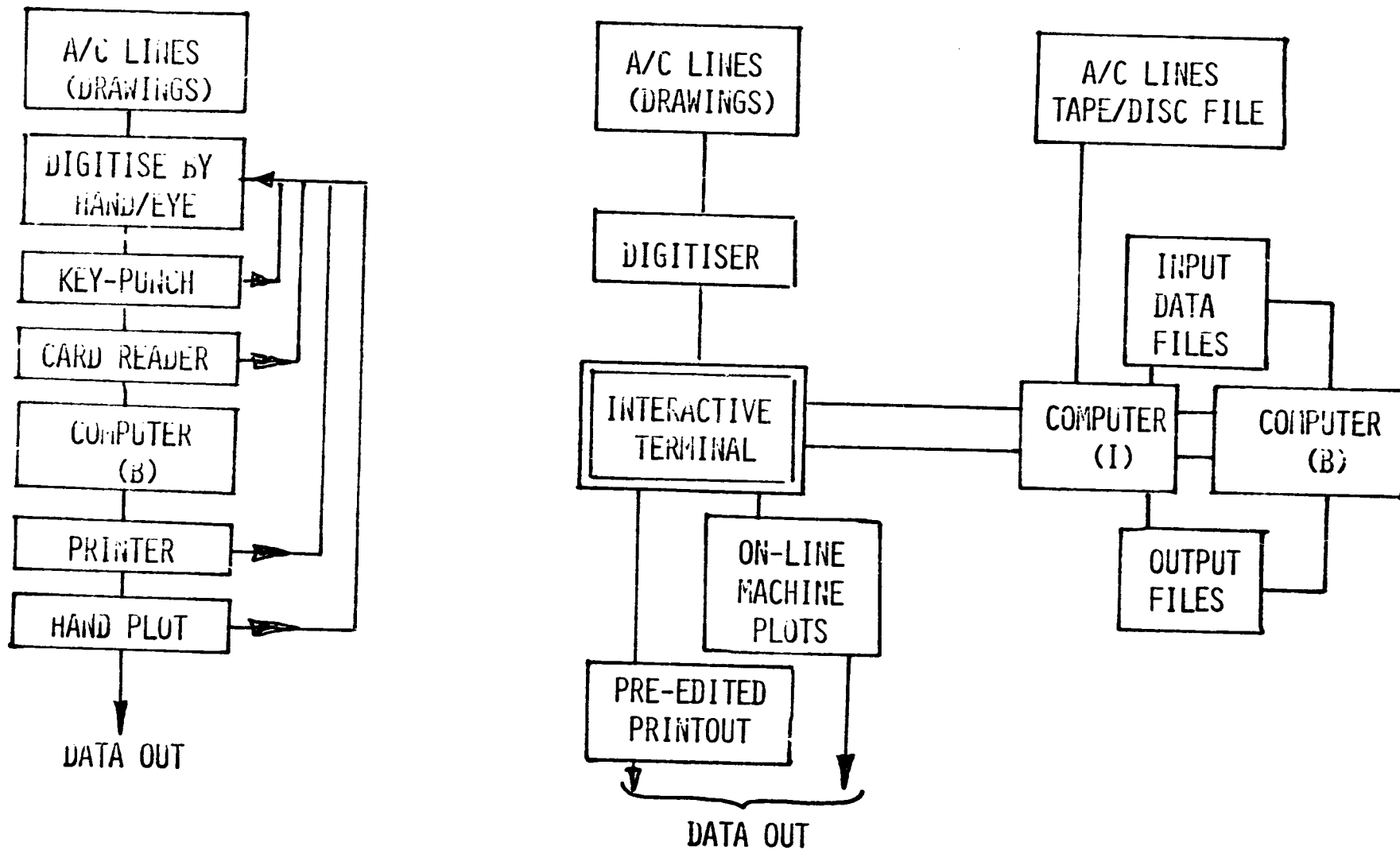
MINIMUM REQUIRED, WITH INTERACTIVE GRAPHICS  
PLAYING A LARGE ROLE.  
( SAVE THE REST OF THE OUTPUT FOR LATER REAPPRAISAL )

IDEAL

AM1

6

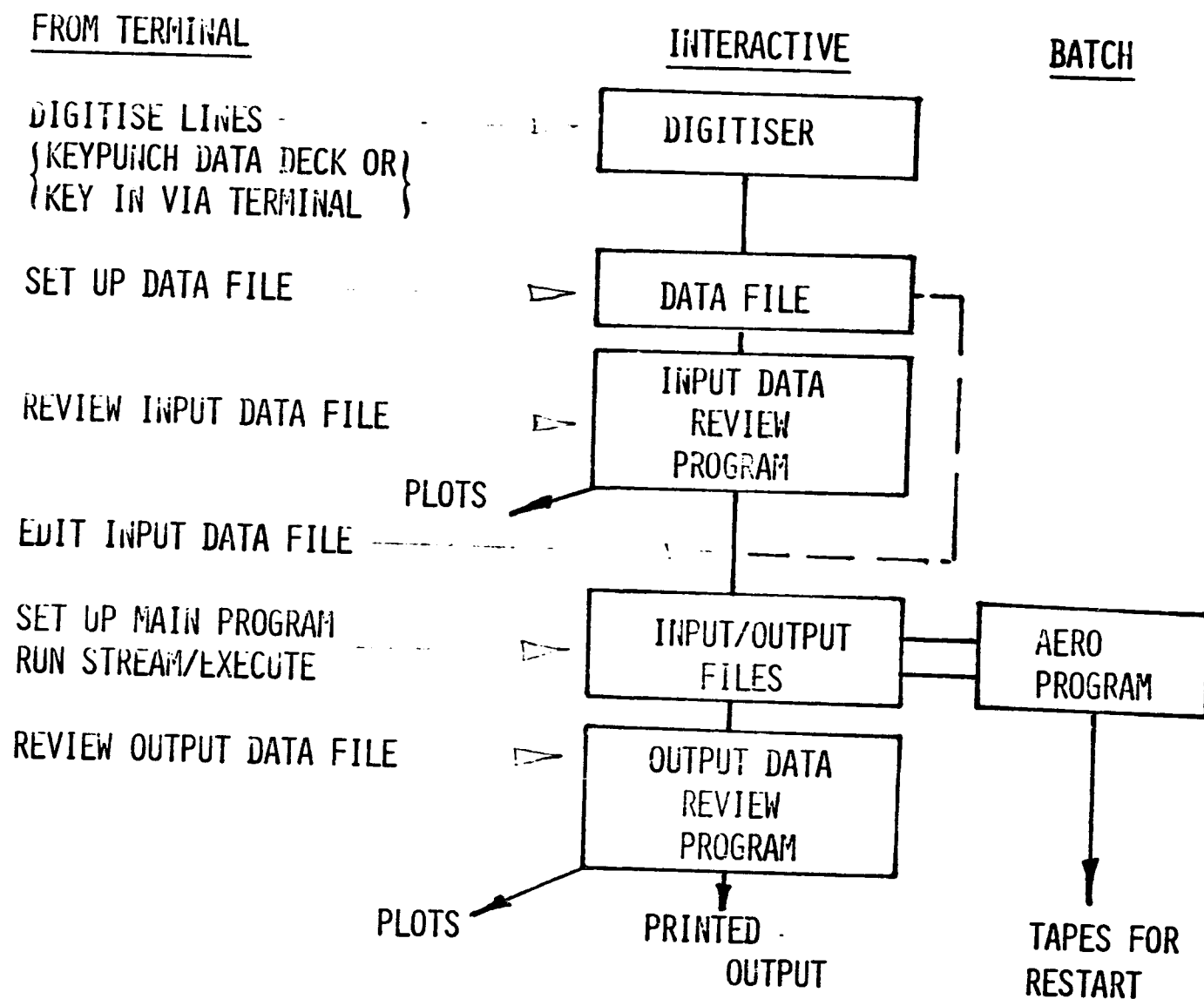
THE USE OF INTERACTIVE COMPUTING WITH GRAPHICS CAN DRAMATICALLY SPEED UP THE DATA FLOW



I = INTERACTIVE; B = BATCH



# AIRCRAFT CONFIGURATION MODELING



THIS PROGRAM PLOTS SHAPES FROM INPUT DATA DECK  
OF THE

\*\*\* WBAERO PROGRAM \*\*\*

INPUT CAN BE FULL WBAERO DATA SET OR PARTIAL, STARTING AT CARD 7

KEY IN BAUD RATE AND RETURN  
? 300

AMI 9

YOU HAVE THE FOLLOWING PLOT OPTIONS

- 1 PLOT ALL SECTIONS
- 2 PLOT ALL SECTIONS IN A DESIGNATED BLOCK
- 3 PLOT ANY DESIGNATED SINGLE SECTION
- 4 COMPARE UP TO 10 DESIGNATED SECTIONS
- 5 TERMINATE!

KEY IN DESIRED OPTION AND RETURN!

? 2

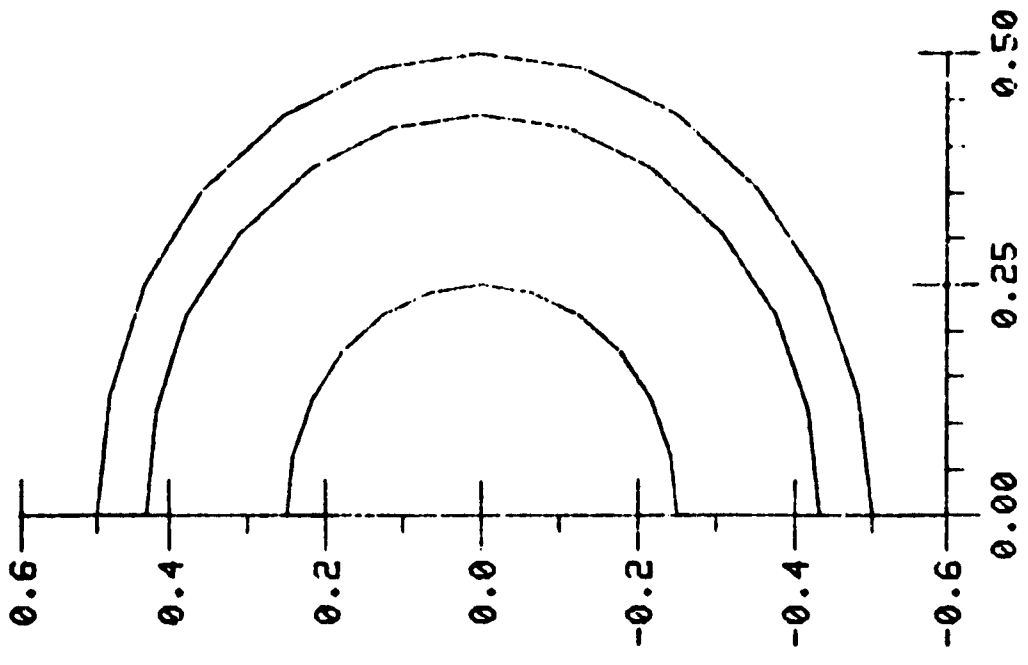
WHAT BLOCK DO YOU WISH TO PLOT?  
KEY IN BLOCK NUMBER AND RETURN!

? 1

2-2

AMI 10

AMI //



?

THIS PROGRAM PLOTS THE OUTPUT DATA FROM  
THE  
WBAERO FAMILY OF PROGRAMS

YOU HAVE THE FOLLOWING OPTIONS.

- 1 GEOMETRY GROUP
- 2 AERODYNAMICS GROUP
- 3 STREAMLINE GROUP
- 4 BOUNDARYLAYER GROUP

KEY IN SELECTED OPTION AND RETURN!  
(eg. 3RETURN)

YOU HAVE SELECTED PLOTS FROM THE STREAMLINE GROUP.  
\*\*\*\*\*

SELECT PARAMETERS TO BE PLOTTED FROM THE MENU BELOW.

- |      |                |        |
|------|----------------|--------|
| 1. X | 5. UX          | 9. CP  |
| 2. Y | 6. UY          | 10. K1 |
| 3. Z | 7. UZ          | 11. K2 |
| 4. S | 8. U RESULTANT | 12. K3 |

NOTE YOU CAN PLOT ANY TWO PARAMETERS AGAINST EACH OTHER

KEY IN PARAMETERS AND RETURN! (eg. 4,9)-----1,3

THERE ARE \*\* 9 \*\* STREAMLINES. DO YOU WISH TO PLOT THEM ALL?

KEY IN YES OR NO AND RETURN!---YES

AMI 13

THIS PROGRAM GENERATES TEKTRONIX PLOTS OF GENERAL 3D BODIES  
INPUT MAY BE READ FROM WBAERO TAPE11 OR VIA THE KEY BOARD  
\*\*\*\*\*

SELECT INPUT MODE

USING TAPE11? KEY IN 1 AND RETURN  
USING KEYBRD? KEY IN 2 AND RETURN,  
\*\*\*NOTE \*\* IF 1 SELECTED TAPE/FILE MUST BE IDENTIFIED \*\*\*

? 1

DO YOU WANT TO DRAW THE WHOLE BODY?

KEY IN YES OR NO AND RETURN!

? no

SECTION OF BODY TO BE PLOTTED MUST HAVE A CONNECTED  
STRING OF PANEL INDICES.  
KEY IN INDICES OF FIRST AND LAST PANELS AND RETURN!  
(EG. 172,431 RETURN!)

? 22,44

AMI /4

KEY IN NVU, IPRINT, IHIDE, IBUG

NVU = NUMBER OF VIEWS \*\* NO MORE THAN 10 \*

IPRINT = 1 PRINTS INPUT DATA  
= 0 NO DATA PRINT OUT

IHIDE = 0 ELLIMINATES HIDDEN LINES  
= 1 LEAVES HIDDEN LINES

IBUG = 0 SUPPRESSES DEBUG PRINT OUT  
= 1 FULL DEBUG PRINT OUT

? 2,0,1,0

IS BODY SYMETRICAL ABOUT X-Z PLANE?

KEY IN YES OR NO AND RETURN!

? yes

DO YOU WANT TO PLOT REFLECTED BODY?

KEY IN YES OR NO AND RETURN!

? no

AMI 15

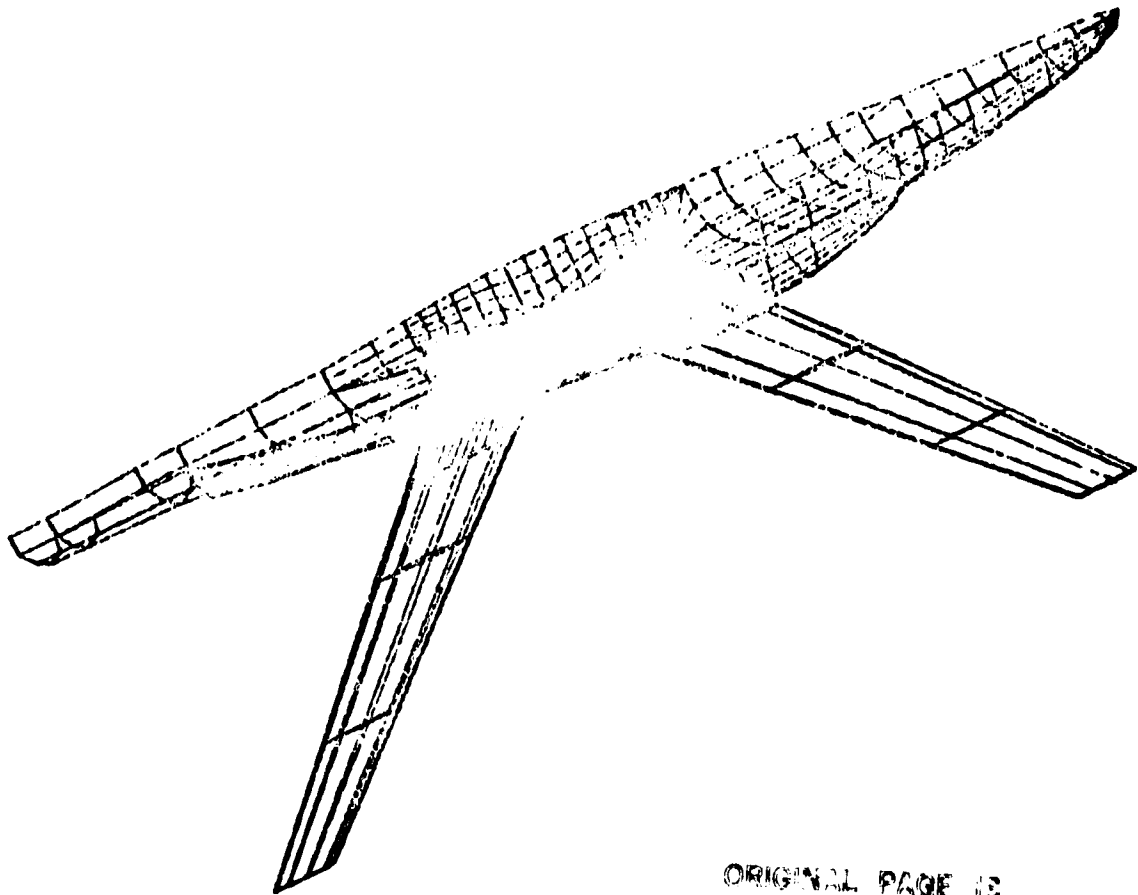


KEY IN XUUE, YUUE, ZUUE - ORDINATES OF VIEW POINT  
\*\*\* POINT MUST LIE OUTSIDE BODY \*\*\*

? 400.0, 300.0, 300.0

AMI 7

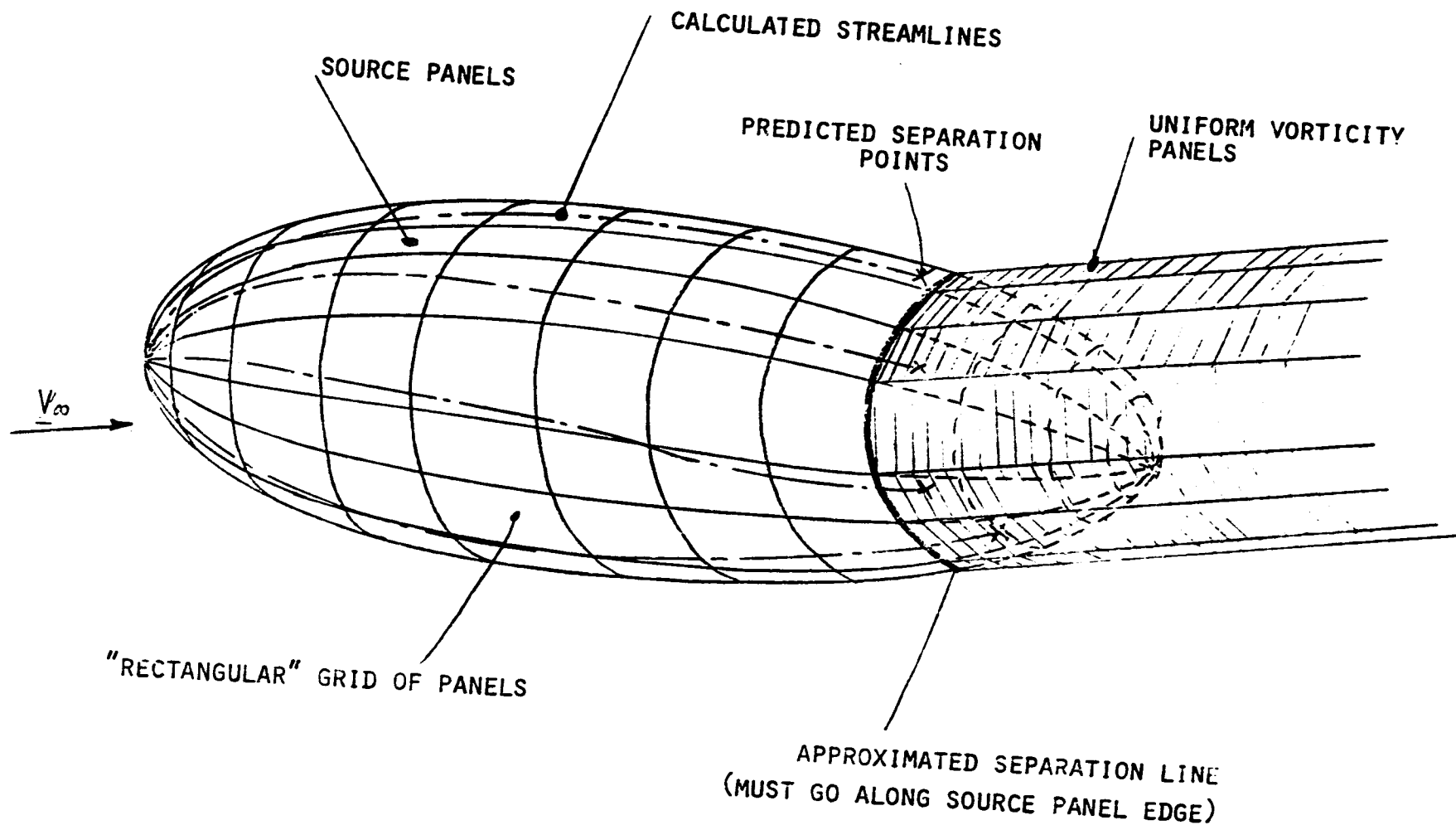
NAVY/ARPA/LOCKHEED  
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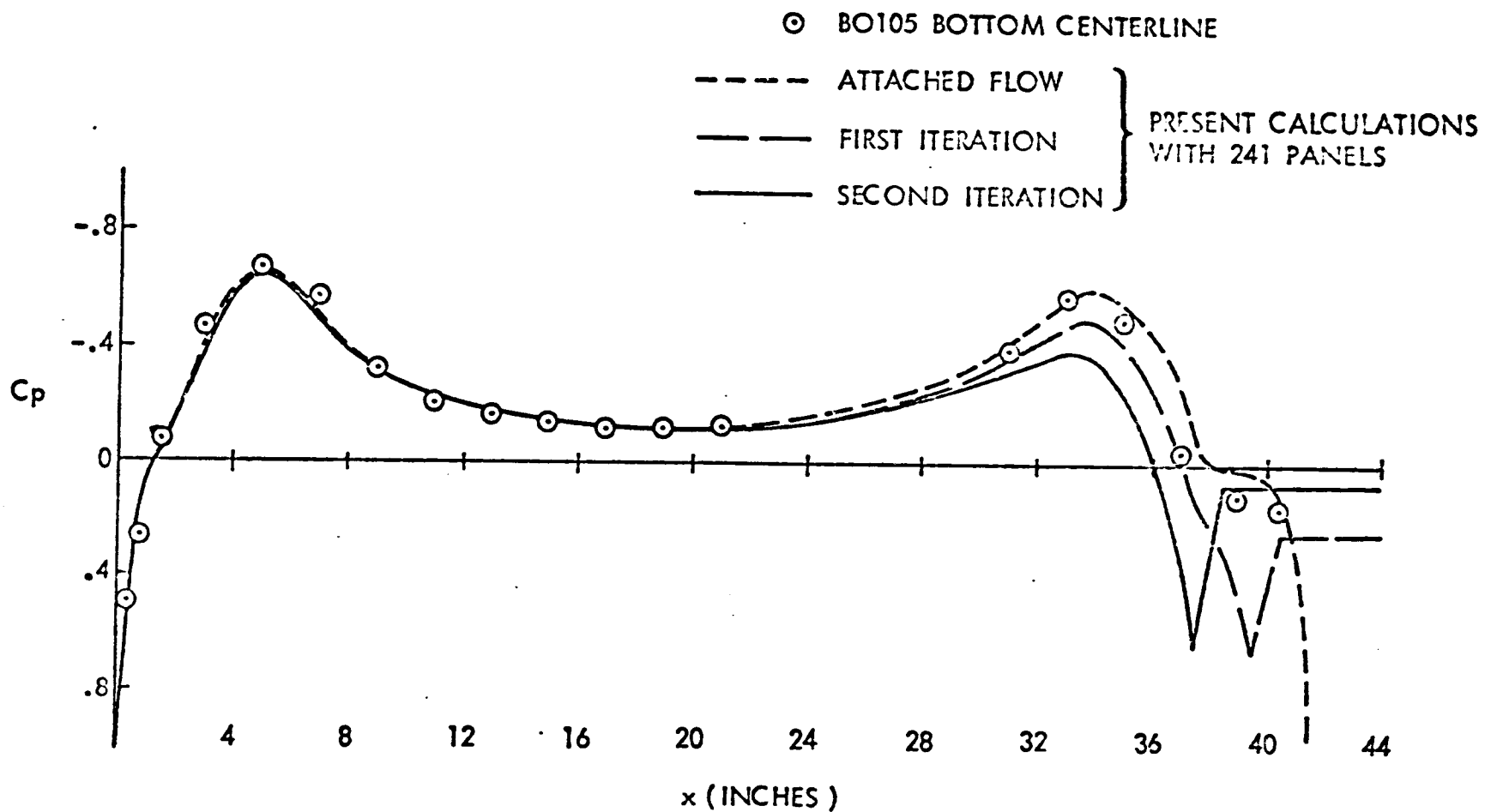


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DRAG PROGRAM

MODEL 1





(a) Top Centerline

Figure 19. Comparison of Calculated and Experimental Pressure Distributions on the BO105 Fuselage.

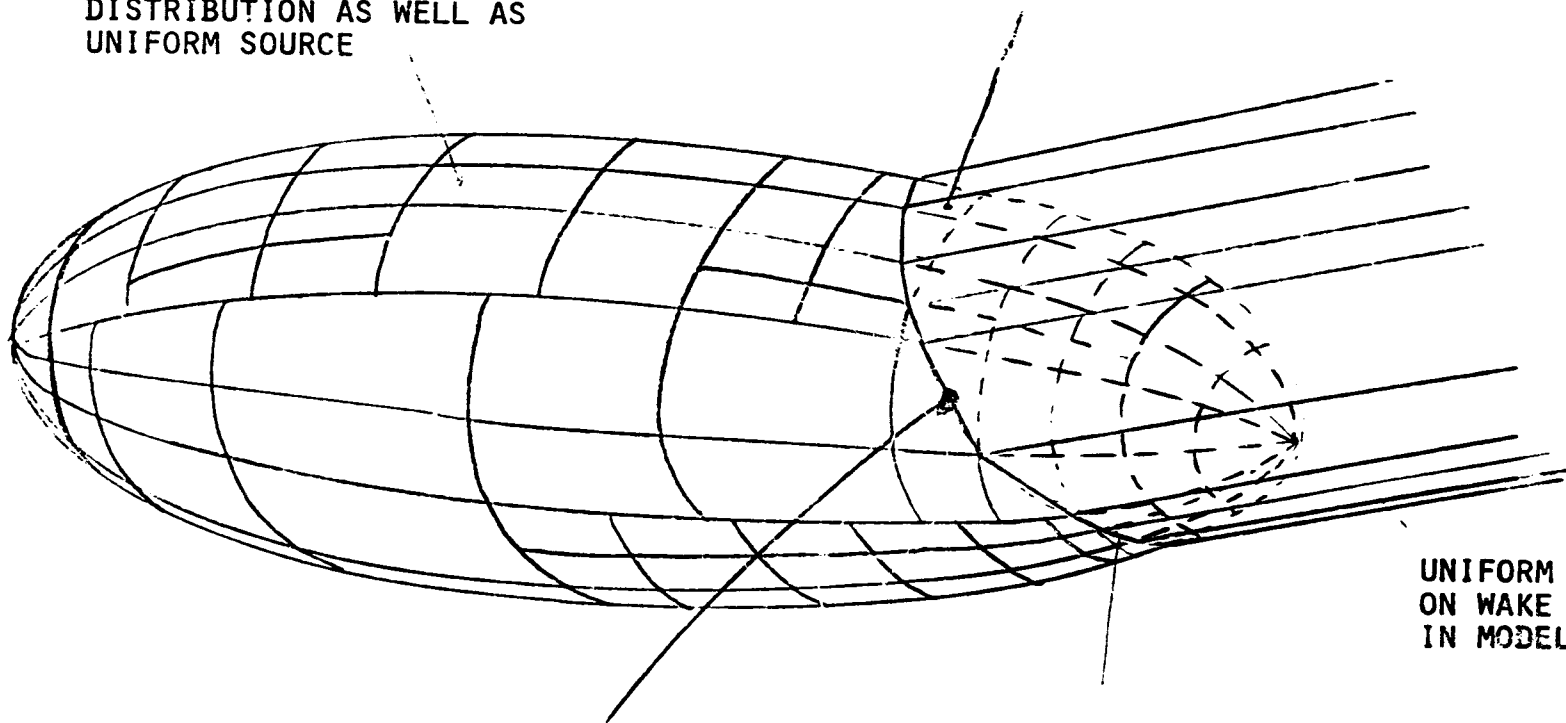
AM1 19

DRAG PROGRAM

MODEL 2. VORTICITY PANELS

PANELS HAVE LINEAR VORTICITY DISTRIBUTION AS WELL AS UNIFORM SOURCE

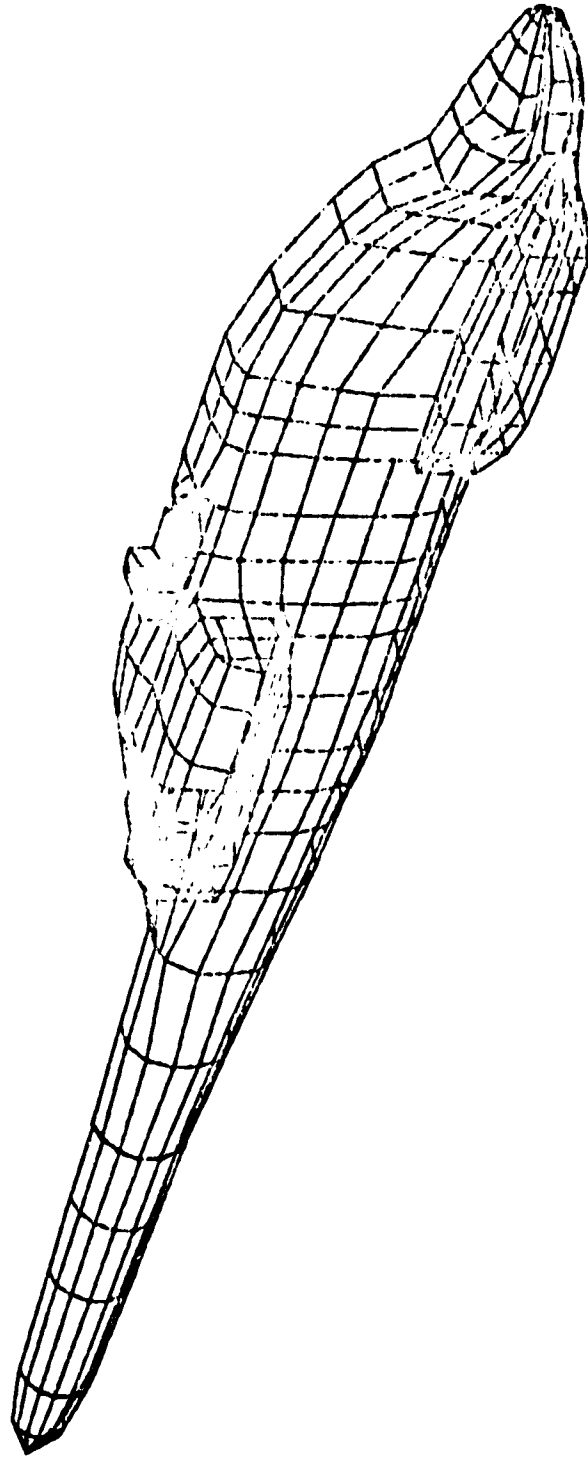
DOWNSTREAM PARTS OF "SPLIT" PANELS HAVE ZERO VORTICITY VALUE



UNIFORM VORTICITY ON WAKE PANELS AS IN MODEL 1

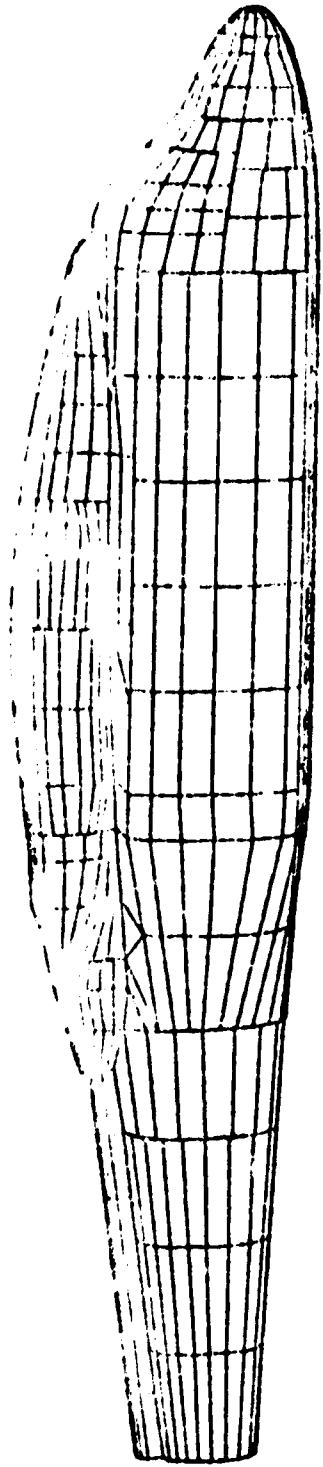
VORTICITY IS CONTINUOUS PASSING FROM THE SURFACE ONTO WAKE PANELS

ARBITRARY SEPARATION LINE



BASELINE AAH (H.H. PANELING)

CLARK AMI 21



BASELINE UTTAS (PANELLED BY S/A)

CLARK AMI 22

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Figure 1:

The method chosen for computation generally dictates the requirement for geometric smoothness. In the case of viscous flow computation in an axisymmetric diffuser duct with a centerbody, one of the approaches is to parabolize the Navier-Stokes equations in a streamline orthogonal coordinate system and then to perform computation by marching. In this coordinate system we observe that, as shown in item (c), to insure stable computation the streamline coordinates have to be accurately determined up to third derivatives.



## VISCOUS FLOW IN A DIFFUSER DUCT

(a) Transform Navier-Stokes Equations to Streamline Orthogonal Coordinate System

(b) Parabolize the Resulting Equations for Marching

$$\frac{\partial}{\partial \psi} \left( \frac{\partial \psi}{\partial \phi} \right) - \frac{G}{V} u_{\phi} \frac{\partial \rho}{\partial \phi} - \frac{G}{V} \rho \frac{\partial u_{\phi}}{\partial \phi} = \rho u_{\phi} \frac{\partial}{\partial \phi} \left( \frac{G}{V} \right),$$

$$\rho u_{\phi} \frac{\partial u_{\phi}}{\partial \phi} - \frac{V}{G} \frac{\partial u_{\phi}}{\partial \psi} \frac{\partial \psi}{\partial \phi} + \frac{1}{\gamma M_r^2} \frac{\partial p}{\partial \phi} = \frac{V}{G} \frac{\partial}{\partial \psi} \left( \frac{G \tau_{\phi \psi}}{V} \right) + \dots$$

...

(c)  $V$  (metric Coeff or Jacobian)

$\sim 1^{st}$  Derivatives of Geometry

$\frac{\partial V}{\partial \psi} \dots \sim 2^{nd}$  Derivatives of Geometry

Discretization Error for  $\frac{\partial V}{\partial \psi} \dots \sim 3^{rd}$  Derivatives

FIG. 1

Figures 2, 3 and 4

Figure 2 shows the mesh distribution of a smoothed annular diffuser duct and the calculated velocity profiles at each station. The computation was terminated normally at the end of the duct. However, if one would use an identical computer program but with an unsmoothed geometry, computation would become unstable and break down shortly after the entrance section. The configuration shown in Figure 4 is a partially smoothed one, but the computation still aborted before it reached the exit section. (An indication of irregularity may be seen at the waist of the centerbody.)

KAO 2

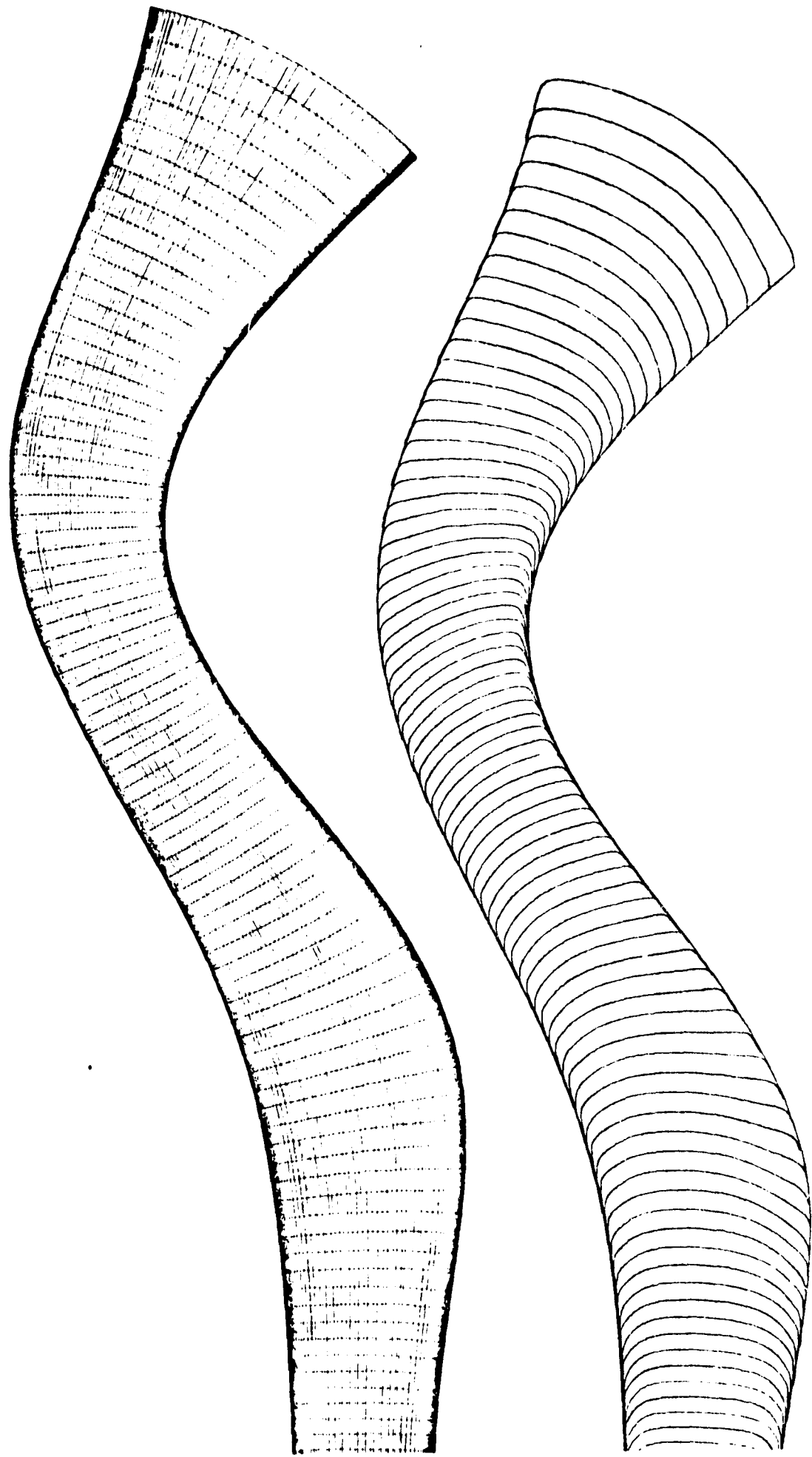
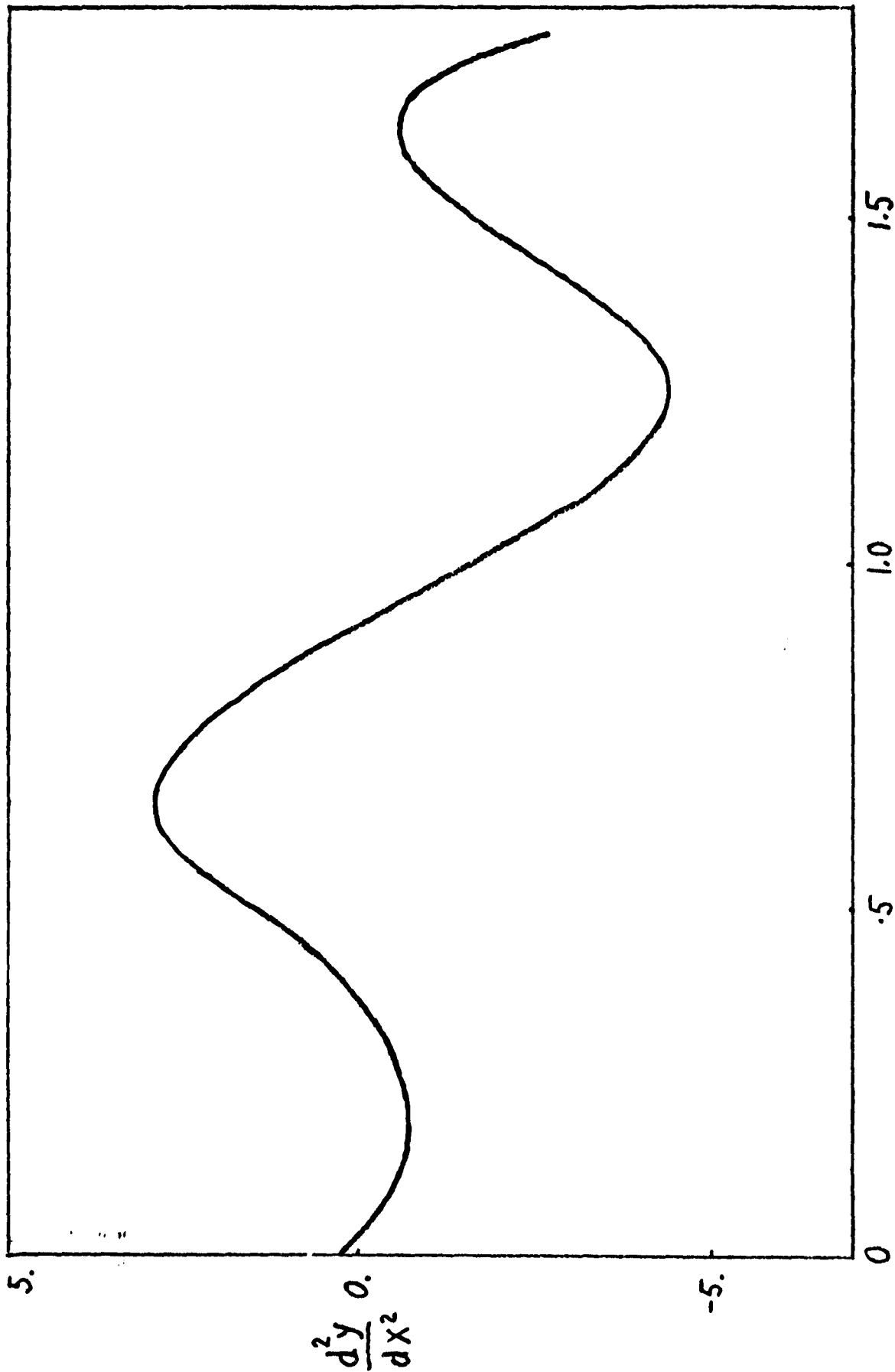


FIG. 2 MESH DISTRIBUTION AND CALCULATED VELOCITY PROFILES OF A SMOOTHED ANNULAR DUCT

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AXIAL DISTANCE

FIG. 3 SECOND DERIVATIVES OF A SMOOTHED CENTER BODY KAO3

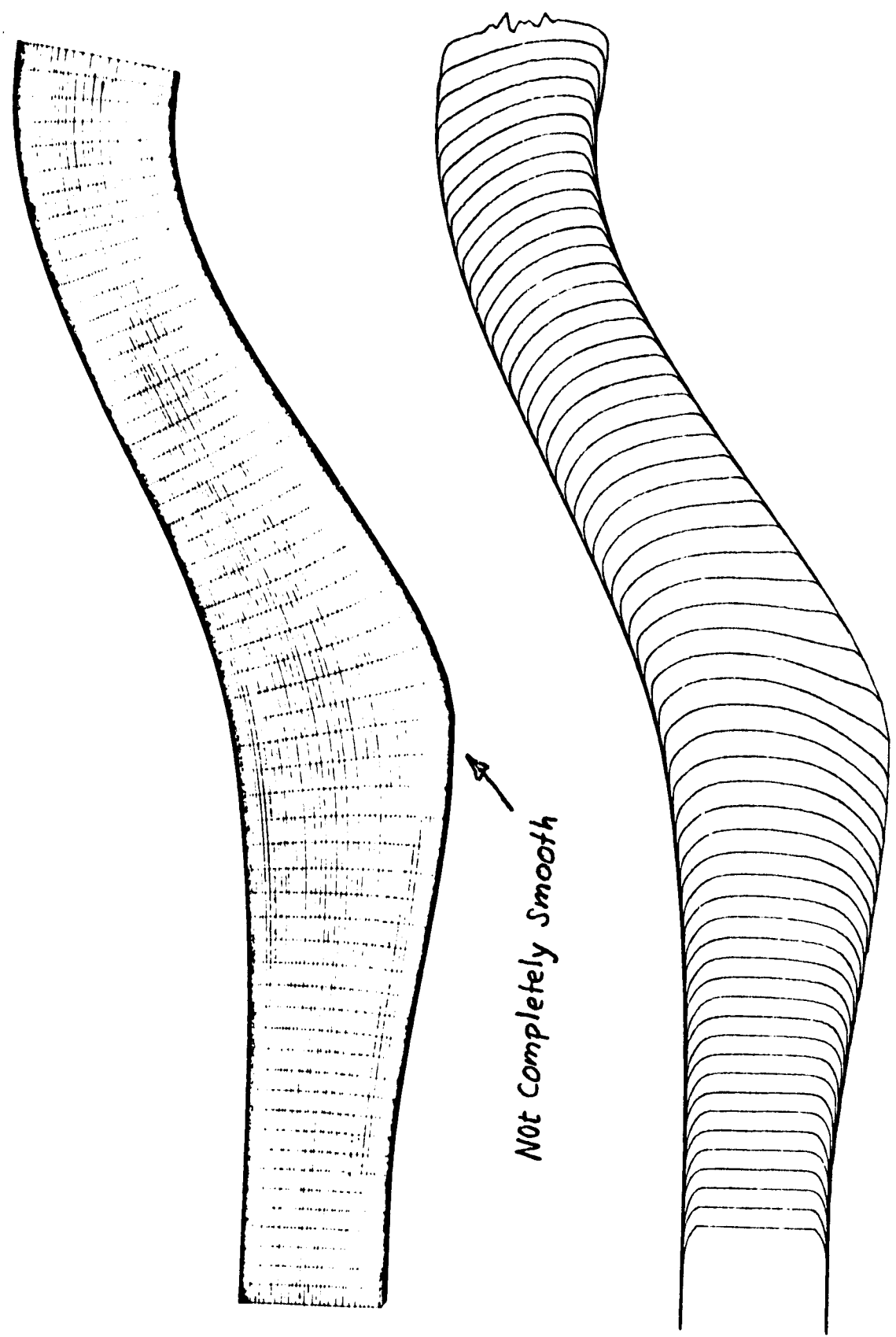
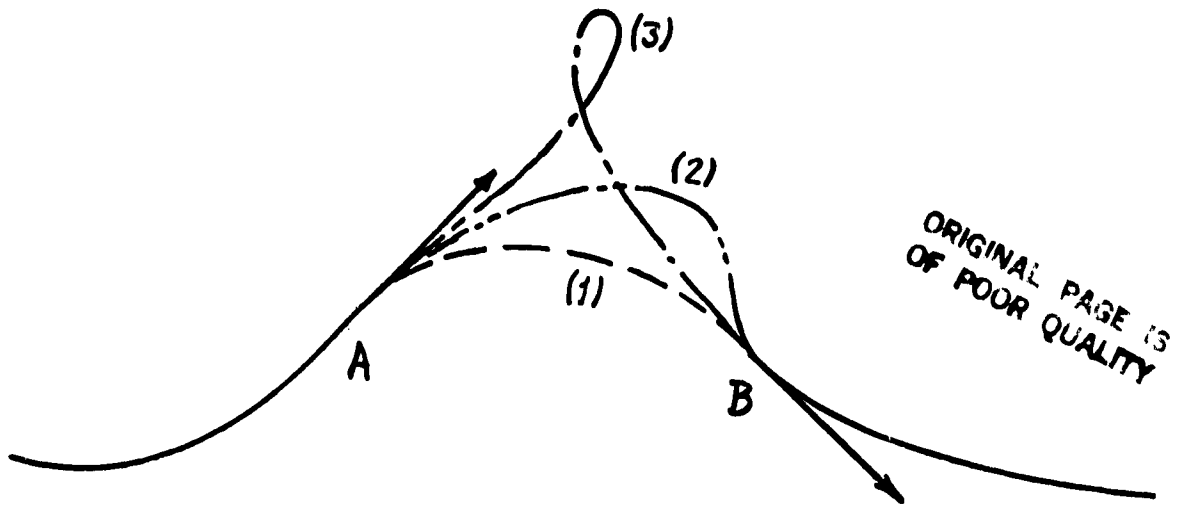


FIG. 4 MESH DISTRIBUTION AND VELOCITY PROFILES OF A PARTIALLY SMOOTHED DUCT

Figure 5:

All three segments of (1), (2) and (3) are the traces of a cubic equation, and they all satisfy the tangency continuity condition at A and B as shown (that is, their unit tangent vectors at A and B match with the unit tangent vectors of the neighboring segments). The striking difference in appearance is solely due to the difference in magnitude of the tangent vectors in terms of  $u$ . Thus, when a general parameter other than the arc length is used for curve fitting, the first derivatives on both sides of a data point need not equal. This property also appears in second and higher derivatives. (The smoothness requirement for second derivatives is to match the curvature on both sides of a data point, which is  $\frac{d^2 p}{ds^2}$ , with  $s$  being the arc length.) Since the degenerated case of a Coons' surface patch equation (say,  $w=0$ ) is a cubic or a fifth degree polynomial, the property of discontinuity in parametric derivatives of  $u$  and  $w$  also prevails in Coons' boundary matrix.



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Cubic:

$${}^{(1)}P(u) = P_A + uP_B + u^2(-2{}^{(1)}P'_A - {}^{(1)}P'_B - 3P_A + 3P_B) + u^3({}^{(1)}P'_A + {}^{(1)}P'_B + 2P_A - 2P_B)$$

$$(0 \leq u \leq 1).$$

Tangency Continuity Req. in Terms of Arc Length (s):

$$\frac{dP_A}{ds_-} = \frac{dP_A}{ds_+}, \quad \frac{dP_B}{ds_-} = \frac{dP_B}{ds_+}$$

Parametric Derivatives in u:

$$1^{st} \text{ Order: } \frac{dP}{du} = \frac{ds}{du} \frac{dP}{ds} \quad \left( \frac{ds}{du} = \left| \frac{dP}{du} \right| \right)$$

$$2^{nd} \text{ Order: } K\vec{V} = \frac{d^2P}{ds^2} = \frac{d^2P}{du^2} / \left( \frac{ds}{du} \right)^2 - c \frac{dP}{du}$$

$$c = \frac{dP}{du} \cdot \frac{d^2P}{du^2} / \left( \frac{ds}{du} \right)^4$$

FIG. 5

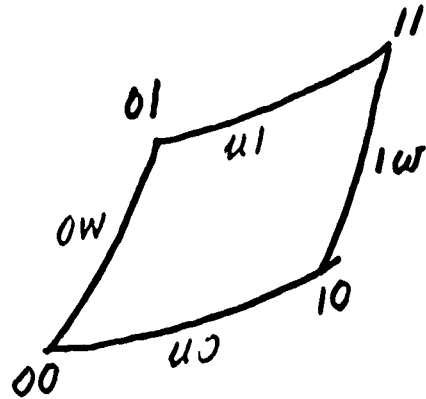
Figures 6, 7, and 8 are self-explanatory.



## FIFTH DEGREE SURFACE PATCH

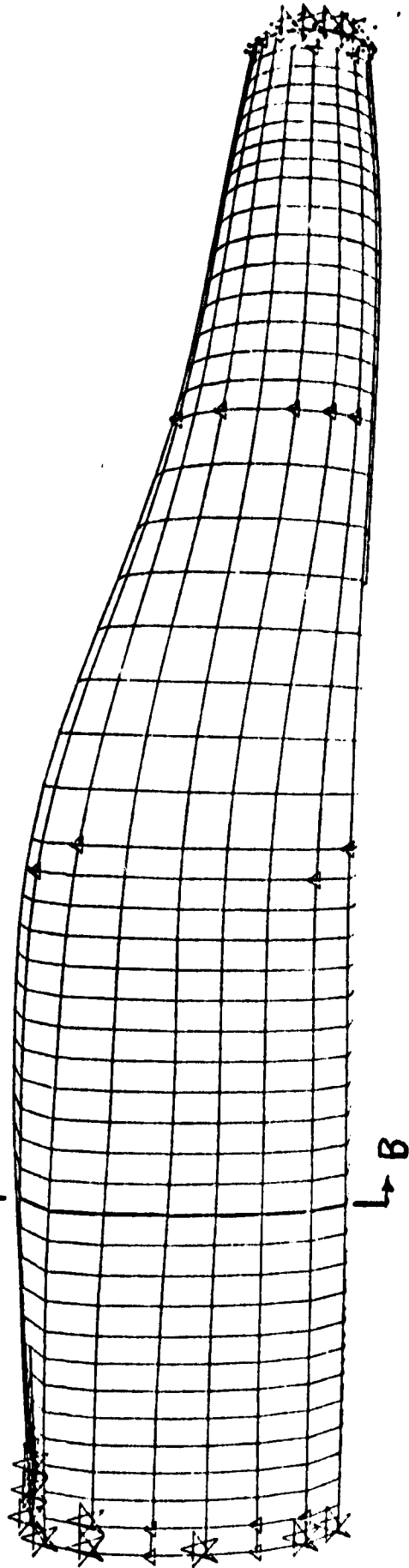
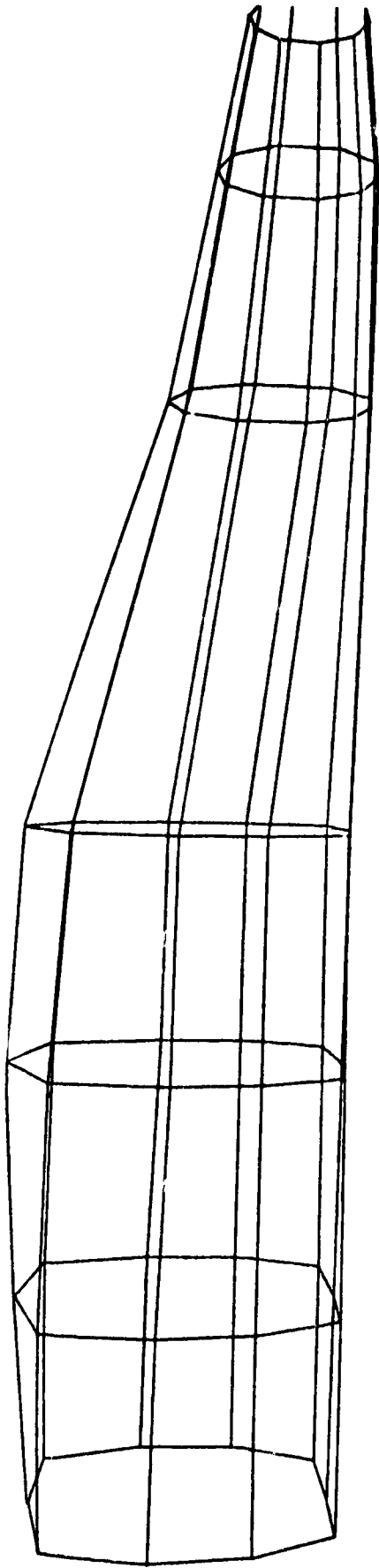
$$V(u,w) = [u^5 u^4 u^3 u^2 u^1] [M] [B] [M]^T [w^5 w^4 w^3 w^2 w^1]^T$$

$$[M] = \begin{bmatrix} 6 & 6 & -3 & -3 & -\frac{1}{2} & \frac{1}{2} \\ 15 & -15 & 8 & 7 & \frac{3}{2} & -1 \\ -10 & 10 & -6 & -4 & -\frac{3}{2} & \frac{1}{2} \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



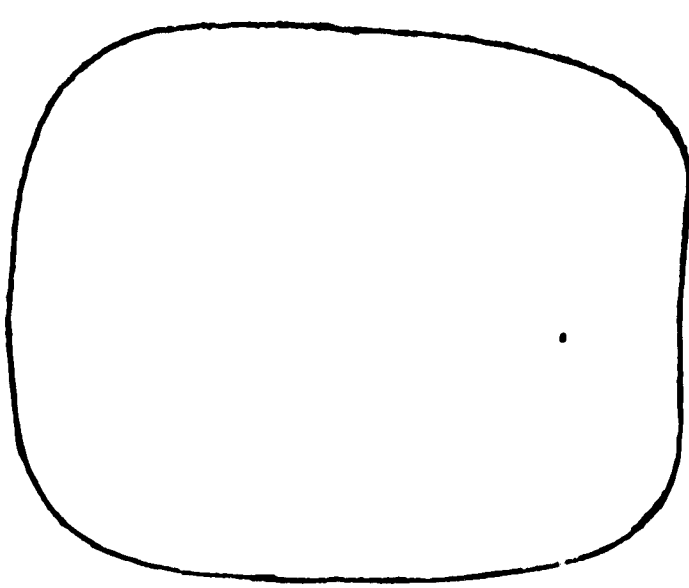
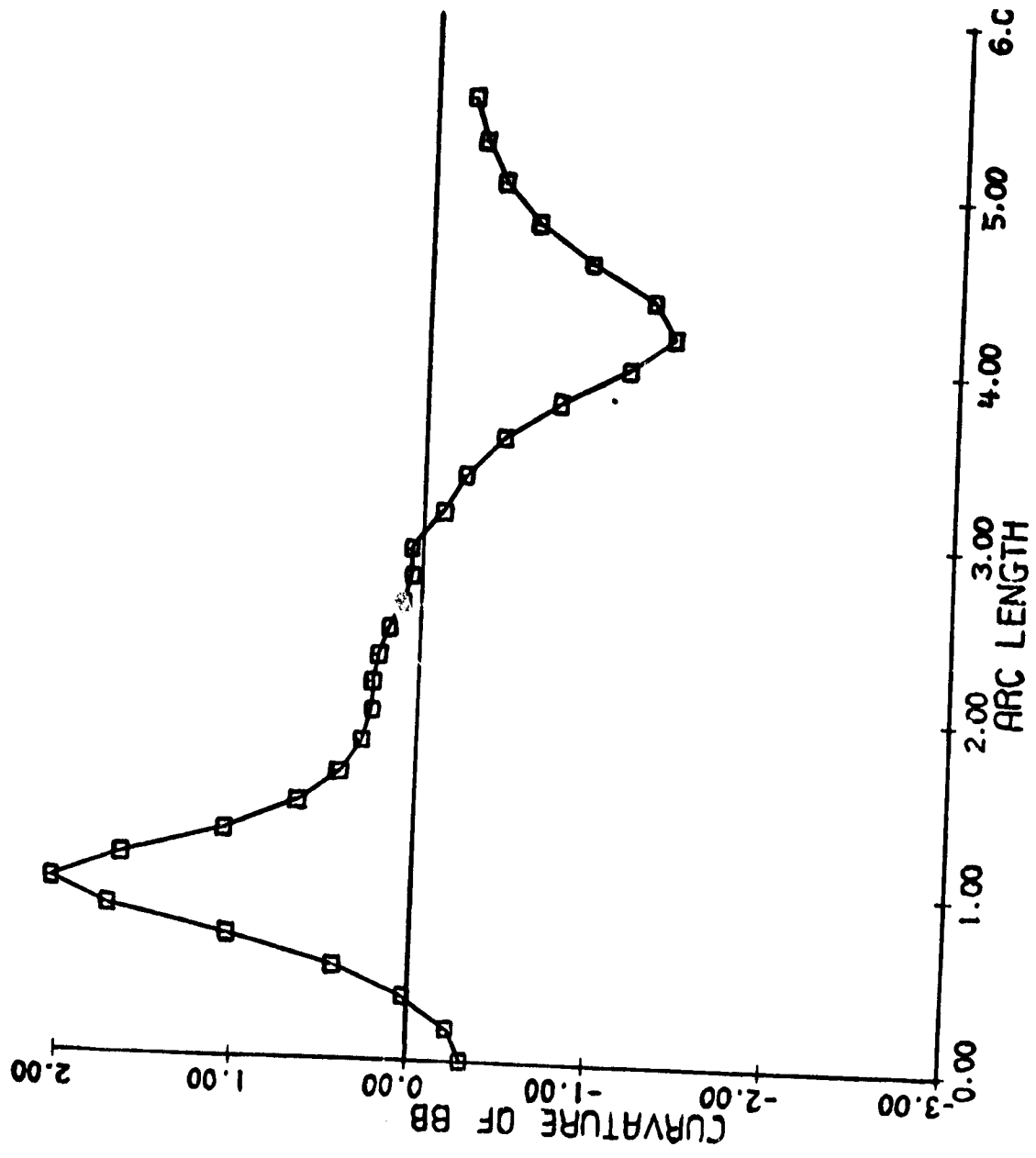
$$[B] = \begin{bmatrix} 00 & 01 & 00_w & 01_w & 00_{ww} & 01_{ww} \\ 10 & 11 & 10_w & 11_w & 10_{ww} & 11_{ww} \\ 00_u & 01_u & 00_{uw} & 01_{uw} & 00_{uww} & 01_{uww} \\ 10_u & 11_u & 10_{uw} & 11_{uw} & 10_{uww} & 11_{uww} \\ 00_{uu} & 01_{uu} & 00_{uww} & 01_{uww} & 00_{uuww} & 01_{uuww} \\ 10_{uu} & 11_{uu} & 10_{uww} & 11_{uww} & 10_{uuww} & 11_{uuww} \end{bmatrix}$$

FIG. 6 BASIC EQUATIONS FOR COONS'  
5<sup>TH</sup> DEGREE SURFACE PATCH



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FIG. 7 INPUT AND ENRICHED CONFIGURATION OF A DUCT



CROSS SECTION BB  
 -1.00 0.00 1.00

FIG. 8 CURVATURE DISTRIBUTION OF CROSS SECTION BB

GEOMETRY REQUIREMENTS FOR UNSTEADY AERODYNAMICS

E. Carson Yates, Jr. and Luigi Morino

①

Accurate calculation of aeroelastic characteristics required for the analysis and design of high-performance aircraft requires accurate and efficient evaluation of steady and unsteady aerodynamic loads on aircraft having arbitrary shapes and motions, including structural deformations. This presentation will address the aircraft geometry requirements for unsteady aerodynamic computations and will emphasize differences between requirements for steady and unsteady flow.

*Foto di Marina*

①

Requirements for aeroelastic analysis and design are in several respects more complicated and more severe than for the more conventional steady-state aerodynamics. For example: (1) The aeroelastician deals with flexible structures so that even in steady-state conditions, the aerodynamic load is a function of structural deformation, and vice versa. (2) The unsteady aerodynamic formulations required in dynamic aeroelasticity involve complex quantities (e.g., normalwash velocities, aerodynamic influence functions, and pressure) that manifest time- or frequency-dependent attenuations and phase shifts relative to steady state. (3) In dynamic aeroelasticity--flutter, for example--the aeroelastician must evaluate pressure distributions for vibration mode shapes that are much more wiggly than a typical steady-state mean-camber surface. The corresponding pressure distributions will also be more wiggly than those for steady state so that computational convergence requirements are usually more severe than for steady state. (4) Flutter analyses, as well as iterative structural resizing, require evaluation of pressure distributions for a multiplicity of mode shapes, frequencies, aircraft loading conditions, etc. Consequently, computational efficiency is vital, and it is essential to minimize the amount of recomputation required when mode shapes and/or frequencies are changed.

With these thoughts in mind, we shall discuss geometry requirements within the framework of the SOUSSA aerodynamic formulation because it is the most general potential-flow program that we now have under development (with regard to aircraft geometry, motion and deformations, and speed ranges) and because present and future SOUSSA geometry requirements are as stringent as those for any aerodynamic program that we now anticipate. Geometry required is considered to be composed of three parts: (1) shape of vehicle, (2) orientation of vehicle, (3) deformation(s). Orientation involves little more than a rotation of coordinate axes and consequently will not be emphasized here. Deformations can be finite but are more usually taken to be infinitesimal and approximated by a linear combination of the natural undamped vibration modes of the aircraft. As many as two dozen modes or more may be required to converge the aeroelastic solution. A corollary geometrical requirement is determination of wake shape which is not known a priori although it may be assumed to be flat for many applications.

64

UNSTEADY COMPLICATIONS:

- o LOAD IS FUNCTION OF DEFORMATION AND VICE VERSA
- o COMPLEX QUANTITIES
- o WIGGLY DEFORMATION MODES
- o MULTIPLICITY OF MODES, FREQUENCIES, ETC.

GEOMETRY REQUIRED:

- o SHAPE
- o ORIENTATION
- o DEFORMATION(S)

To set the stage, a brief review of SOUSSA formulation is in order. Application of Green's theorem leads to an integral equation for the perturbation velocity potential  $\phi$  at any point P in the flow or on the flow boundary (i.e., on S). Note that the second integral contains only linear terms which are integrated over the boundary surface S, whereas the first integral contains nonlinear terms F, involving products of derivatives of  $\phi$ , which must be integrated over the fluid volume.

The boundary condition clearly shows the effect of time variation of S. If the variation is harmonic, for example, the  $\frac{\partial S}{\partial t}$  term becomes  $i\omega S$  so that the normalwash at  $S = 0$  becomes complex. The imaginary part, however, involves only surface ordinates (including displacements and deformations), whereas the real (steady-state) part involves derivatives of surface ordinates. Thus, introduction of unsteadiness does not impose more stringent requirements on surface definition as far as quantities required are concerned. It may, however, require greater accuracy and greater amounts of geometrical information (e.g., for more points on the surface) in order to define adequately the wiggly modes of deformation referred to previously.

The influence of nonlinear terms F is being studied in the development of SOUSSA aerodynamics for the transonic range. However, these terms are not included in the present computer program.



# STEADY, OSCILLATORY AND UNSTEADY SUBSONIC AND SUPERSONIC AERODYNAMICS

(SOUSSA)

Objective: An accurate, general, unified method for calculating steady and unsteady loads on complete aircraft with arbitrary shape and motion in subsonic or supersonic flow, with emphasis on application in computer-aided structural design

Approach: Green's theorem is used to formulate exact integral equation for potential.

$$\phi(P, t) = \iiint G F dV, dt, + \iint [\nabla \cdot S (G \nabla \phi - \phi \nabla G) - \frac{1}{\alpha^2} \frac{dS}{dt} (G \frac{\partial \phi}{\partial t} - \phi \frac{\partial G}{\partial t})] |\square S|^{-1} dS dt,$$

where  $\phi$  = perturbation velocity potential  
 $G$  = Green's function  
 $F$  = nonlinear terms  
 $S(x, y, z, t) = 0$  defines body surface  
 $|\square S| = \sqrt{S_x^2 + S_y^2 + S_z^2 + S_t^2}$

Exact boundary condition on body is

$$\frac{D S}{D t} = \frac{\partial S}{\partial t} + \nabla \phi \cdot \nabla S = \frac{\partial S}{\partial t} + U_\infty (\vec{i} + \nabla \phi) \cdot \nabla S = 0$$

E. C. Yates

Surface paneling and Laplace transform solution yield a matrix equation relating the unknown potential  $\phi$  on the vehicle surface to the normalwash  $\psi$ . Elements of the coefficient matrices are independent of normalwash (and hence deformation) and are simple functions of the Laplace variable  $s$ . For a given paneling arrangement they depend only on Mach number.

Use of arbitrary nonplanar quadrilateral panels permits matching nodes of the aerodynamic panels to the nodes of a structural finite-element model, if desired, in order to use the nodal coordinates and calculated displacements directly without requirement for interpolation. In general, however, solution for the velocity-potential matrix requires the following geometrical input: (1) Coordinates of panel nodes usually obtained by interpolation (lofting) from aircraft shape information. (2) Time-dependent normalwash at control points which usually do not coincide with panel nodes. Normalwash involves coordinates and slopes obtained from aircraft shape plus orientation plus deformation. Note that increasing the number of deformation modes used involves only adding columns to the  $\psi$  and  $\phi$  matrices, and updating the entire set of deformation modes, as in a structural design application, involves only replacing the  $\psi$  matrix. The Y and Z matrices are unaffected in either case.

Surface pressures are obtained from Bernoulli's equation. Generalized aerodynamic forces, including aerodynamic coefficients and stability derivatives, are determined from weighted integrals of the pressure which require values of surface displacement (due to rigid-body rotation and/or modal deformation) at a set of integration points which may not coincide with the panel nodes nor normalwash control points.

The geometrical information required by SOUSSA can, of course, be generated with any suitable geometry preprocessor as long as the results are cast in required SOUSSA input format. It is evident, however, that automatic paneling capability is essential to the efficient processing of complicated shapes and deformations that may require many hundreds of panels. Such capability should include not only automatic calculation of the coordinates of nodes, normalwash control points, and integration points, but also automatic identification numbering for these points as well as for the panels and systematic identification of which nodes go with which panels.

Solution by spatial discretization with arbitrary nonplanar quadrilateral surface panels and time solution by Laplace transform results in

$$[\tilde{Y}_{jh}]\{\tilde{\Phi}_h\} = [\tilde{Z}_{jh}]\{\tilde{\Psi}_h\}$$

where  $\tilde{\Phi}_h$  = Laplace transform of perturbation velocity potential  
 $\tilde{\Psi}_h$  = Laplace transform of normalwash

$$\tilde{Y}_{jh} = \delta_{jh} - (C_{jh} + s D_{jh}) e^{-s \theta_{jh}} - \sum_n (F_{jn} + s G_{jn}) S_{nh} e^{-s(\theta_{jn} + \Pi_n)}$$

$$\tilde{Z}_{jh} = B_{jh} e^{-s \theta_{jh}}$$

s = Laplace transform variable

$B_{jh}, C_{jh}, D_{jh}, F_{jn}, G_{jn}$  = integrals over surface panels, independent of normalwash and s

$\theta_{jh}, \Pi_{jh}$  = lag functions

$$S_{nh} = \pm 1$$

Surface pressures are obtained from Bernoulli's equation.

The upper part of this figure lists some of the features of the SOUSSA aerodynamic formulation .  
The lower part indicates some expanded capabilities and improvements that are under development and that will influence surface geometry requirements. These are discussed in the following figures.

*Upper & Lower*

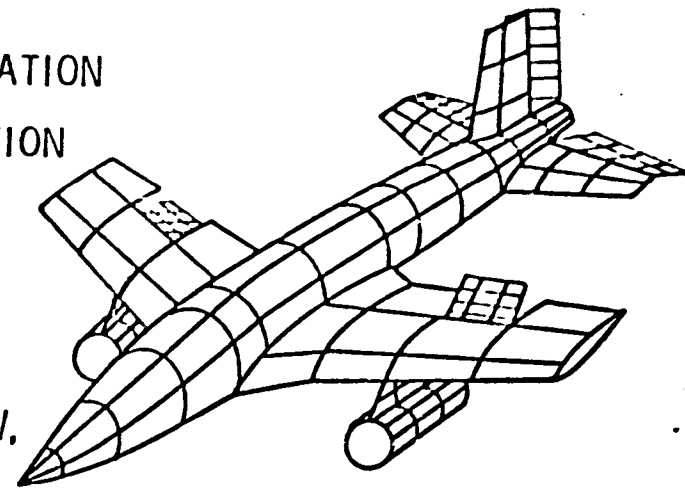
## GENERAL POTENTIAL-FLOW AERODYNAMICS (SOUSSA)

### GENERAL FINITE-ELEMENT METHOD:

- ARBITRARY COMPLETE A/C CONFIGURATION
- STEADY AND GENERAL UNSTEADY MOTION
- SUBSONIC AND SUPERSONIC
- COMPUTATIONAL EFFICIENCY

### CURRENT DEVELOPMENTS:

- NONLINEAR EFFECTS (TRANSONIC FLOW, WAKE DEFORMATION)
- IMPROVED FINITE ELEMENTS (HIGHER ORDER, SPECIAL PURPOSE)
- ROTATIONAL FLOW (TURBULENCE, VISCOSITY)



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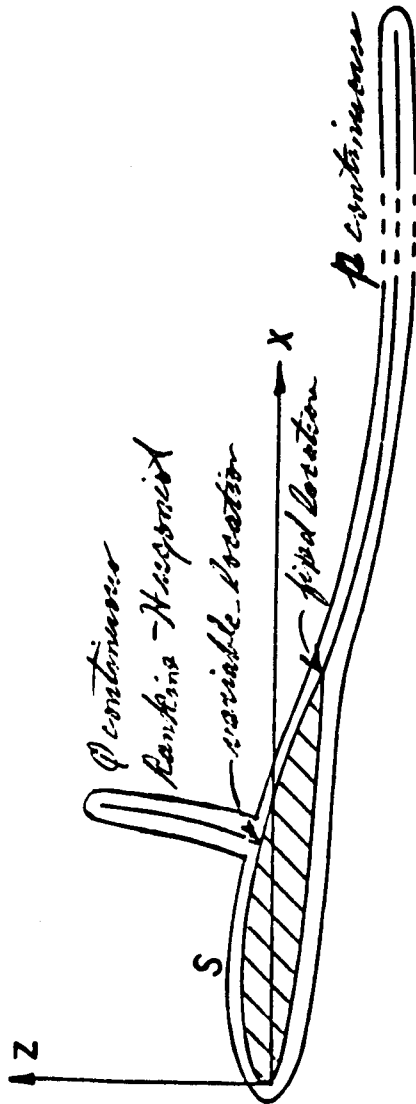
In the integral equation for the velocity potential (previously shown) the surface integration extends over the surface of the aircraft plus its wake, and the no-penetration boundary condition  $DS/Dt = 0$  applies over both. Moreover, the pressure must be continuous across the wake although the potential is discontinuous. The forward edge of the wake of a lifting surface is, of course, always located at the lifting-surface trailing edge, but the position of the rest of the wake is not known a priori, is variable, time-dependent, and must be determined in the calculation. This variability requires relocation and reorientation of the wake and its panels during the calculation, perhaps many times if the calculation is iterative.

This figure also shows a shockwave which is isolated from the flow field by a portion of the surface  $S$ . Over this portion of  $S$  the no-penetration boundary condition must be replaced by Rankine-Hugoniot conditions which quantify shock-induced discontinuities in derivatives of the potential although the potential itself is continuous across the shock. These discontinuities make it desirable to have panel edges lie along the foot of the shock. But shock location, shape, extent, strength, and velocity relative to the vehicle surface are time dependent. Moreover, motion of finite amplitude--even small amplitude--that is needed to investigate limit-cycle aeroelastic response can lead to large-amplitude shock motion and even discontinuous shock location. Consequently, requiring panel edges to coincide with the foot of the shock can require extensive repaneling in the vicinity of the shock during calculations for unsteady motion. In contrast, nonlinear calculations for shock-free transonic flow require no repaneling and impose no special requirements for surface geometry.

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# THE SURFACE S



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Shocks and wakes from lifting surfaces impinge upon fuselages or other portions of the vehicle along lines that are time dependent. Because of the discontinuities in potential or its derivatives at these impingement lines, it is desirable that panel edges coincide with them. Hence, time dependent repaneling in these vicinities is also indicated.

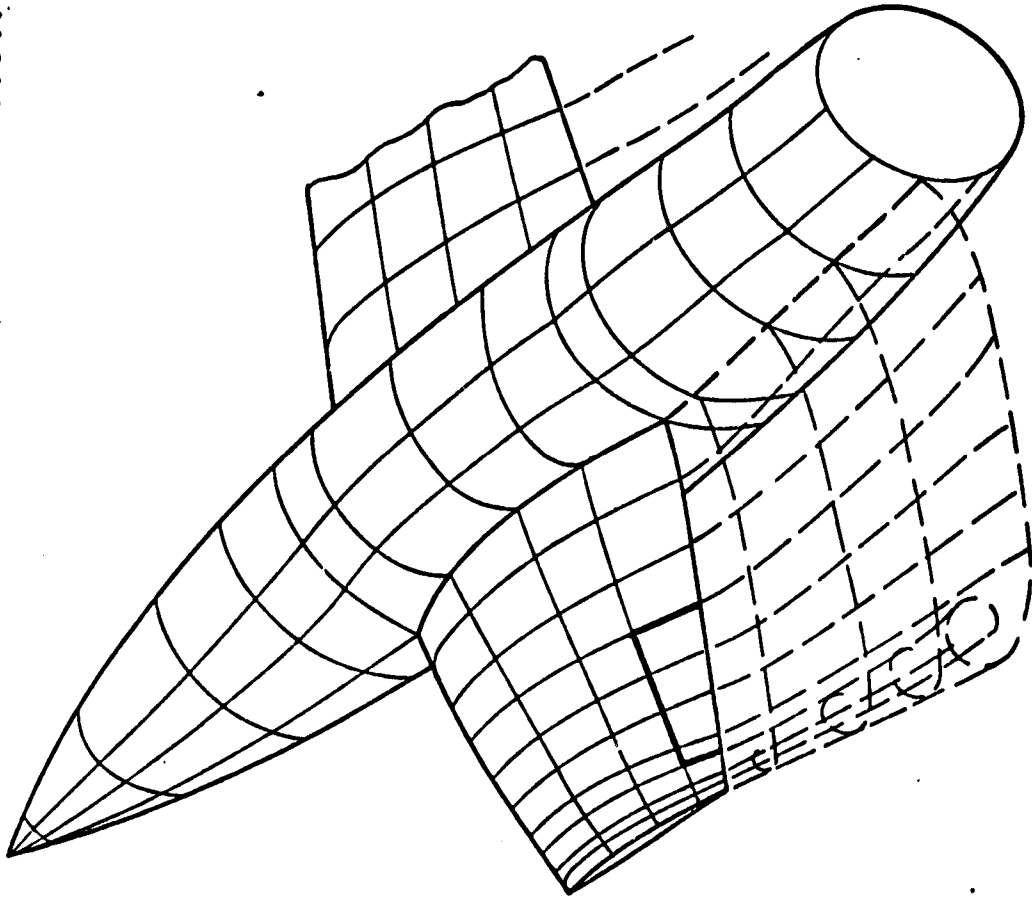
For simplicity in its development, the present SOUSSA program contains zeroth-order (constant-potential) aerodynamic elements. However, it has been intended from the beginning that the program would employ higher-order elements in order to reduce the number of elements required to converge the solution. Such elements have been developed and will soon be incorporated into the program. In addition, special-purpose elements are being developed for paneling in regions where correct variation of potential is theoretically known. These elements have built-in shape functions to produce the correct variation of potential, for example, adjacent to normalwash discontinuities such as control-surface hinge lines and side edges, or correct variation of potential derivatives as at subsonic trailing edges. In addition, flow-through elements are required to model engine thrust in nacelles and to panel shockwaves. Such elements impose no new requirements for surface geometry information. Note that no special panels are required adjacent to shock or wake impingement on the body surface. Use of higher-order and special-purpose elements should reduce computer time and storage requirements but probably will do little to reduce the amount of geometrical input information required. Although fewer elements are used, more information is required per element. Detailed accuracy of information out requires detailed accuracy of information in irrespective of the level of sophistication.

Finally, incorporating the effects of viscosity and rotational flow will impose a requirement for relatively high accuracy of computed pressure gradients and hence will require higher-order elements (at least third order) than would be required for most potential-flow problems. Alternatively, it is possible that required accuracy and order of continuity may be attained from solutions using lower-order elements followed by spline (or other) interpolation of the calculated potential.

Specific treatment of aircraft geometry in the SOUSSA program itself will next be described by Dr. Morino.



WAKE-FUSELAGE INTERSECTION



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United States Marine

The rest of this presentation is devoted to the specific geometry requirements for the program SOUSSA P (Steady, Oscillatory and Unsteady, Subsonic and Supersonic Aerodynamics; Production Version). As presented above, the Green's function method yields an integral equation over the surface of the aircraft and its wake (with differential-delay dependence on time). Dividing the surfaces in quadrilateral elements and assuming the potential, the normalwash and the potential discontinuity to be constant within each element, one obtains Eq. (1).

The coefficients  $B_{jh}$ ,  $C_{jh}$ , etc., are evaluated analytically, with the original surface  $\sigma_h^{jh}$  approximated by a hyperboloidal paraboloid (hyperboloidal element). Numerical quadrature is used for distant element.

In order to complete the formulation three additional relationships are required:

1. Boundary conditions, relating normalwash  $\psi$  to the generalized coordinates  $q_m$  (Eq. 2)
2. Bernoulli's theorem relating pressure coefficient  $C_p$  to potential  $\phi$  (Eq. 3)
3. Definition of generalized forces,  $e_m$ , as functionals of the pressure coefficient  $C_p$  (Eq. 4)

Finally combining Eqs. 1 to 4 one obtains the matrix E relating the generalized forces,  $e_m$ , to the generalized coordinates,  $q_m$ .

# POTENTIAL NORMALWASH RELIATIONSHIP

MORINO 8

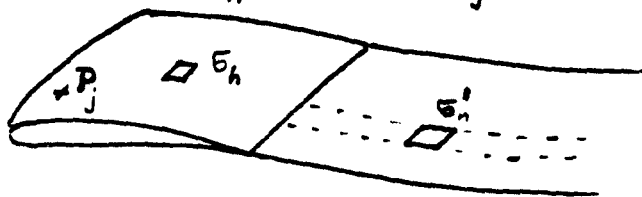
$$\boxed{\tilde{\Psi} = \tilde{E}_2 \tilde{\Psi}} \quad (\tilde{E}_2 = \tilde{Y}^{-1} \tilde{Z}) \quad (1)$$

WITH

$$\begin{aligned} \tilde{Y}_{jh} &= \delta_{jh} - (C_{jh} + s D_{jh}) e^{-s \Theta_{jh}} + \sum_n (F_{jn} + s G_{jn}) S_{nh} e^{-s(\Theta_{jn} + \Pi_n)} \\ \tilde{Z}_{jh} &= B_{jh} e^{-s \Theta_{jh}} \end{aligned}$$

WHERE, FOR INSTANCE,

$$B_{jh} = \frac{1}{2\pi} \iint_{\sigma_h} \frac{1}{R} d\sigma_h \Big|_{P=P_j} \quad C_{jh} = \frac{1}{2\pi} \iint_{\sigma_h} \frac{\partial}{\partial N} \frac{1}{R} d\sigma_h \Big|_{P=P_j}$$



## BOUNDARY CONDITIONS

GIVEN  $\vec{v} = -U_\infty \vec{i} + \sum_m \dot{q}_m \vec{M}_m$  AND  $\vec{n} = \vec{n}_s + \sum_m q_m \Delta \vec{n}_m$

$\psi \equiv \frac{\partial \phi}{\partial N} = \vec{v} \cdot \vec{n}$  YIELDS

$$\boxed{\tilde{\Psi} = \tilde{E}_1 \tilde{q}} \quad (2)$$

## BERNOULLI'S THEOREM

$c_p = -2 \left( \frac{\partial \phi}{\partial t} + U_\infty \frac{\partial \phi}{\partial x} \right)$  YIELDS  $\boxed{\tilde{c}_p = \tilde{E}_3 \tilde{\phi}}$  (3)

## GENERALIZED FORCES

$e_m = \oint (-c_p \vec{n} \cdot \vec{M}_m) d\Sigma$  YIELDS  $\boxed{\tilde{e} = \tilde{E}_4 \tilde{c}_p}$  (4)

## COMBINING

$$\boxed{\tilde{e} = \tilde{E} \tilde{q}} \quad (\tilde{E} = \tilde{E}_4 \tilde{E}_3 \tilde{E}_2 \tilde{E}_1) \quad (5)$$

This slide shows the flow chart for the program SOUSSA, and it is presented in order to indicate how the geometric information is used in the program. The check points will be discussed later. Here only the function of each module is briefly described.

### Interfaces

BODYG. CONTG and WAKEG: Elaborate the geometry input of checkpoints 1 and 2 (user oriented) into the checkpoints 5, 6 and 7 as needed in the rest of the program.

### Potential-normal wash relationship (mode independent)

COEFB: evaluates the body coefficients  $B_{jh}$ ,  $C_{jh}$ ,  $D_{jh}$  and  $\theta_{jh}$

COEFW: evaluates the wake coefficients  $F_{jn}$ ,  $G_{jn}$ ,  $S_{nh}$ ,  $\theta_{jn}$  and  $\Pi_n$

YZMOD: combines the above frequency-independent coefficients to yield the frequency-dependent matrices  $[Y_{jh}]$  and  $[Z_{jh}]$ .

### Boundary conditions (mode dependent)

E1MOD: evaluates the matrix  $\tilde{E}_1$  relating  $\tilde{\Psi}$  to  $\tilde{q}$

### Bernoulli's Theorem (mode independent)

E3MOD: evaluates the matrix  $\tilde{E}_3$  relating  $\tilde{C}_p$  to  $\tilde{\phi}$

### Generalized Forces (mode dependent)

E4MOD: evaluates the matrix  $\tilde{E}_4$  relating  $\tilde{e}$  to  $\tilde{C}_p$

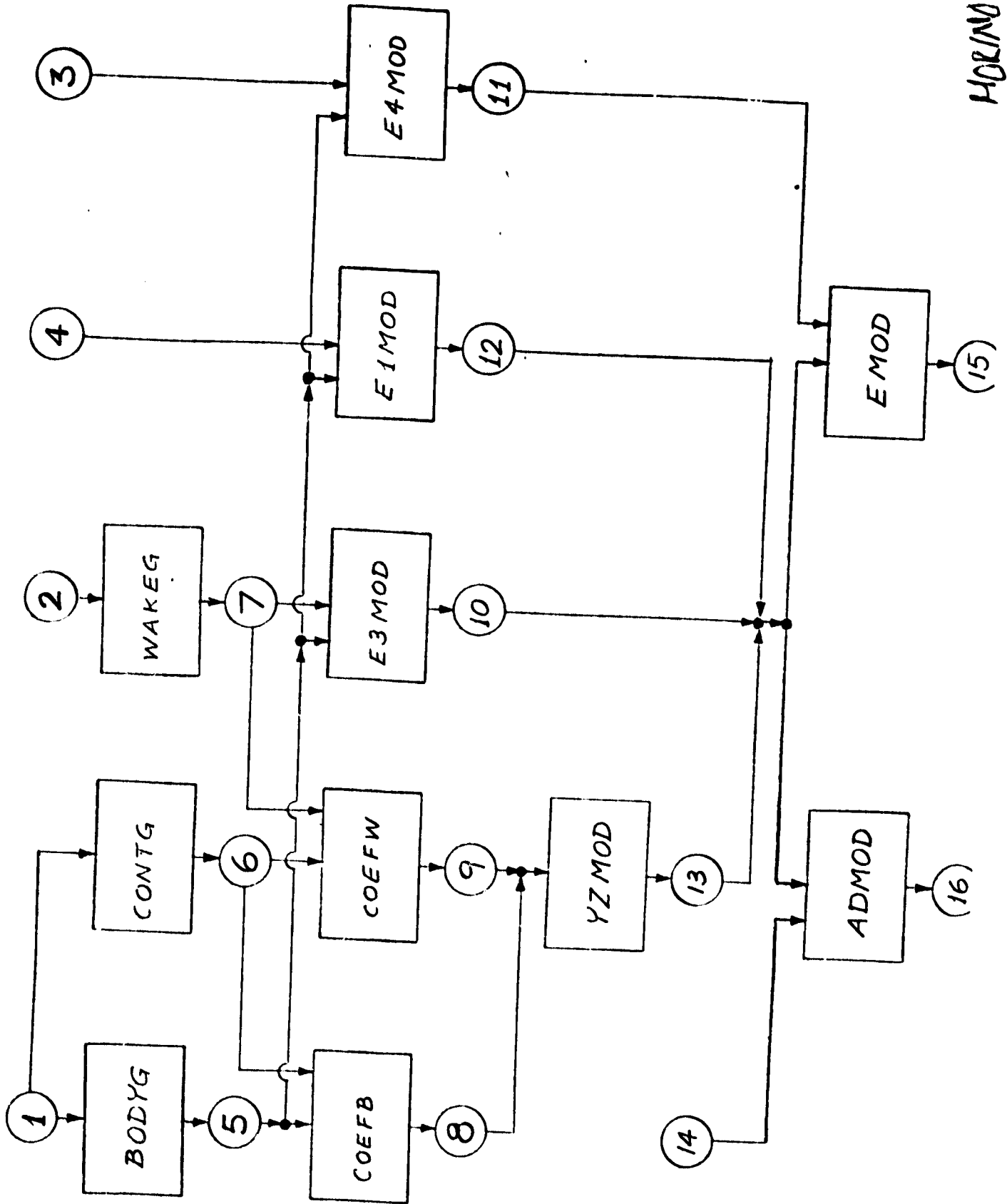
### Combining

EMOD: evaluates the generalized-aerodynamic-force matrix

$$\tilde{E} = \tilde{E}_4 \tilde{E}_3 \tilde{E}_2 \tilde{E}_1$$

ADMOD: implements an aerodynamic design method which yields the shape from a prescribed pressure distribution.

SOUSSA P 1.1



HORNO 9

(8)

*John + Marina*

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14

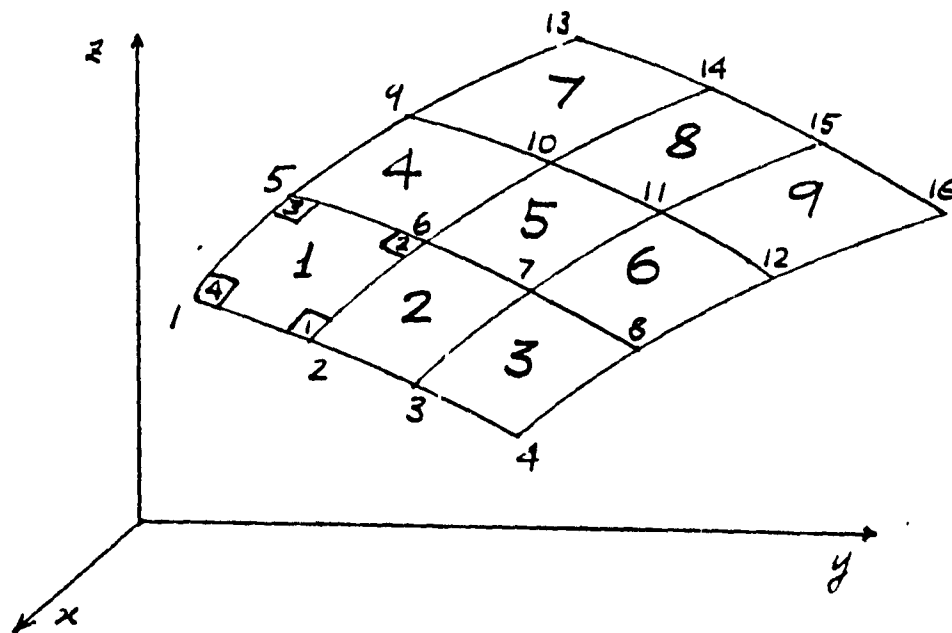
This slide presents the contents of Checkpoint #1 (input to module BODYG), which consists of information describing the geometry of the aircraft body. It is user-oriented in that the quantities required are compatible with the output of state-of-the-art geometry preprocessors. Also, if the aircraft is symmetric with respect to the x-z plane, then only the right half need be supplied. The same is true for the x-y plane.

Regarding the individual components of Checkpoint #1:

- o The Cartesian coordinates of the nodes are assumed to be already rotated; that is, the aircraft is oriented as desired by the user.
- o Referring to the example depicted on the slide, element number 1, corner 1 yields node number 2.
- o The body-symmetry code numbers reflect whether symmetry is considered with respect to the x-z and/or y-z planes.
- o The element code numbers provide information such as whether or not a wake emanates from an edge of an element, or if an edge coincides with a hinge line, etc.

## CHECKPOINT # 1

- Cartesian coordinates of nodes,  $\vec{P}_n$ .
- $i_n (i_E, i_K)$ : matrix relating node number to element and corner numbers.
- body-symmetry code numbers.
- code number for elements (e.g. TE, hinge,...)



This slide presents the contents of Checkpoints #2 (input to Module WAKEG), #3 (input to Module E4MOD) and #4 (input to Module ELMOD).

Checkpoint #2 consists of information describing the geometry of the wake. By describing the wake as a collection of strips, many different forms of input can easily be made compatible. If a wake strip is symmetric with respect to the x-z plane, then only the right half need be supplied (same for the x-y plane).

Also,

- o Desired orientation of the wake with respect to the aircraft is assumed to already be satisfied.
- o The matrix that relates each wake strip no. with the corresponding four trailing-edge element numbers is used in evaluating the trailing edge values of the potential and for determining the values of the pressure discontinuity at the centroid of the trailing-edge elements.

Checkpoint #3 corresponds to the generalized-forces deformation modes, and Checkpoint #4 corresponds to the boundary-condition deformation modes.

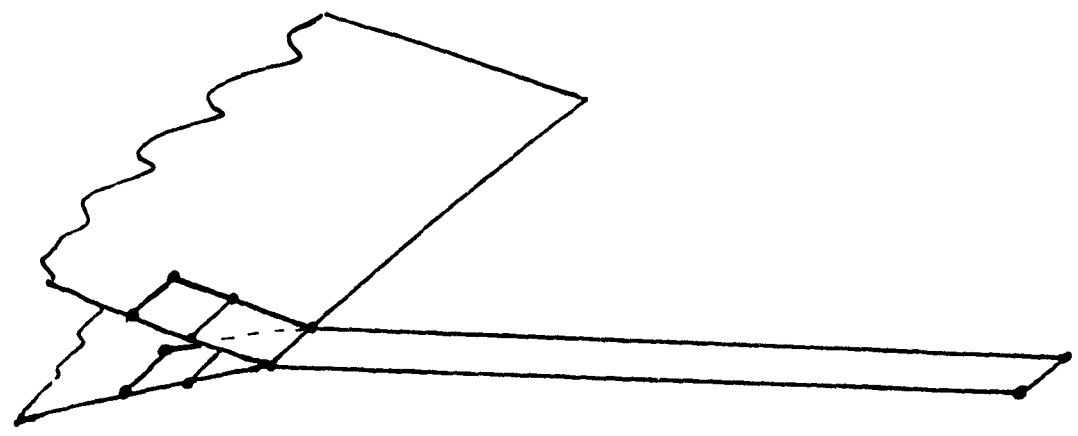
(10)

*John A. Morrison*



CHECKPOINT # 2

- Cartesian coordinates of corners of wake strips
- Symmetry codes for each strip
- Matrix relating each strip to the four corresponding trailing edge elements.
- Number of element per strip.



CHECKPOINTS # 3 AND 4

3-D (vector) mode shapes,  $\vec{M}_m(P_h)$ , at nodes,  $P_h$

(2)

This slide presents the contents of Checkpoints #5 (input to module COEFB) and #6 (input to modules COEFB and COEFW). These checkpoints are at a lower level than checkpoints #1-4 if one views the SOUSSA P flow diagram as a top-down representation. The implications of this are that these checkpoints are not as "user-oriented" as higher-level checkpoints, since program execution has progressed to this point. This is evidenced by the fact that for Checkpoint #5, the same quantities as Checkpoint #1 are required except that symmetry conditions (and their advantages in preparing geometrical input) are not considered. Furthermore, geometrical quantities such as the base vectors and normals of surface elements are not as readily available from geometry preprocessors as the information contained in Checkpoint #1. These considerations must be accounted for by those users desiring to begin execution of SOUSSA P at this level.

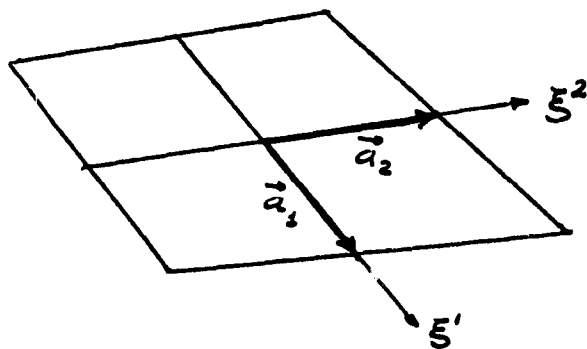
For version 1.1 of SOUSSA P, the location of the control points must be specified as the geometrical centroids of the body elements. For future versions (first-order finite element formulation), the location of the nodes will be the necessary input.

(11)

*Yates & McCain*

CHECKPOINT #5

- Same quantities as checkpoint #1, but for complete aircraft
- base vectors  $\vec{a}_1$  and  $\vec{a}_2$  and normal  $\vec{a}_1 \times \vec{a}_2$  at centroids of elements for complete aircraft

CHECKPOINT #6

- Cartesian coordinates of the control points.

This slide presents the contents of Checkpoint #7 (input to module COEFW). This is also not a top-level checkpoint, hence, its contents may not be as "user-oriented" as, say, Checkpoint #2. For instance, at this level:

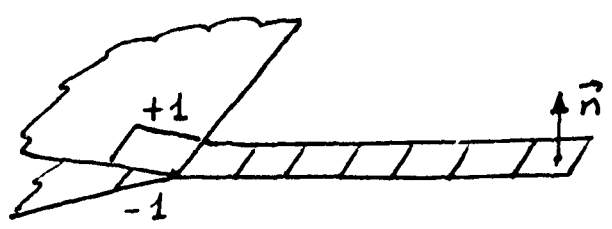
- o The coordinates of the wake elements (as opposed to the wake strips) are required, and no symmetry conditions may be taken advantage of (i.e., all the elements must be input).
- o The matrix used in correction for the trailing-edge potential values, for example, must be given for the elements comprising the complete wake.
- o Most geometry preprocessors would not provide the matrix of the coefficients of influence of the trailing-edge elements that determines the value of the potential discontinuity for each wake element. Note for SOUSSA P 1.1 these coefficients are simply 1 and -1, but for later versions, splines will be used to determine these coefficients.

(12)

*Yates & Marino*

CHECKPOINT #7

- Cartesian coordinates of the corners of the wake elements for the entire wake.
- Matrix relating each wake element to the four trailing-edge elements (see checkpoint #2), for the entire wake.
- Matrix relating each wake element to the coefficients of influence,  $\pm 1$ , for the two trailing edge elements



STEGER /

## FLOW FIELD GRID GENERATION

1. DISCUSSION OF CURVILINEAR GRID GENERATION
2. EFFECTS OF INACCURATE SURFACE REPRESENTATION

The accurate three-dimensional simulation of flow fields by finite difference or related methods will require a very accurate representation of the surface geometry. Continuity of surface slope and curvature is needed unless the configuration is, indeed, discontinuous in these features. To support this view the problem of curvilinear grid generation for finite difference (or finite volume and some finite element) procedures is briefly sketched. The sensitivity of the numerical solution to inaccurate surface representation is then illustrated with examples (numerous examples of inaccuracy have been generated over the years, but they tend to be quickly discarded).

Steger 1.

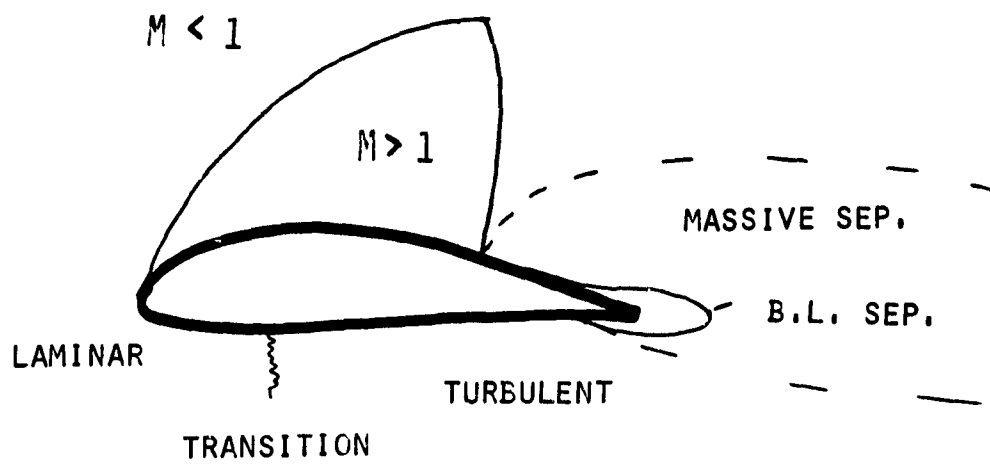
Finite difference methods are used when nonlinear effects such as compressibility and strong viscous interaction are important. In a finite difference problem a solution is obtained over the entire flow field domain.

Steger 2.



2 3235

# FINITE DIFFERENCE SIMULATION



In the finite difference method the flow field is discretized (or meshed) and derivatives are replaced by difference approximations. This process results in a large nonlinear system of algebraic equations which may require simultaneous solution. Generally the equations are sparse and well ordered so that efficient solution methods can be devised that are often amenable to vectorized computer processing. This is especially true if the aerodynamic configuration is forced to coincide with a grid surface.

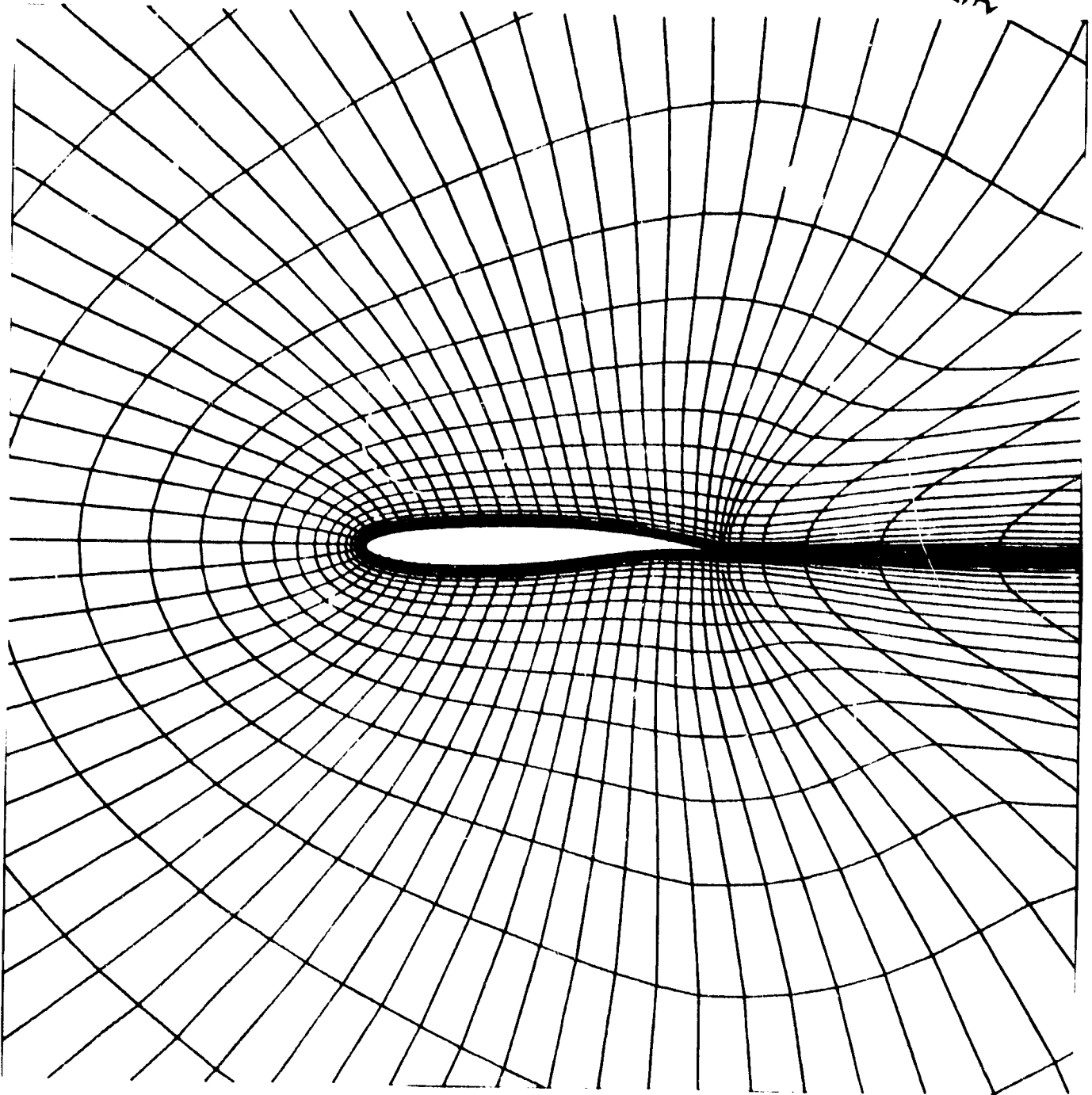
To maintain accuracy, grid points should be clustered to the action regions of the flow field. In this example points are clustered to the leading and trailing edge of the airfoil. Viscous layers are resolved by clustering to the airfoil surface.

Steger 3.

VISCOUS AIRFOIL GRID

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STAGER 3



Stager 3

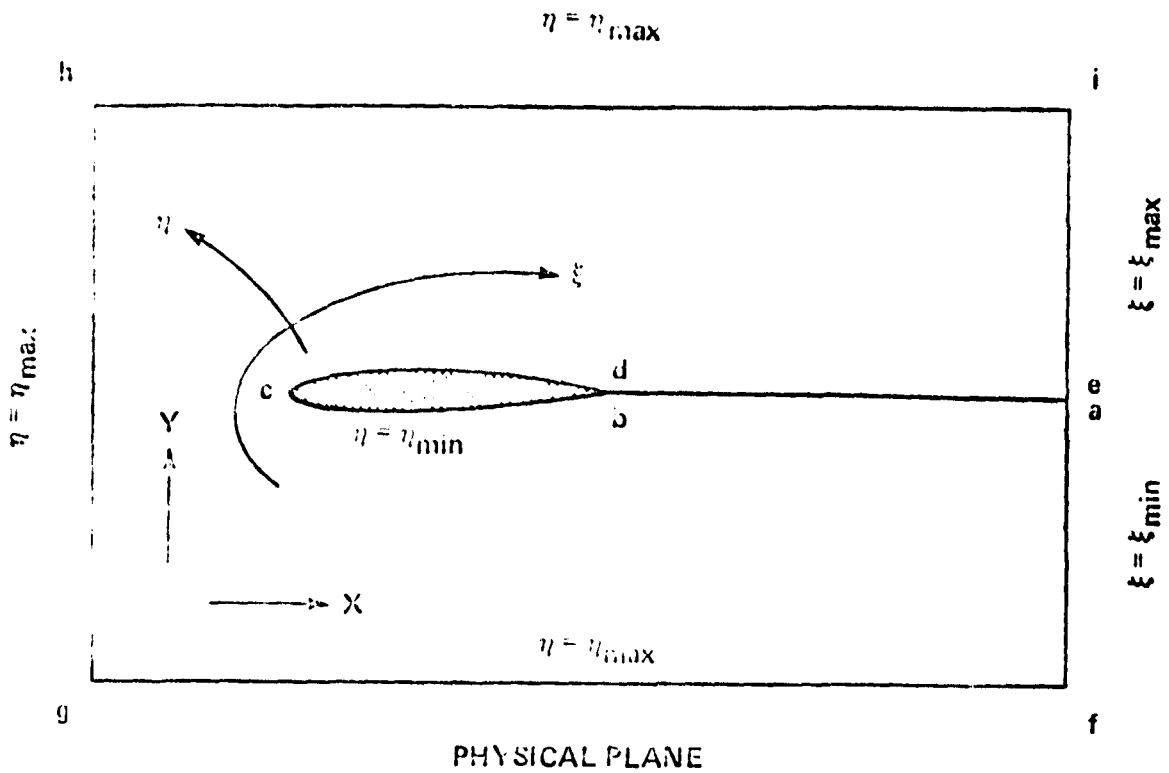
In one form of grid generation, which is illustrated here in two dimensions, points are distributed on the body and outer boundaries. Curvilinear coordinates  $\xi$  and  $\eta$  are then generated by the solution of an elliptic equation that satisfies a maximum principle. By properly choosing minimum and maximum values of  $\xi$  and  $\eta$  on the boundaries (see sketch), contour levels of monotonically increasing values of  $\xi$  and  $\eta$  can be found that trace out a curvilinear coordinate system.

In practice, the elliptic equations are solved in a transformed plane along specified  $\xi$  and  $\eta$  coordinate lines. The solution for  $x$  and  $y$  along  $\xi, \eta$  coordinates in the transformed plane then automatically finds constant lines of  $\xi$  and  $\eta$  in the physical plane.

Accurate surface representation enters into this process only once. When the grid points are specified along the body surface, they must lie on or very near the correct boundary curve. Otherwise an error will result, not in generating a grid, but in later solving for the flow field about the correct configuration.

# FROM SURFACE REPRESENTATION TO GRID GENERATION

4



PHYSICAL PLANE

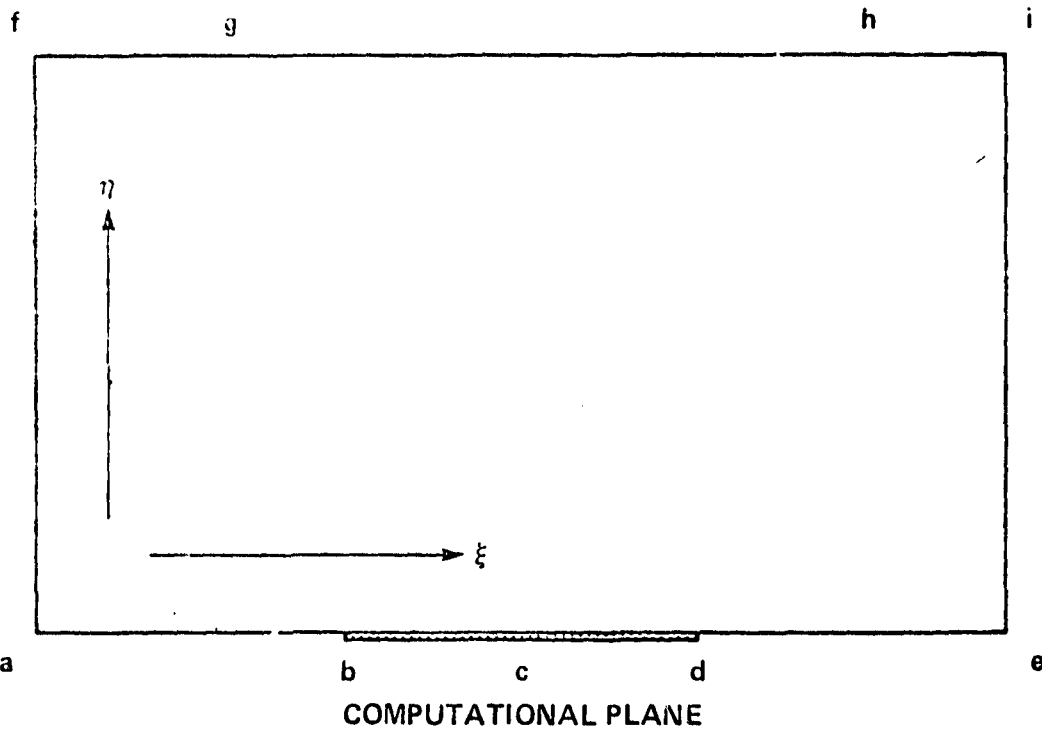
$$\xi = \xi(x, y)$$

$$\eta = \eta(x, y)$$



$$\nabla^2 \xi = 0$$

$$\nabla^2 \eta = 0$$



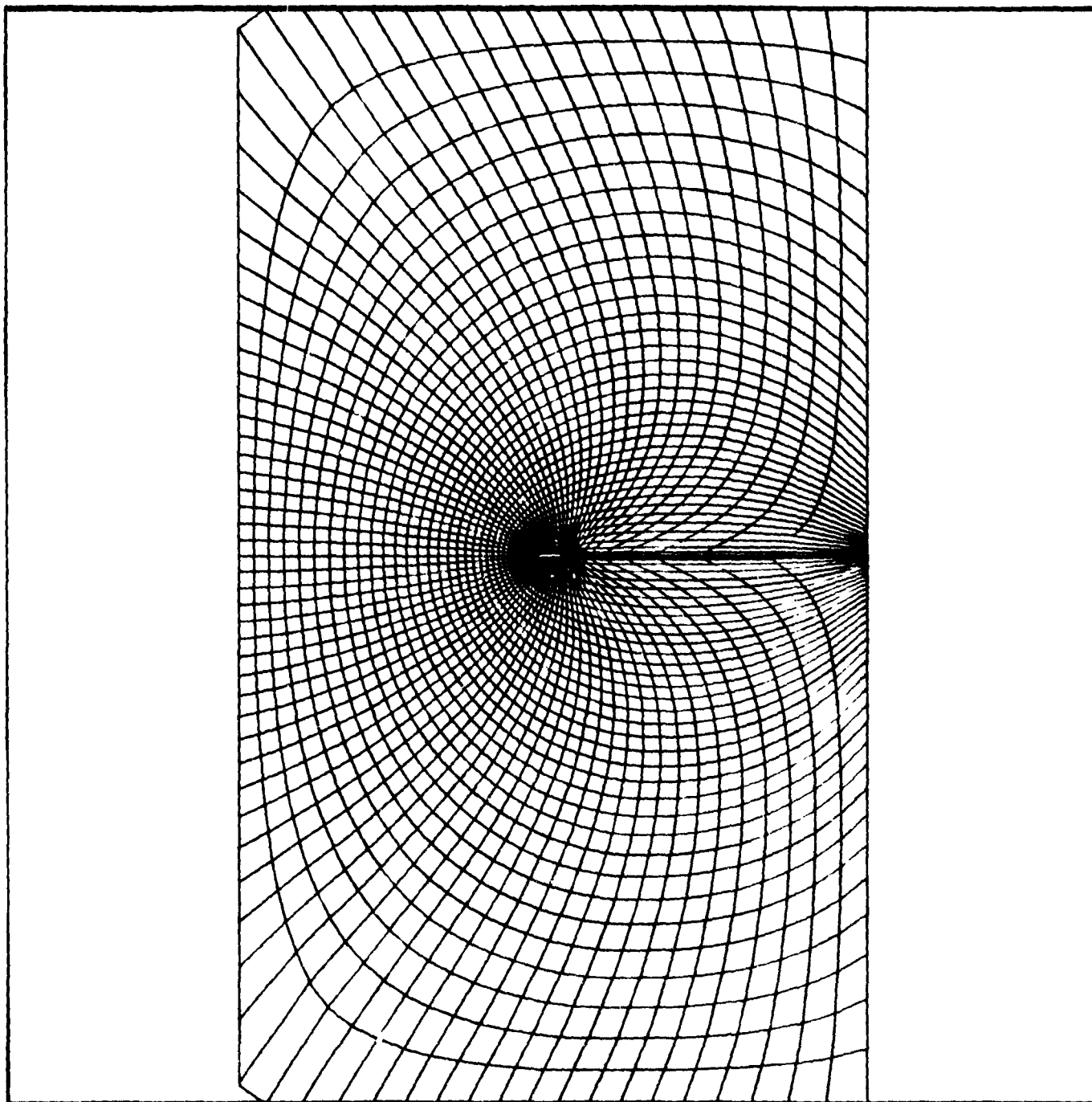
COMPUTATIONAL PLANE

A grid generated by the previously described procedure prior to viscous layer reclusterling.

Steger 5.

10

GRID GENERATED BY ELLIPTIC EQUATIONS



Steger 5

15

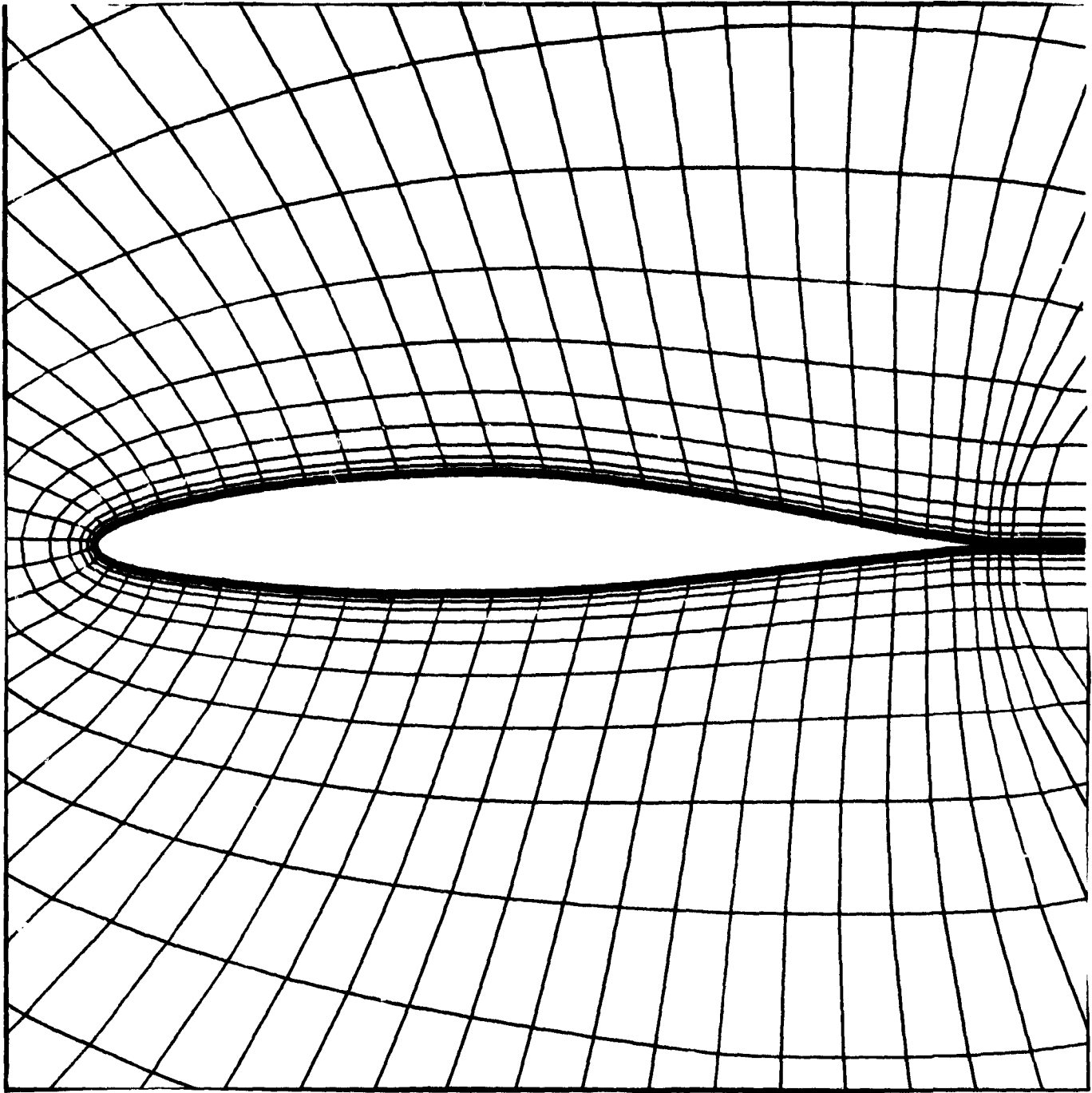
Grid detail near body surface after viscous  
layer reclustered.

Steger 6.



6

# RECLUSTERED GRID



Steger 6

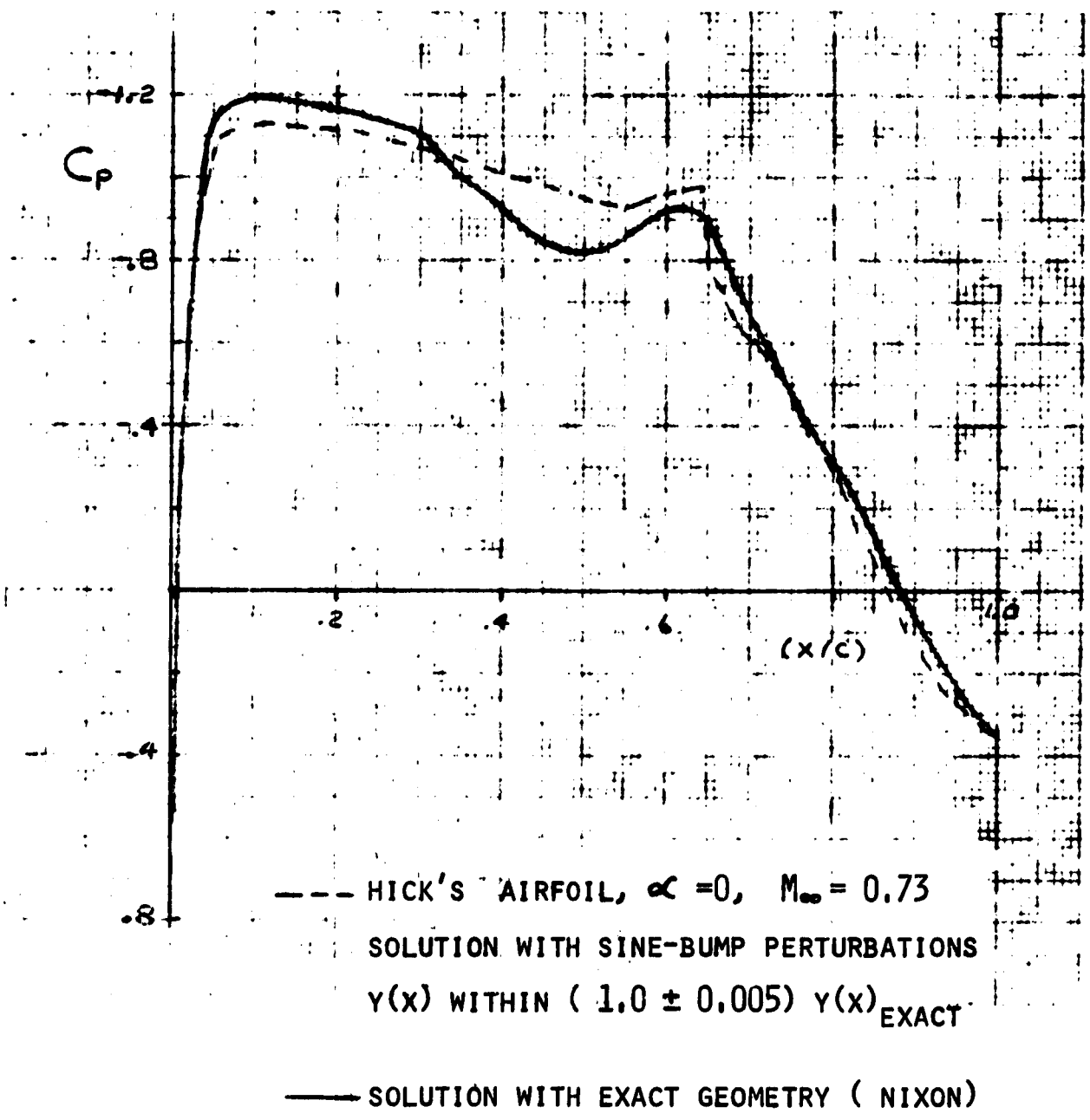
5

Small inaccuracies in the surface representation of a configuration can lead to much larger errors in predicted aerodynamic quantities. In this example (furnished by David Nixon), airfoil ordinates are slightly altered by placing sine-wave bumps on the upper surface of the profile. The perturbed ordinates are always within 1/2 percent of their correct local value, yet the percentage error in the  $C_p$  distribution is in places much greater.

In general the computer processing work of generating an accurate surface representation is much less than the work in obtaining an accurate finite difference simulation. Consequently, the geometry should be much more accurately represented than the estimated accuracy of the finite difference method.

Steger 7.

# EFFECT OF INCORRECT GEOMETRY ON $C_p$ DISTRIBUTION



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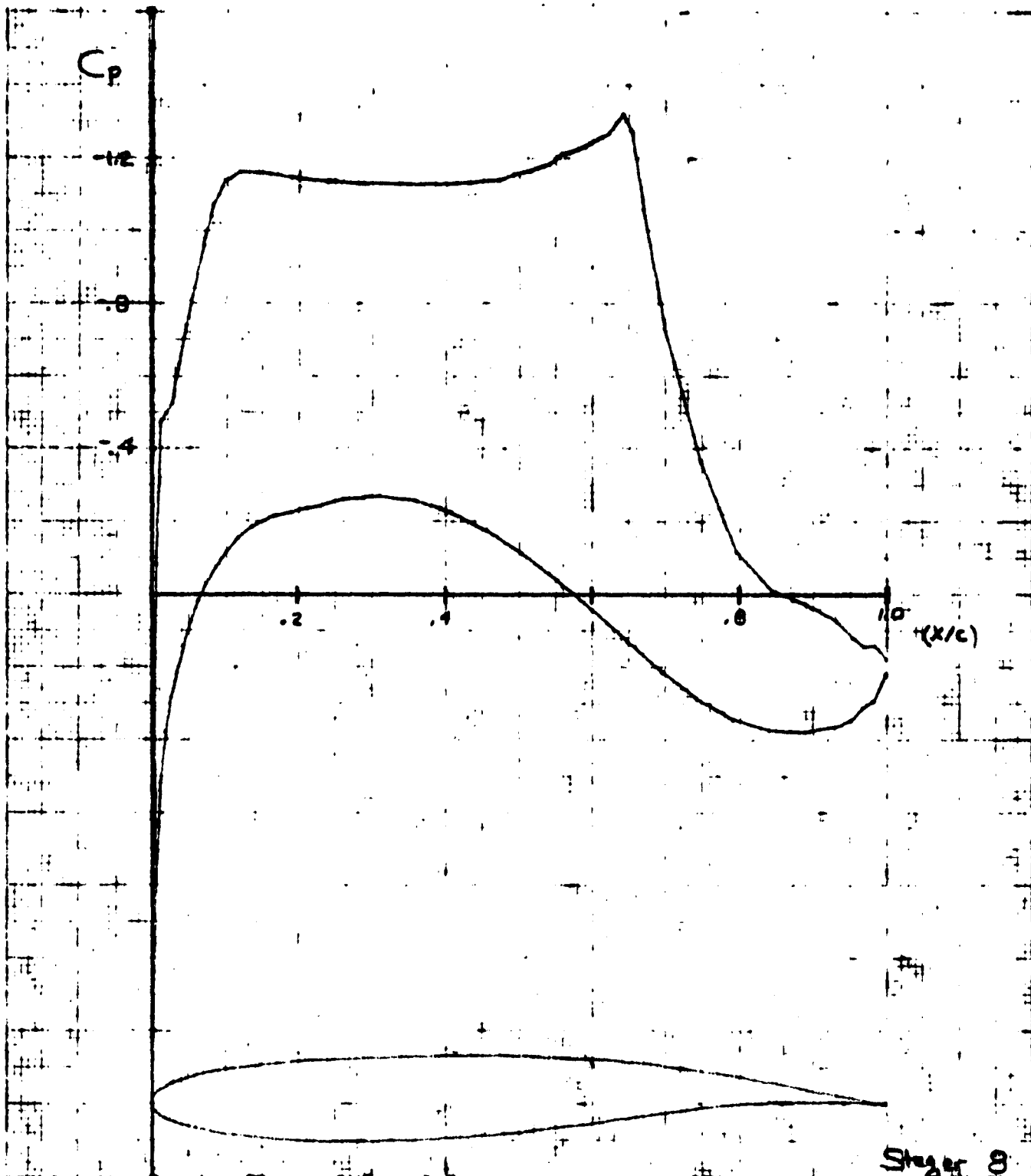
In this example of viscous transonic flow the radius of curvature of the airfoil actually changes near the leading edge. The finite difference scheme responds to the change with the peak in pressure distribution shown at the leading edge. A discontinuity in curvature due to inaccurate surface representation will result in similar peaks in the pressure distribution.

Steger 8.

# EFFECT OF DISCONTINUOUS RADIUS OF CURVATURE

$$M_{\infty} = 0.756, R_E = 21 \times 10^6, \alpha = 1.7$$

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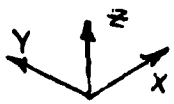
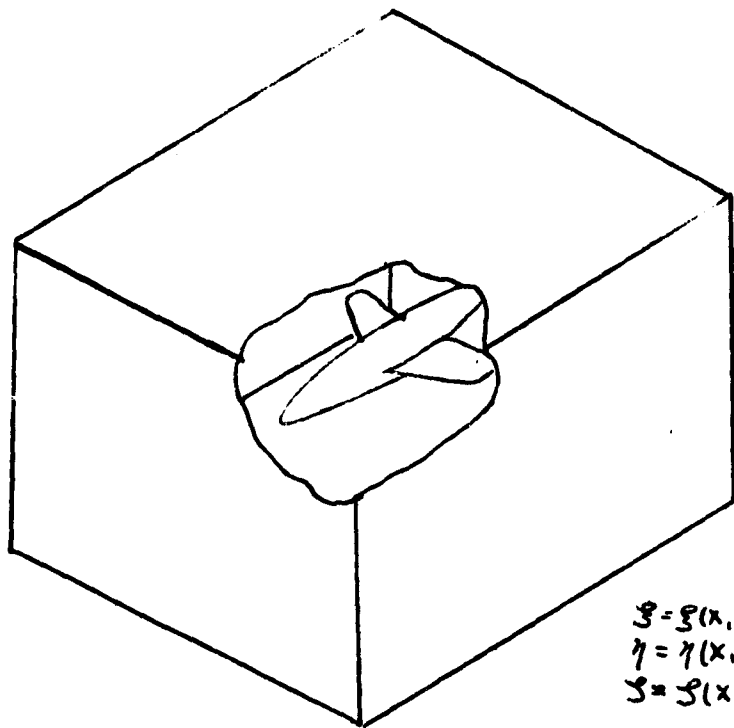
Shaper 10

One possible mapping scheme for three  
dimensions.

Steger 9.

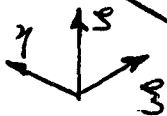
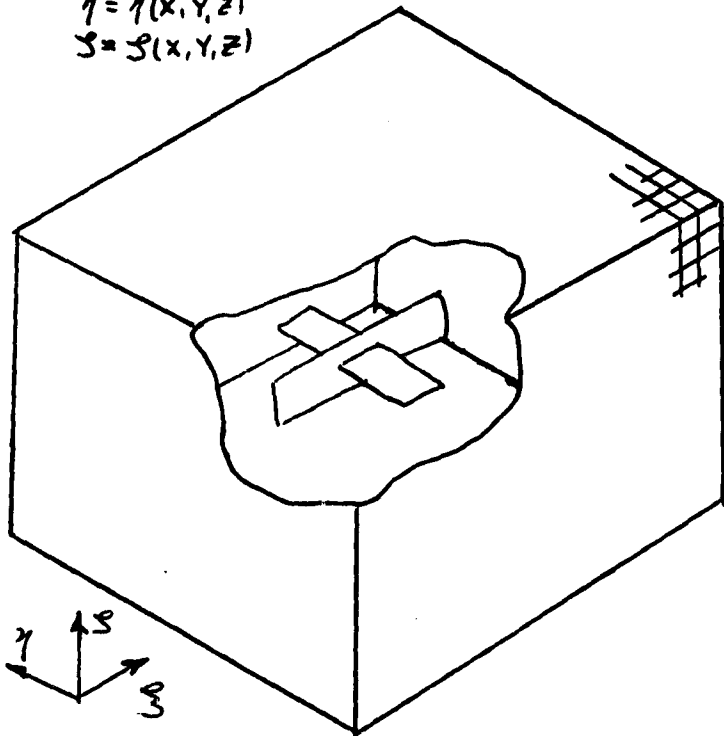
# WELL ORDERED GRID MAPPINGS

## PAPER AIRPLANE MAPPING ( THAMES )



$$\begin{aligned} \nabla^2 \phi &= P \\ \nabla^2 \eta &= Q \\ \nabla^2 \zeta &= R \end{aligned}$$

$$\begin{aligned} \phi &= \phi(x, y, z) \\ \eta &= \eta(x, y, z) \\ \zeta &= \zeta(x, y, z) \end{aligned}$$



Another possible mapping scheme for three dimensions. The axis singularity is definitely not a problem for certain formulations of the transformed flow equations.

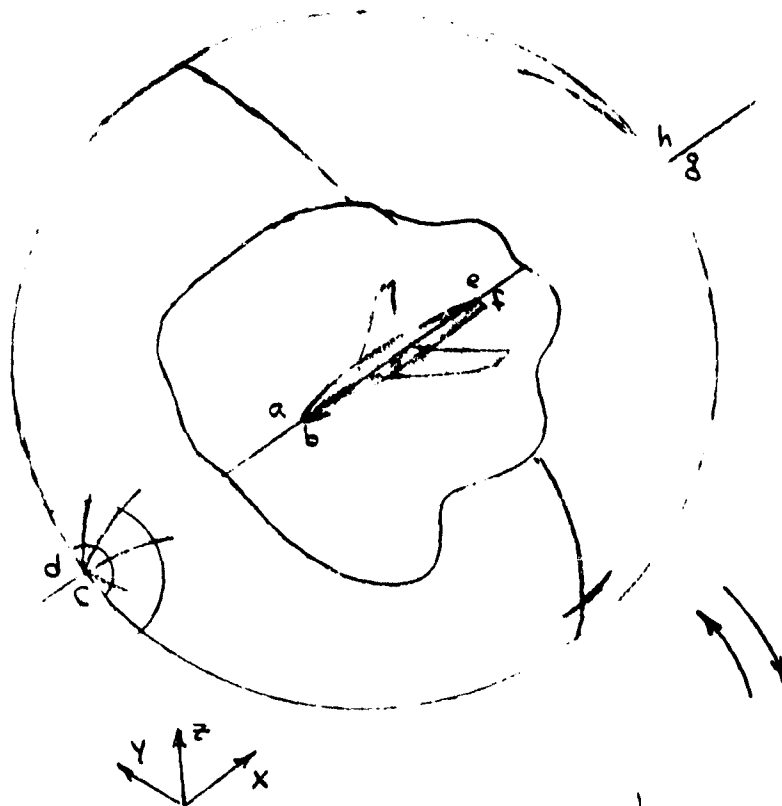
Steger 10.



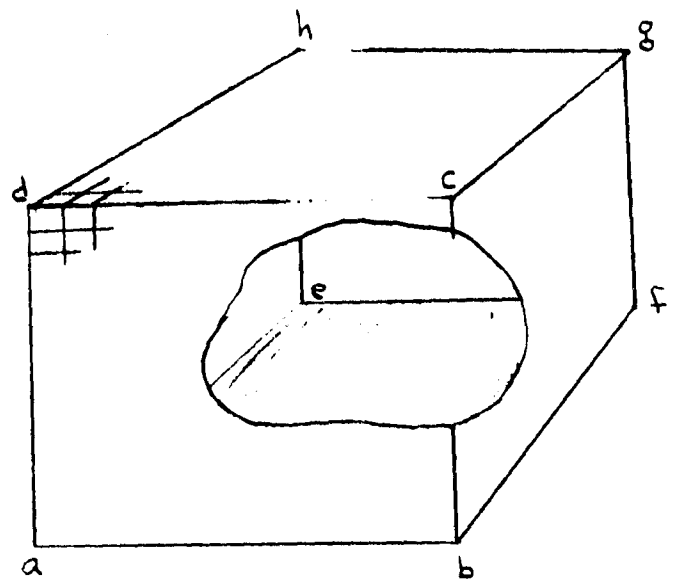
# WELL ORDERED GRID MAPPINGS

## WARPED SPHERICAL MAPPING

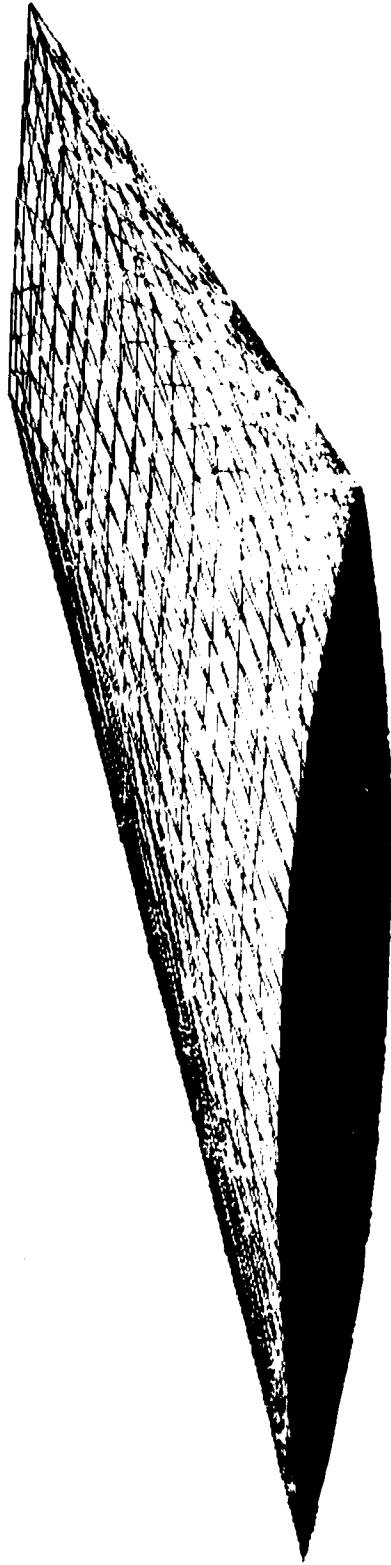
STEGER 10



$$\xi = \xi(x, y, z)$$
$$\eta = \eta(x, y, z)$$
$$\zeta = \zeta(x, y, z)$$

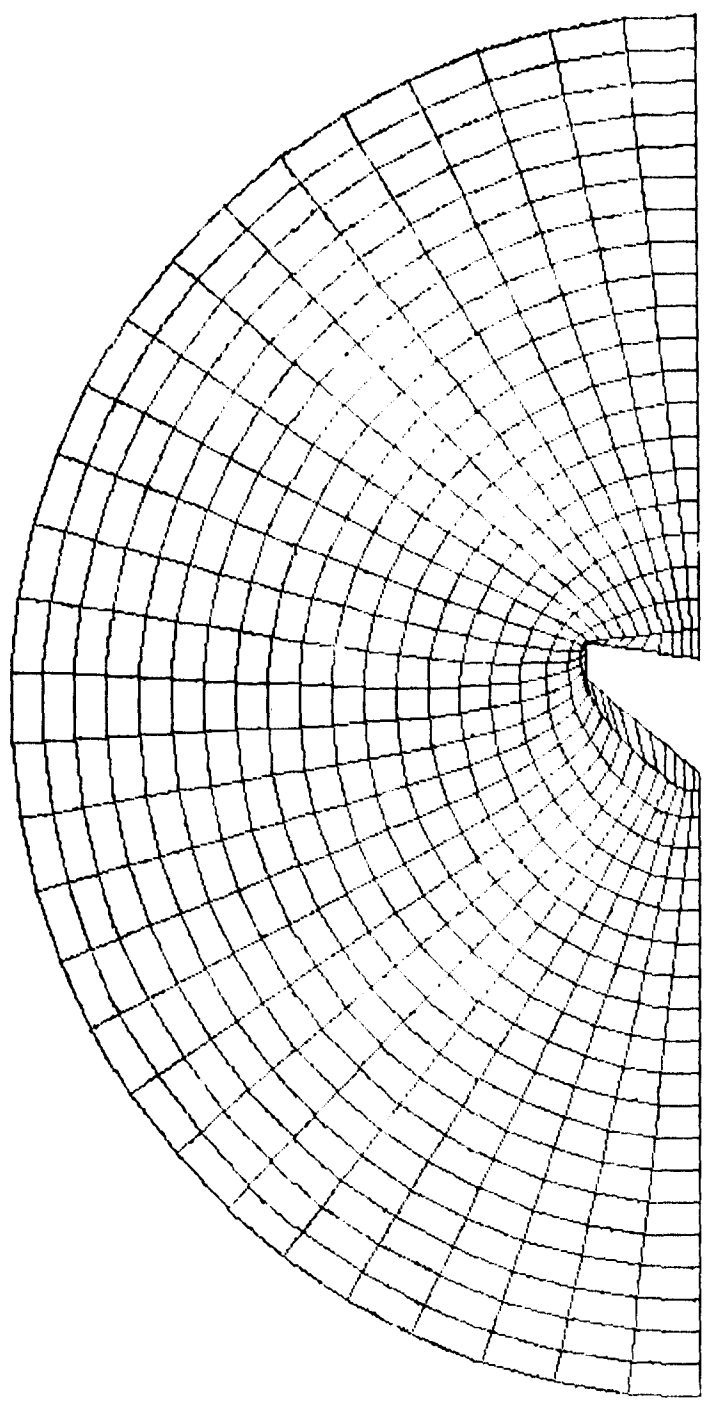


GRID POINT DISTRIBUTION ON WING SURFACE



A PLANFORM VIEW OF WARPED SPHERICAL GRID

STEGER 11



Steger 12

A HEADON VIEW OF WARPED SPHERICAL GRID

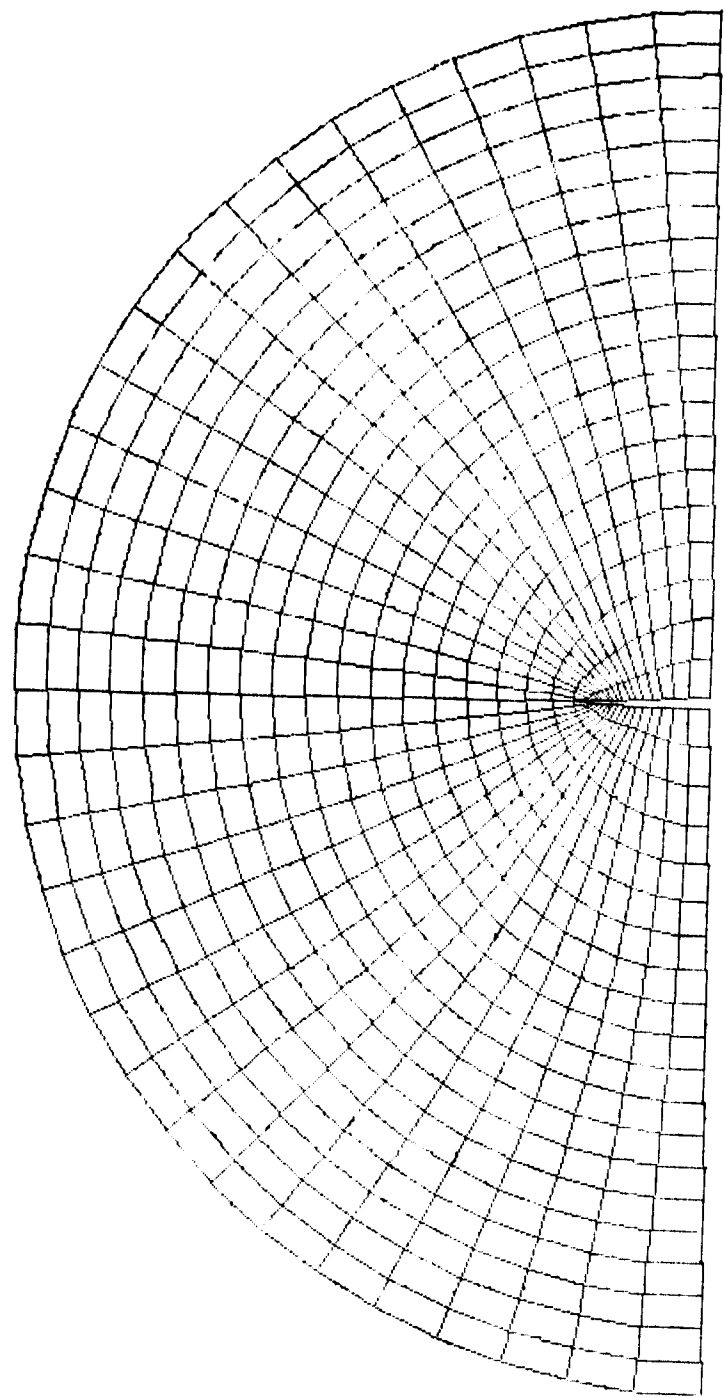


FIGURE 1 - TITLE SLIDE

GRAPHICS STATION REQUIREMENTS  
for a  
LARGE SCALE NUMERICAL  
AERODYNAMIC SIMULATION FACILITY

by Ralph L. Carmichael

NASA SURFACE REPRESENTATION WORKSHOP  
AMES RESEARCH CENTER

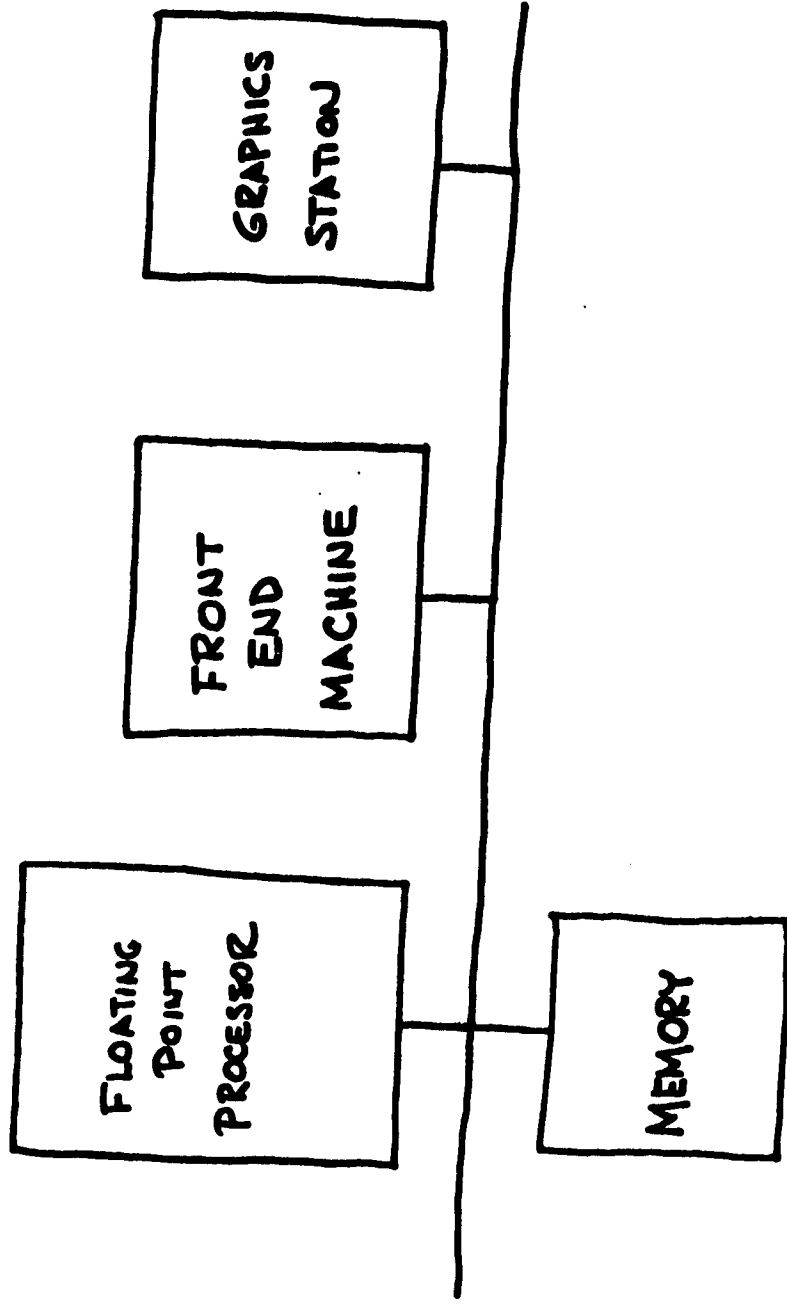
MARCH 1-2, 1978  
MOFFETT FIELD, CALIFORNIA

CARMICHAEL 1

## FIGURE 2 - NASF CONFIGURATION

NASA is at the preliminary definition phase of a project to create a numerical calculation of turbulent flow over complex shapes. A central element of the facility is the high-speed parallel processor capable of computing speeds in the range of 10 floating point operations/sec. (1 gigaflop). An essential feature of the facility is a graphics station. The objective of this presentation is to outline the general requirements for this station and to relate the qualitative nature of the displays desired as well as the quantitative levels of data required to create such displays.

# NASF CONFIGURATION



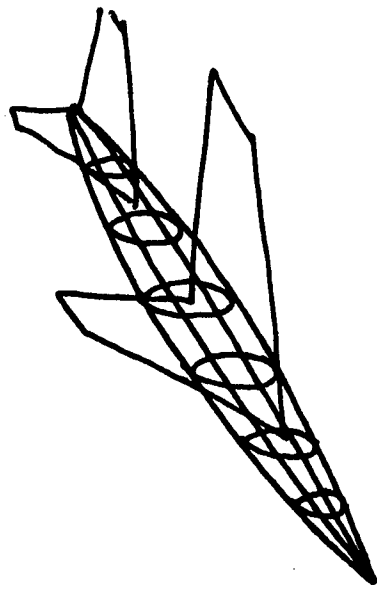
CARMICHAEL 2



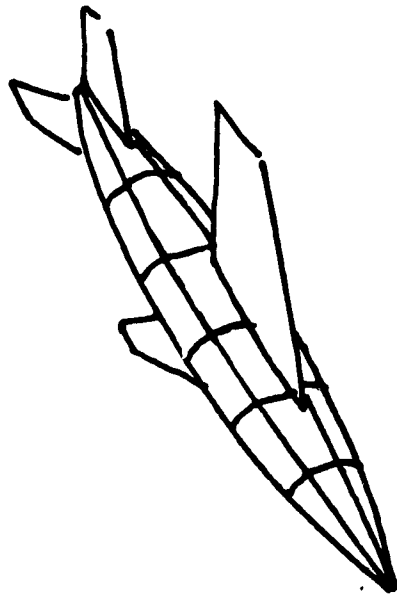
### FIGURE 3 - SURFACE GEOMETRY

An obvious use of the station is the display of surface geometry. Several techniques are available for such displays. The configuration may be shown by a line drawing system as a "wire-frame". Several display systems exist that enable such pictures to be rotated, zoomed, and clipped very rapidly and give the impression of motion on the screen. This picture gains in realism and depth by display if only the visible surface boundaries. At this time, it is not possible to manipulate such a display in real-time because of the heavy computational load required to sort the surfaces into hidden and visible. A third type of display, the shaded surface, is possible using video techniques rather than line drawing. While these pictures gain a great deal of realism, they lack the fine resolution of the line drawing system. This author's opinion is that the wire frame type display is the most useful for this station.

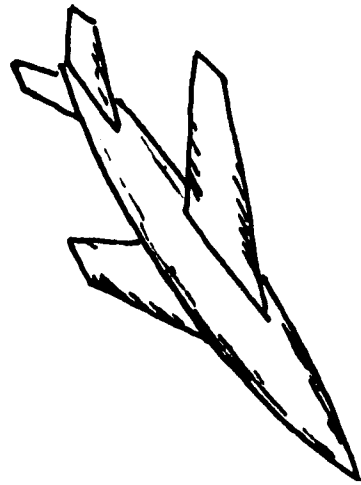
# SURFACE GEOMETRY



WIRE FRAME



VISIBLE SURFACE

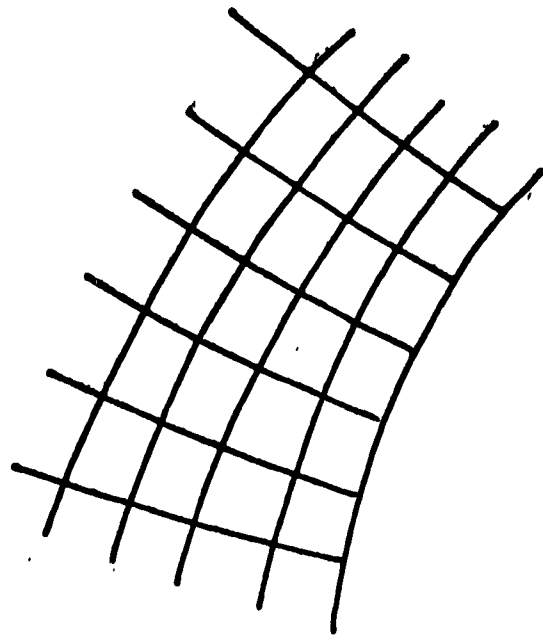


SHADED SURFACE

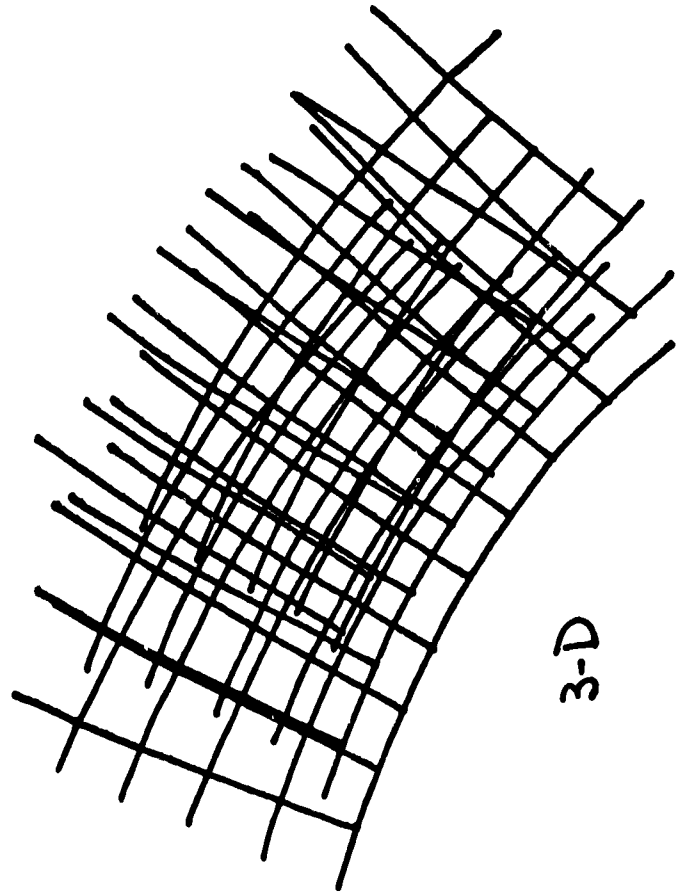
#### FIGURE 4 - 2-D AND 3-D FLOW FIELD GRIDS

Previous speakers have alluded to the problem of computing grid points at which finite difference methods are used to compute solutions to non-linear partial differential equations. One use of the graphics station is the display of such grids. While this is clearly feasible for the 2-D grid, the 3-D grid contains so many lines that it is confusing. Clearly, some innovative techniques will be required to allow the user to understand the network.

# 2-D AND 3-D FLOW FIELD GRIDS



2-D

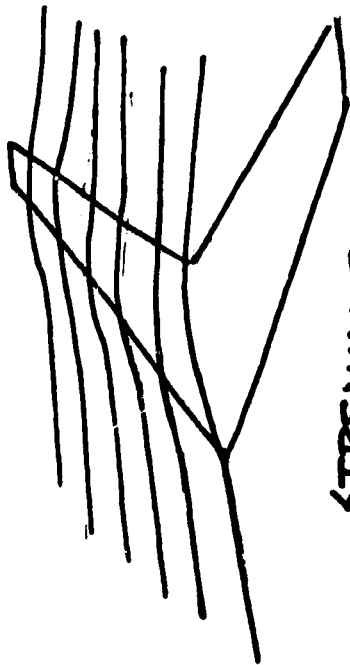


3-D

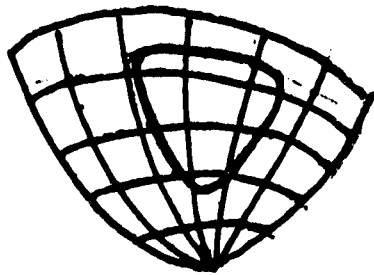
## FIGURE 5 - PHYSICAL RESULT

The results of the aerodynamic calculations must be presented to the user of the simulation facility. As with the 3-D flow field grids, considerable innovation will be required to present meaningful displays. A combination of dynamic displays with variable intensity and color will probably be required.

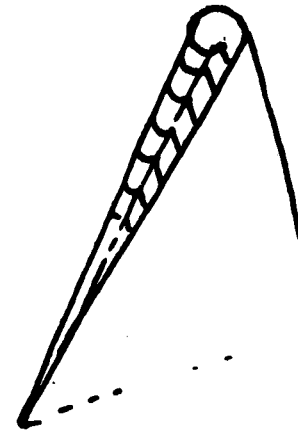
# PHYSICAL RESULTS



STREAMLINES



SHOCK WAVES

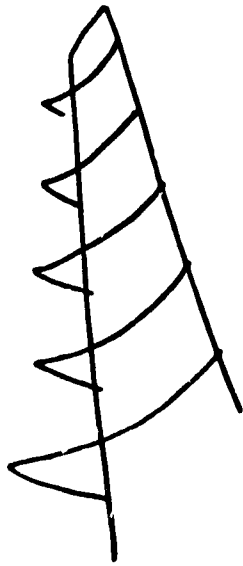


SEPARATION SURFACES

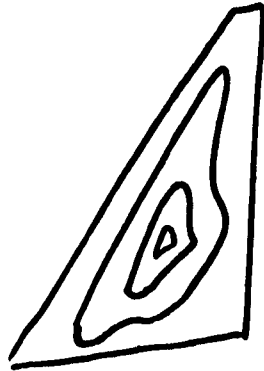
## FIGURE 6 - PRESSURE DISPLAYS

A number of well-known techniques are available for display of pressure distributions on wings. These are not easily adapted to fuselages and blended configurations. Again, considerable innovation will be required.

# PRESSURE DISPLAYS



PROFILES



CONTOURS



### FIGURE 7 - SURFACE GEOMETRY - WING

The next 7 figures are an outline of the data requirement for surface geometry and flow field grids. A wing of reasonable complexity could be represented by either of 1) a dense set of data; 2) a set of spline curves; or 3) a set of parametric patches. Regardless of the representation used, the data requirements are approximately  $10^3$  points.

# SURFACE GEOMETRY - WING

dense data

$$10 \text{ chords} \times 50 \text{ (x,z) pairs} = \frac{\text{data points}}{1000}$$

Splines - (10 intervals/spline)

$$10 \text{ splines} \times (5 \times \text{intervals} + 2) \text{ pts/spline} = 520$$

patches -

$$4 \text{ strips} \times 5 \text{ patches/strip} \times 48 \text{ points/patch} = 960$$

CONCLUSION: TOTAL DATA POINTS =  $10^3$

FIGURE 8 - SURFACE GEOMETRY - NACELLE

In a similar way, a nacelle requires also about  $10^3$  points.

# SURFACE GEOMETRY - NACELLE

## dense data

10 meridians, 50 (x,r) pairs 1000

## parametric spline (10 intervals/spline)

3 coordinates x 10 splines x (5 x intervals + 2) pts/spline = 960

## Patches

4 strip x 5 patch/strip x 48 points/patch 960

CONCLUSION: TOTAL DATA POINTS =  $10^3$

### FIGURE 9 - SURFACE GEOMETRY - FUSELAGE

There are different types of fuselages - either transport or fighter. It appears that transport fuselages will require about 1000 points while fighter fuselages will require about 5000 points.

# SURFACE GEOMETRY - FUSELAGE

Transport-type

10 meridians, 50 (x,r) pairs

1000

Fighter-type

50 meridians, 50 (x,r) pairs

5000

OR

50 stations, 50 (r,θ) pairs

5000

CONCLUSION: TOTAL DATA POINTS =  $5 \times 10^3$

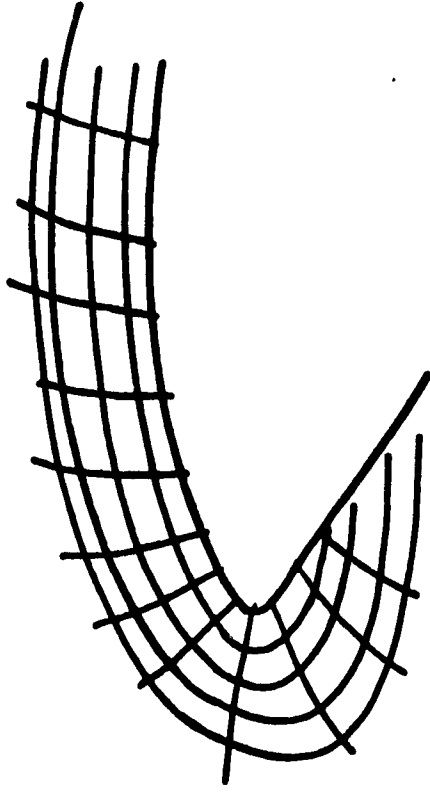
FIGURE 10 - SURFACE GEOMETRY - INTERSECTION

In the region of component intersections, some detailed definition is required. A typical intersection could have approximately 3750 points.

# SURFACE GEOMETRY - INTERSECTION

25 CURVES, 50(x,y,z) POINTS/CURVE

= 3750 POINTS





## FIGURE 11 - SURFACE GEOMETRY

The results of the previous 4 figures are summarized here. To build up a rather idealized configuration of a transport fuselage, 2 or 3 wing-like surfaces and 1 or 2 podded nacelles will require about 5000 points. A more detailed configuration with complex fuselage, several intersections and the full set of wings and tails would require about  $10^5$  points. Of course, a truly detailed airplane configuration with control surfaces, high lift system, external stores and armament (such as a wind-tunnel model) could easily require  $10^6$  or even  $10^7$  points for its definition. However, it is doubtful if configurations of this complexity can be simulated numerically in the foreseeable future.

# SURFACE GEOMETRY

POINTS  
1000

WING-LIKE SURFACES

TRANSPORT FUSELAGE

1000

FIGHTER FUSELAGE

5000

INTERSECTION DETAILS

3750

PODDED NACELLE

1000

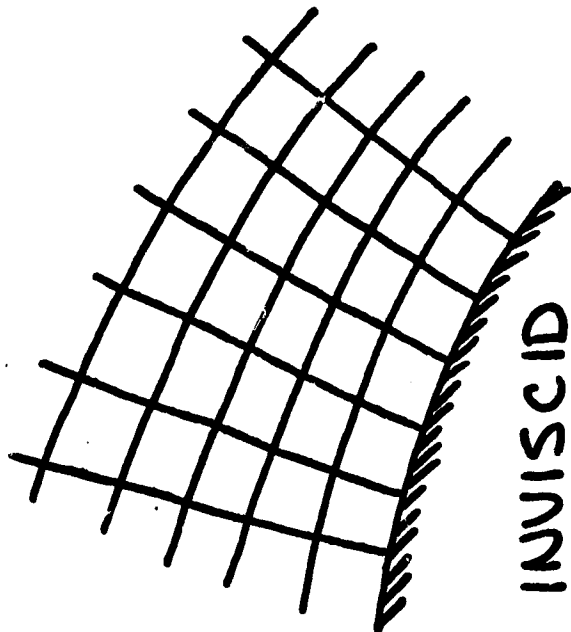
IDEALIZED CONFIGURATION =  $5 \times 10^3$

DETAILED CONFIGURATION =  $10^5$

FIGURE 12 - FLOW FIELD GRID GEOMETRY

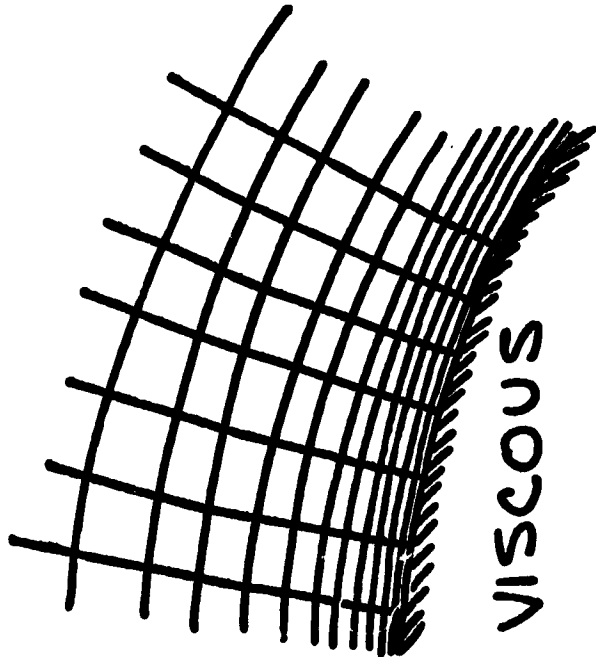
The size of the flow field grid is strongly related to the surface grid. Two different types of grids are utilized, depending upon whether the equations being solved are inviscid or viscous. The resulting size of the flow field grid is approximately  $10^6$  points.

# FLOW FIELD GRID GEOMETRY



INVISCID

20-40 layers



VISCOUS

50-100 layers

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GRID FOR IDEALIZED CONFIGURATION -  $10^6$

### FIGURE 13 - DATA VOLUMES

From the previous 2 figures, the surface geometry and grid geometry requirements are seen to be about  $10^4$  and  $10^6$ , respectively. All other results are related to these figures. About 10 physical quantities are computed at each computation point, thereby giving  $10^7$  points in the field and  $10^5$  on the surface. By integration into quantities such as spare loadings, moments, etc., this data is further compressed.

# DATA VOLUMES

SURFACE GEOMETRY  $10^4$

GRID GEOMETRY  $10^6$

PHYSICAL RESULTS AT GRID POINTS  $10^7$

PHYSICAL RESULTS ON SURFACE  $10^5$

INTEGRATED PHYSICAL PARAMETERS  $10^4$

PROGRAM INSTRUCTIONS  $10^4$

#### FIGURE 14 - TIME TO MOVE DATA

Now that the sizes of the various pieces of data are known, the times required to move data from one computer to another can be estimated. The speed limits associated with various facilities are shown on the horizontal axis. Several points are of interest. If telephone grade lines are used, it is impractical to transmit more than  $10^4$  words. Even with high speed lines, the input/output limitations of most minicomputers are limited to the  $10^4$ - $10^5$  bit/second range, making the process of transmitting a 3-D flow field grid a matter of an hour or so.

# TIME TO MOVE DATA

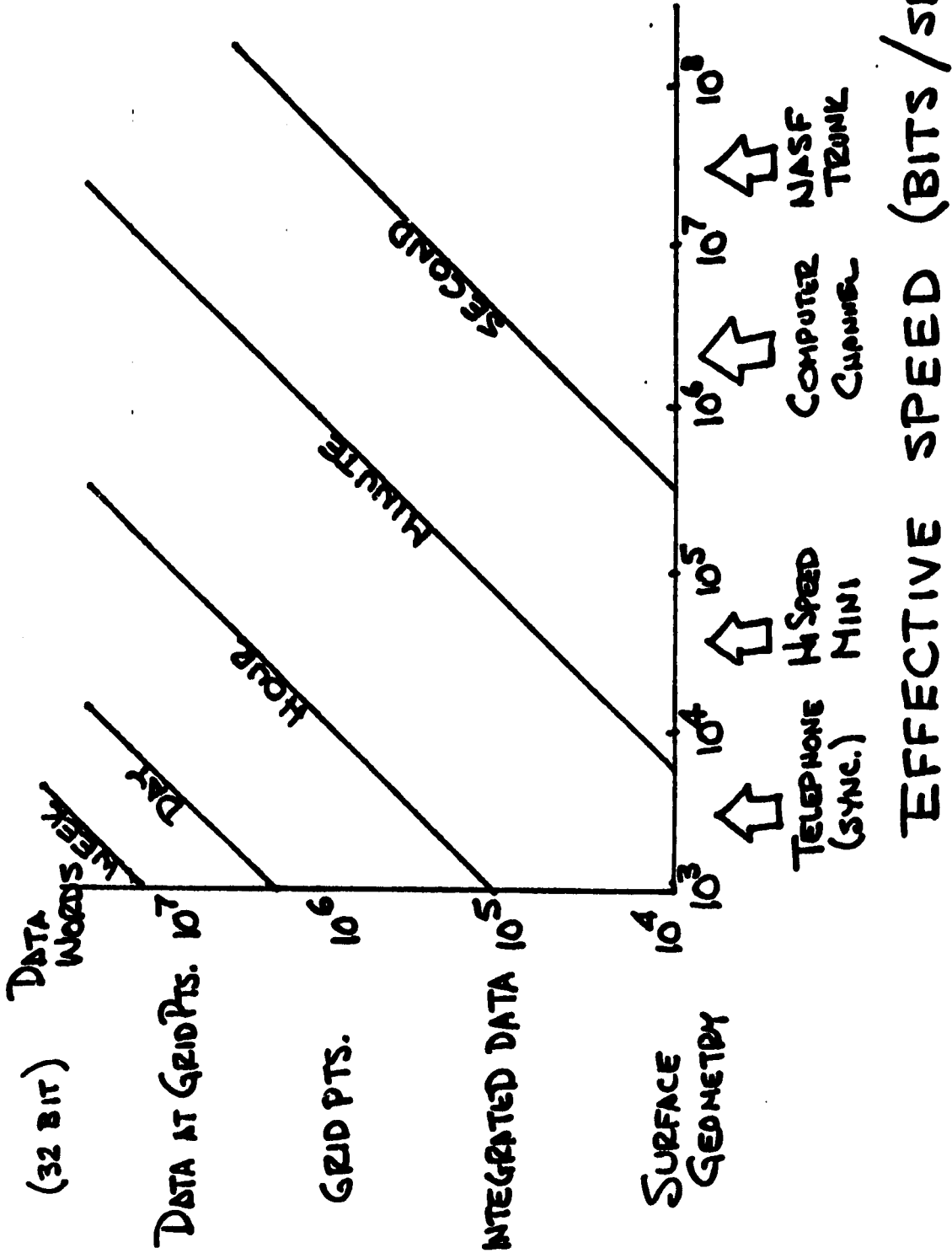




FIGURE 15 - CONCLUSIONS

## CONCLUSIONS

---

- LARGE DATA REQUIREMENTS FOR SOME DISPLAYS
- LINE DRAWING SYSTEMS PREFERABLE TO VIDEO
- 3-D DATA REQUIREMENTS MAY EXCEED I/O CAPABILITIES
- INNOVATIVE DISPLAY TECHNIQUES NEEDED  
FOR 3-D GRIDS & RESULTS

CARMICHAEL 15

**MACHINE SHOP AND WIND TUNNEL**

**MODEL REQUIREMENTS**

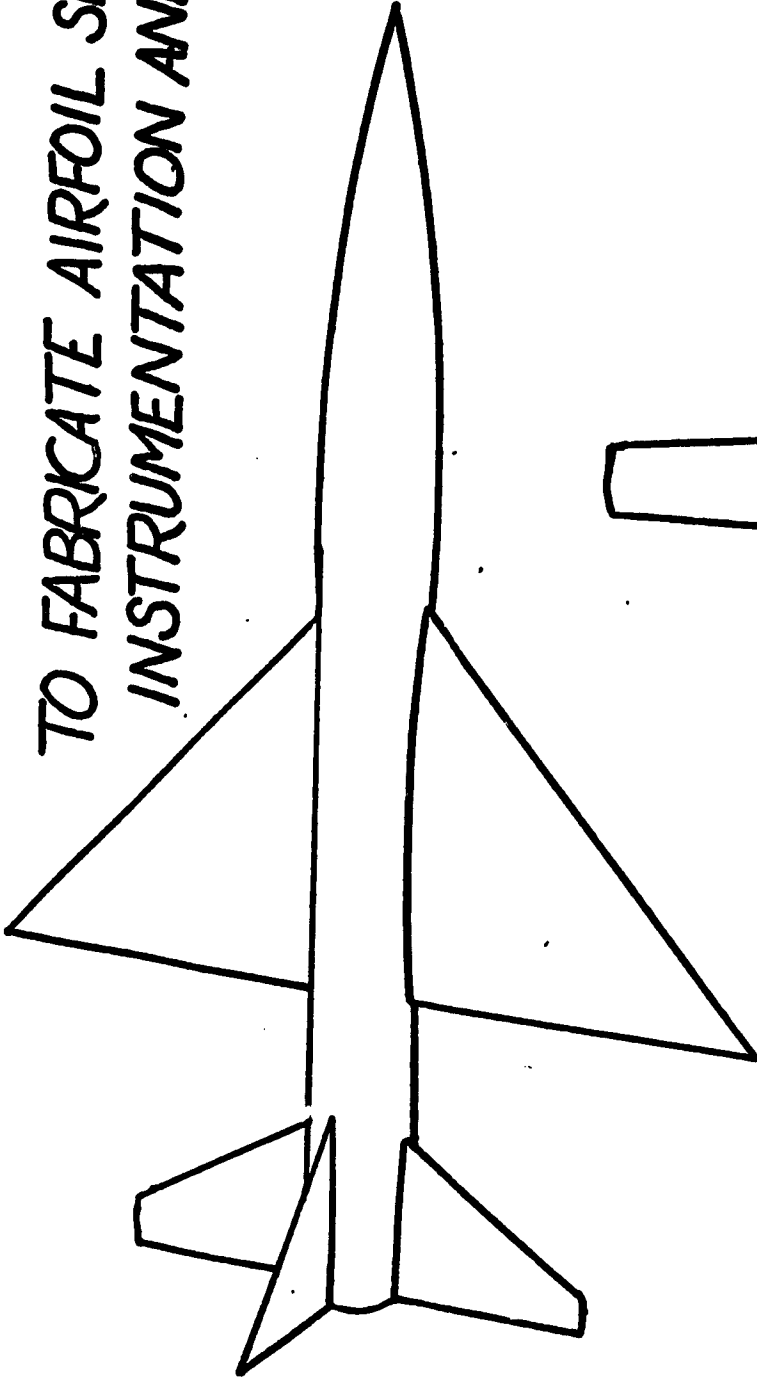
**WALTER MANN - NASA-AMES RESEARCH CENTER**

**March 1, 1978**

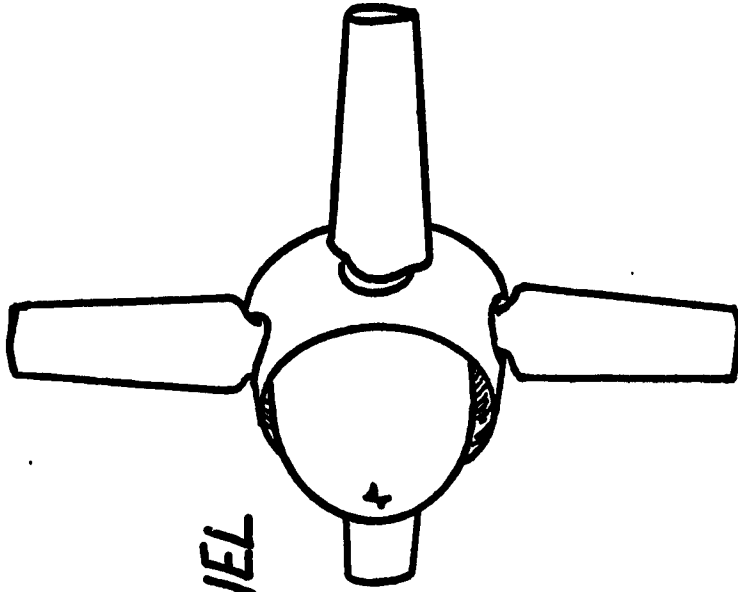
*MANN 1*

In this talk it is desired to focus attention on and place in perspective the machine shop's role in wind tunnel research. Clearly this role includes the fabrication of airfoil shapes that are to be instrumented and tested. In many cases it also includes fabrication of wind tunnel components such as rotor blades.

TO FABRICATE AIRFOIL SHAPES FOR  
INSTRUMENTATION AND TESTING



TO FABRICATE WIND TUNNEL  
COMPONENTS SUCH AS  
ROTOR BLADES



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MACHINE SHOP'S ROLE IN WIND TUNNEL TESTING MAN 2

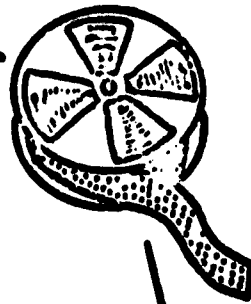
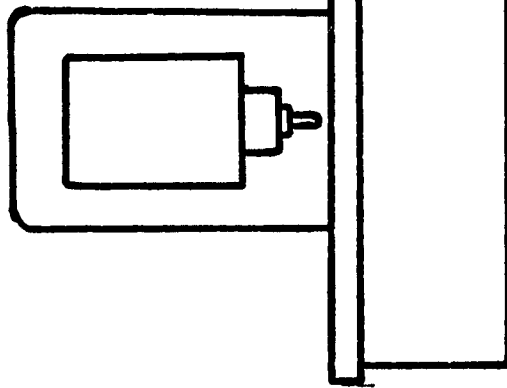
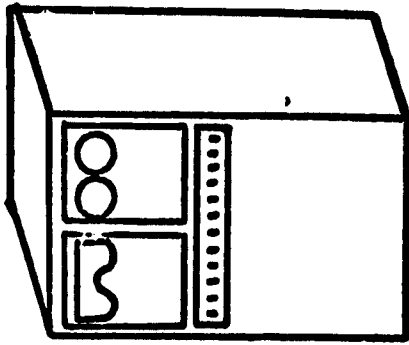
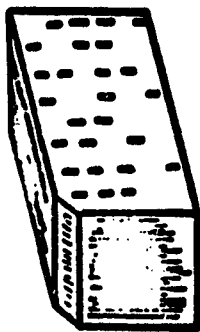
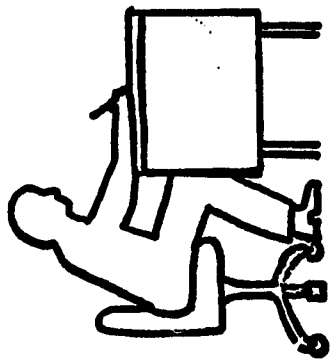
To fabricate the airfoil shapes the machine shop will usually employ numerically controlled (N/C) machine tools. The data that controls the operation of these machine tools will usually be generated on computers by N/C programs of which APT is the best known but not the only example. It is at this level that I wish to focus attention - on the requirements and performances of the N/C programs that produce the cutter path data for control of the fabrication process.

INDUSTRY INVOLVED

PART PROGRAMMER

N.C PROGRAMS-APT

COMPUTER



MACHINE TAPE

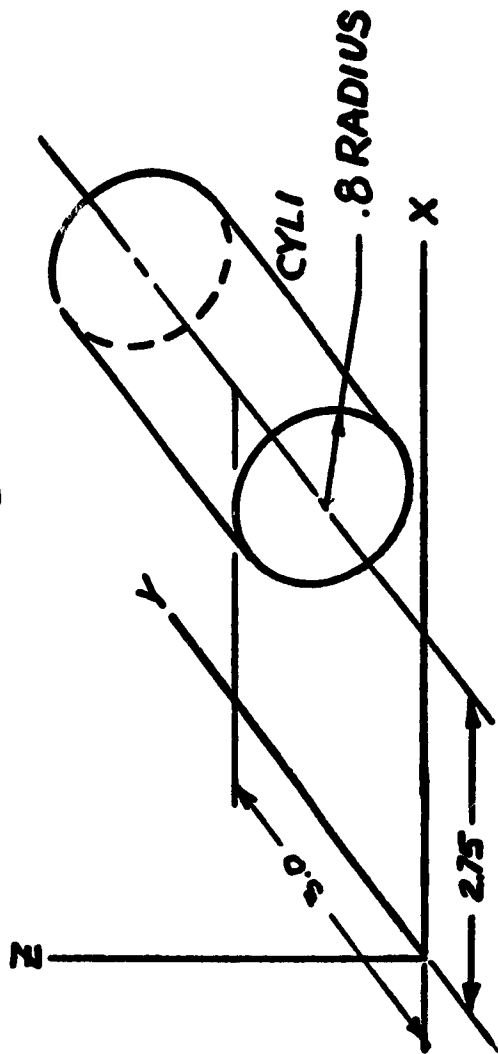
MACHINE TOOL

An input requirement of the N/C program is that shape geometry be defined according to established format. If the geometry definition requirement is met, the shop part programmer may then write instructions for an N/C program to calculate a cutter path and provide associated machining data. In theory this is all there is to it.



IVL FKUGKAMD KEQUIKE

GEOMETRY DEFINITION

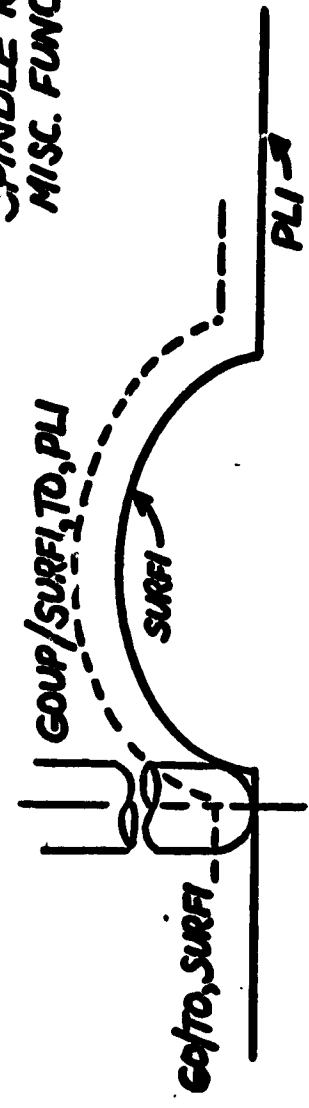


CYLI=CYL NDR/CANON,2.75,3,0,0,1,0,.8

PATH CALCULATION AND MACHINING TECHNOLOGY

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CUTTER DESCRIPTION  
FEEDRATE  
PINDLE RPM  
MISC. FUNCTIONS



MAP 6

In practice, however, there are two realities with which the shop must contend.

The first is that the shape data which comes from the engineer may not be in a form acceptable to the N/C program and must therefore be massaged or reformulated. If the given data need only be translated, rotated or scaled, it presents no great problem. However, if the data is to be generated, say for a fillet between two defined surfaces, or if it is to be extracted by digitization from an accurate scale drawing or actual model, it may well present difficulty.

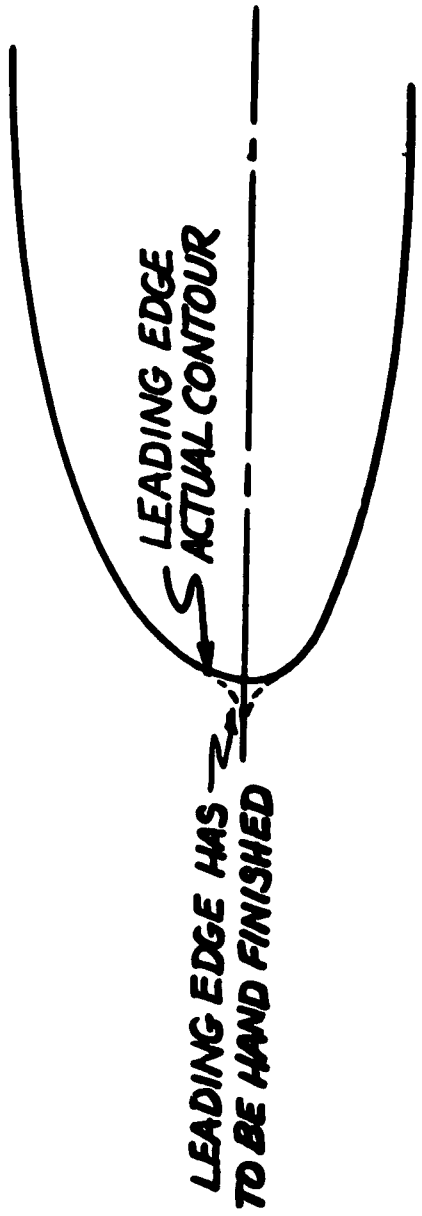
The second is that the cutter path algorithms of the N/C programs, even at this late stage in their development, are not yet 100 percent reliable. Indeed some are more reliable than others and it is the task of the part programmer, where he has a choice, to reformulate the data in the form appropriate for the most reliable algorithm. One comment on this last matter is that a joint international effort is now underway to resolve this last problem and hopefully in two or three years it will not be a consideration in part fabrication.

TWO REALITIES MACHINE SHOP MUST CONTEND

1) ENGINEER'S GEOMETRY DEFINITION MAY NOT BE COMPLETE

- EG. • UNDEFINED FILLER
- UNSPECIFIED BETWEEN SECTIONS

2) CUTTER PATH ALGORITHMS NOT 100% RELIABLE



Now let us return to the first stated reality - the need to reformulate input geometry to acceptable form.

Present N/C programs taken in their totality allow geometric input of three basic types:

1. Pure analytical - planes, conics, quadrics, general parametrics, etc.
2. Pure discrete - points and vectors for tabulated cylinders and meshes of points and vectors for sculptured surfaces.
3. Composite of both analytical and discrete.

# N/C PROGRAMS ALLOW THREE BASIC TYPES OF GEOMETRY DEFINITION

- 1) PURE ANALYTICAL - PLANES, CONES, QUADRICS, GENERAL PARAMETRICS
- 2) PURE DISCRETE - POINTS AND VECTORS FOR TABCYLS AND MESHES OF POINTS AND VECTORS FOR SCULPTURED SURFACES
- 3) COMPOSITE ANALYTICAL AND DISCRETE

If the engineer describes a shape by pure analytic means (please no differential equations) then he may expect an adequate representation of the shape in the fabricated part. However, if the engineer describes his shape with discrete data (less than a semi-dense set) then he must be aware that this data must be fitted to equations by the part programmer before it is input to the N/C program or that its fitting is a function of the N/C program.

**DISCRETE DATA MUST BE FITTED  
BY EQUATIONS:**

- 1) SELECTED BY PART PROGRAMMER**
- OR**
- 2) BUILT INTO N/C SYSTEM**

If the data adequately characterizes the shape in terms of the fitting procedure, no problem arises. If it does not, the question is always whether the data is inadequate or the fitting procedure is at fault.



IF DATA AND FITTING PROCEDURE DO NOT  
ADEQUATELY CHARACTERIZE SHAPE

1) IS DATA INADEQUATE ?

2) IS FITTING PROCEDURE AT FAULT ?

Thus whenever discrete data is presented to the machine shop the engineer is not out of the woods until he can accept the final fabricated shape or some intermediate verification data.

**WITH DISCRETE DATA DEFINITION  
THE ENGINEER MUST BE INVOLVED UNTIL**

**1) DATA IS VERIFIED BY PLOTS**

**OR**

**2) FINAL FABRICATED SHAPE IS ACCEPTED**

**ENDING**

What then is the best shape definition for the machine shop? Analytic data. What is the next best? Discrete or composite data for which N/C program fitting procedures are considered acceptable. What is least desirable? Just points.

## **BEST GEOMETRY DEFINITIONS**

- **EQUATIONS**

## **NEXT BEST**

- **DISCRETE DATA**

**E.G. POINTS, SLOPES, TANGENTS, NORMALS,  
CURVATURES, RULING DIRECTIONS, ETC.**

**IN FORMAT ACCEPTABLE TO N/C PROGRAMS**

## **WORST**

- **POINTS**

GEOMETRY AND GRAPHICS IN IPAD

CLY MOUNIER

BOEING COMMERCIAL AIRPLANE COMPANY  
SEATTLE, WA.

AND

G. L. GILES

NASA-LANGLEY RESEARCH CENTER  
HAMPTON, VA.

WORKSHOP ON AIRCRAFT SURFACE REPRESENTATION  
FOR AERODYNAMIC COMPUTATION

NASA - AMES RESEARCH CENTER  
MOFFETT FIELD, CA.

MARCH 1-2, 1978

PRESENTED BY  
RALPH E. MILLER, JR.

## PRESENTATION SCOPE

- o IPAD SYSTEM ARCHITECTURE
- o GRAPHICS ARCHITECTURE WITHIN IPAD SYSTEM
- o GEOMETRY STANDARDS & IMPACT ON IPAD
- o GRAPHICS STANDARDS & IMPACT ON IPAD
- o STANDARDS & RELATIONSHIP TO EXISTING CAD SYSTEMS

MILLER

R E M	3-1-78
PAGE 1	OF 17

## IPAD - GENERAL SYSTEM ARCHITECTURE

IPAD as a system has been designed to this point within a total corporate complex and its use of computers. Part A of this viewfoil shows the topmost consideration in this general system architecture and envisions that a corporate complex is comprised of several CAD/CAM complexes which communicate with each other through a corporate network.

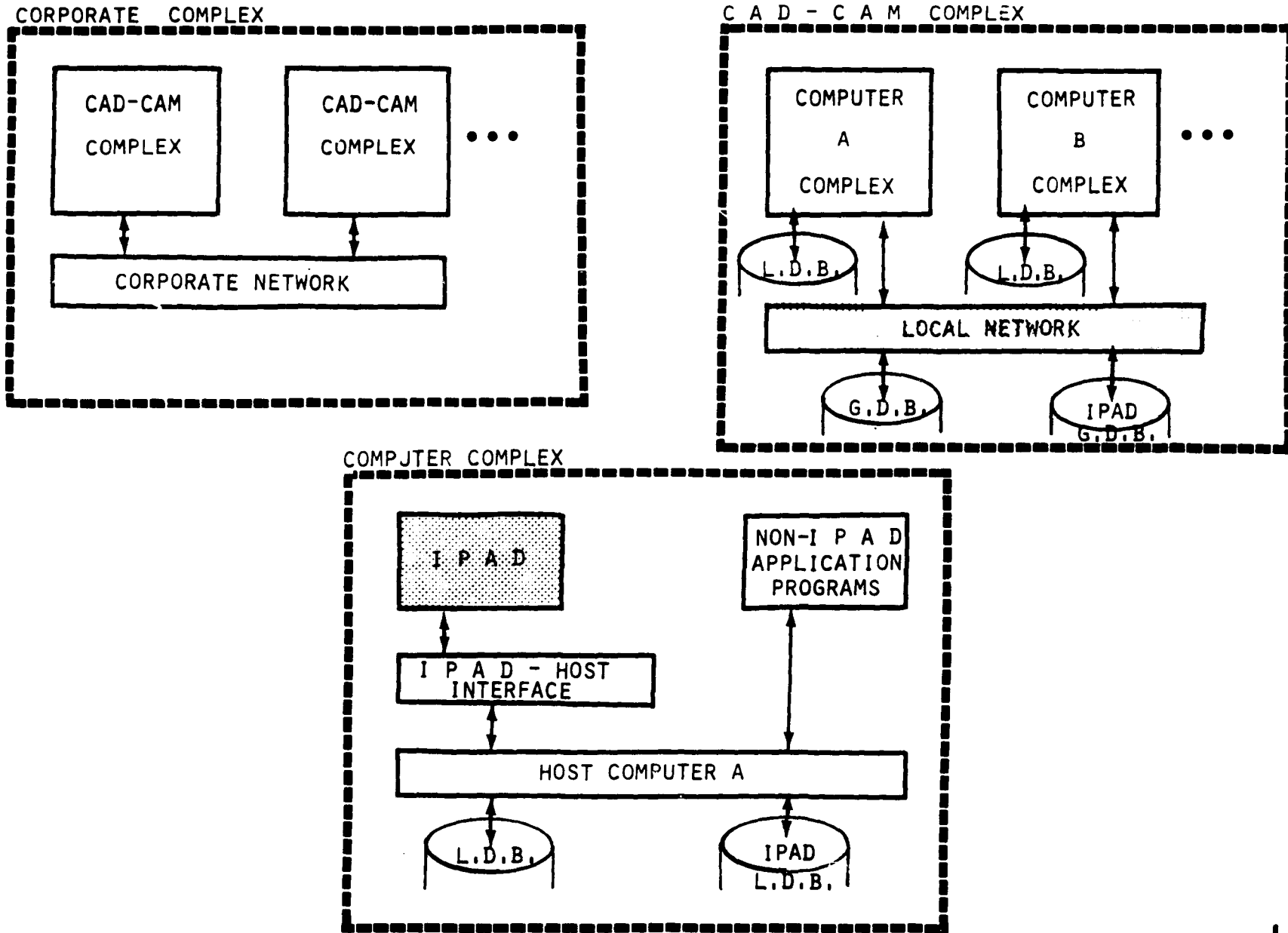
The CAD/CAM complex in turn is composed of several computer complexes, each of which have their local data base and they in turn communicate with each other through a local network which has attached to the local network, a global data base and an IPAD global data base.

In general, these two networks have markedly different communications characteristics. The corporate network is characterized by the utilization of normal communications or microwave media and is characterized by speed in the order of kilo baud. On the other hand, the local network utilizes specialized communications technology and a series of microprocessors. These microprocessors provide the means for attaching heterogeneous computers to the local network. The local network operates in distances in the order of thousands of feet and at speeds in the order of megabaud.

Within any one of these computer complexes, we find a host computer, its local data base and an IPAD local data base. An interface between the host and the IPAD system, the IPAD system and a body of non-IPAD program application programs as well.



I P A D - GENERAL SYSTEM ARCHITECTURE

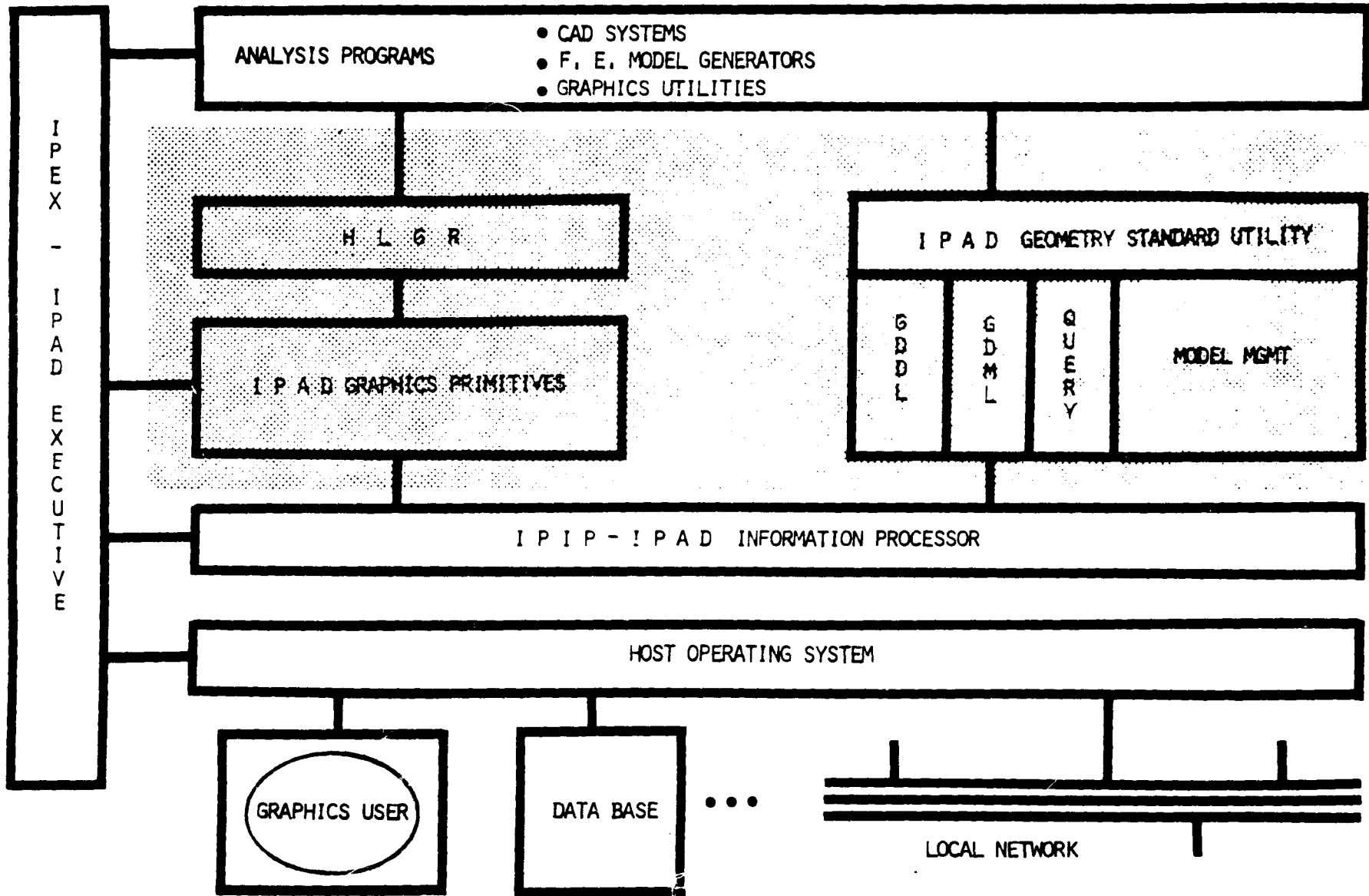


## INTEGRATION OF GEOMETRY-GRAPHICS INTO IPAD SYSTEM

This slide repeats some of the elements of a computer complex and some of the elements of the IPAD system architecture. In addition, as shown in the highlighted portion of the slide, the particular components that are associated with the Geometry-graphics system are indicated. Shown here are: 1) IPAD Geometry Standard Utility, High-Level Graphics (HLGR) which is optional. HLGR provides high-level FORTRAN-callable subroutines that is not purely graphics (e.g., data modeling, plotting formats). They can be considered graphics-related macros which are used to generate frequently used displays; and 2) the IPAD graphics primitives.

The IPAD graphics primitives and the IPAD geometry standard utility will be discussed in detail in the following slides. It should be noted from this slide that the graphics user interfaces with the host operating system (using graphics interface software) who in turn interfaces with the IPAD executive. Through the IPAD executive, the graphics user has access to the analysis programs and the various components of the IPAD system as shown. The graphics user also has access to the data base through the IPAD information processor, and access to the local network and all the resources that cascade outward from the local network as shown on the earlier architecture slides.

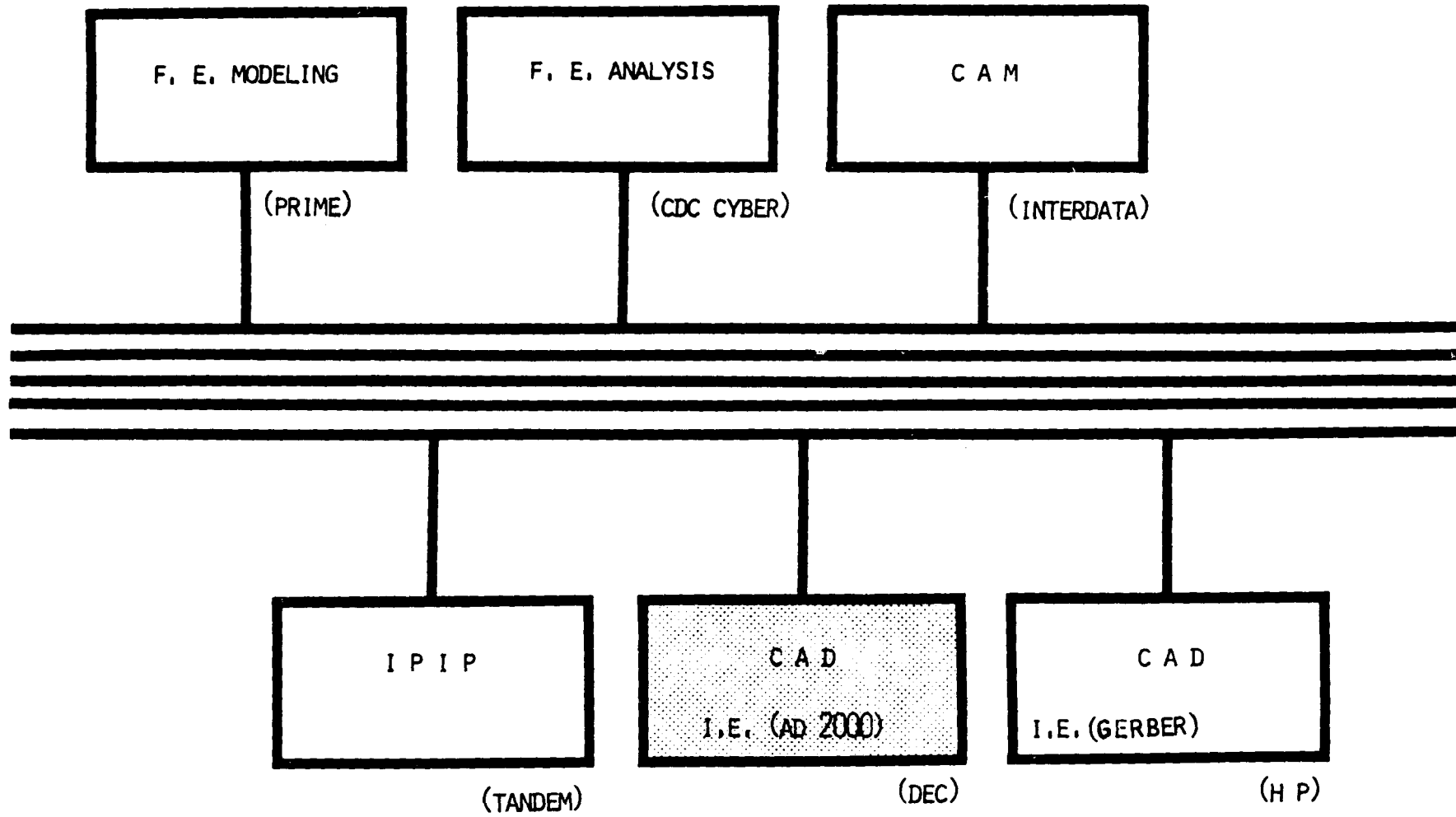
INTEGRATION OF GEOMETRY - GRAPHICS INTO I P A D SYSTEM



## DISTRIBUTED IPAD LOCAL NETWORK EXAMPLE

As mentioned, the graphics user has access through the host operating system to the local network. The IPAD architecture anticipates as typical implementations of this distributed architecture, a variety of processors (computers) which might be specialized to particular tasks or processing requirement (i.e., graphics nodes). Such an example of processing requirements is shown on this slide where, associated with the prime might be finite element modeling, associated with a larger processor like a CDC CYBER finite element analysis and so forth, as illustrated. It is the intent, presently, of the IPAD development, to allocate a CAD system such as AD2000 to a DEC PDP/11-70 processor and to associate this processor with other processors in the network as shown here.

DISTRIBUTED I P A D NETWORK EXAMPLE



## IPAD GEOMETRY STANDARDS

This slide discusses various standards items and their impact on the IPAD system design. Standards would be concerned with primitives covering point, curve and so forth as well as primitives for text and dimensioning, etc. Such primitives thus cover the aspects of geometry as well as drafting. Secondly, relationships between the primitives are of concern covering items such as union replication. Thirdly, geometry model management is also a concern. Model management cover aspects such as save, restore, and copy for dealing with models which have been constructed through the use of primitives and primitive relationships. Such models represent the needs of analysis, parts for manufacturing, kinematic studies, and so forth.

These standards impact various aspects of the IPAD system design. As an example, it is anticipated in the language area of the IPAD system that a geometry data definition language and a geometry data management language will be required to be implemented, and in the case of the geometry definition, all of the primitives are of direct impact upon this language. Similarly, the primitive relationships have a direct impact on the manipulation language.

The data management aspects of the IPAD system are impacted very heavily by the requirements of model management. Thus IPIP, the data base management system utility in IPAD, will be directly influenced by the data structures that are implied in the model management aspects of the standard as well as the particular data structures associated with the primitives and the primitive relationships. This portion of the IPAD data manager will have to be tailored for high performance to meet the response time requirements of a highly interactive user engaged in geometry modeling.

The data communication implications of the standards will have an effect upon both the local data base and global data base aspects of the architecture as shown on the earlier configuration charts. The highly interactive dialog work is expected to be handled, on a data communication basis, through the local network and to be handled between not only the local data base to the local data base, but also be handled internally within any given processor to the local data base directly. Large data volumes and traffic over longer distances which might take place between the various CAD complexes as shown on the earlier architectural slides, would be handled at lower speeds on a corporate network.

IPAD GEOMETRY STANDARDS

STANDARD ITEM	IPAD SYSTEM DESIGN IMPACT
<u>PRIMITIVES</u>	<u>LANGUAGES</u>
POINT CURVE SURFACE SOLID TEXT DIMENSIONS : : :	GDDL - GEOMETRY DATA DEFINITION LANG. GDML - GEOMETRY DATA MANIPULATION LANG. QUERY - PRIMITIVE OR MODEL LEVEL MODEL MGT.
<u>PRIMITIVE RELATIONSHIPS</u>	<u>DATA MANAGEMENT</u>
UNION REPLICATION DELETE : : :	IPIP (DBMS) UTILITY - DATA STRUCTURES SUPPORTED - TAILORED FOR HIGH PERFORMANCE
<u>MODEL</u>	<u>DATA COMMUNICATION</u>
MODEL MANAGEMENT SAVE RESTORE COPY : : :	- DATA VOLUMES AND TRAFFIC ON LOCAL NETWORK - RESPONSE FOR HIGHLY INTERACTIVE DIALOGUE

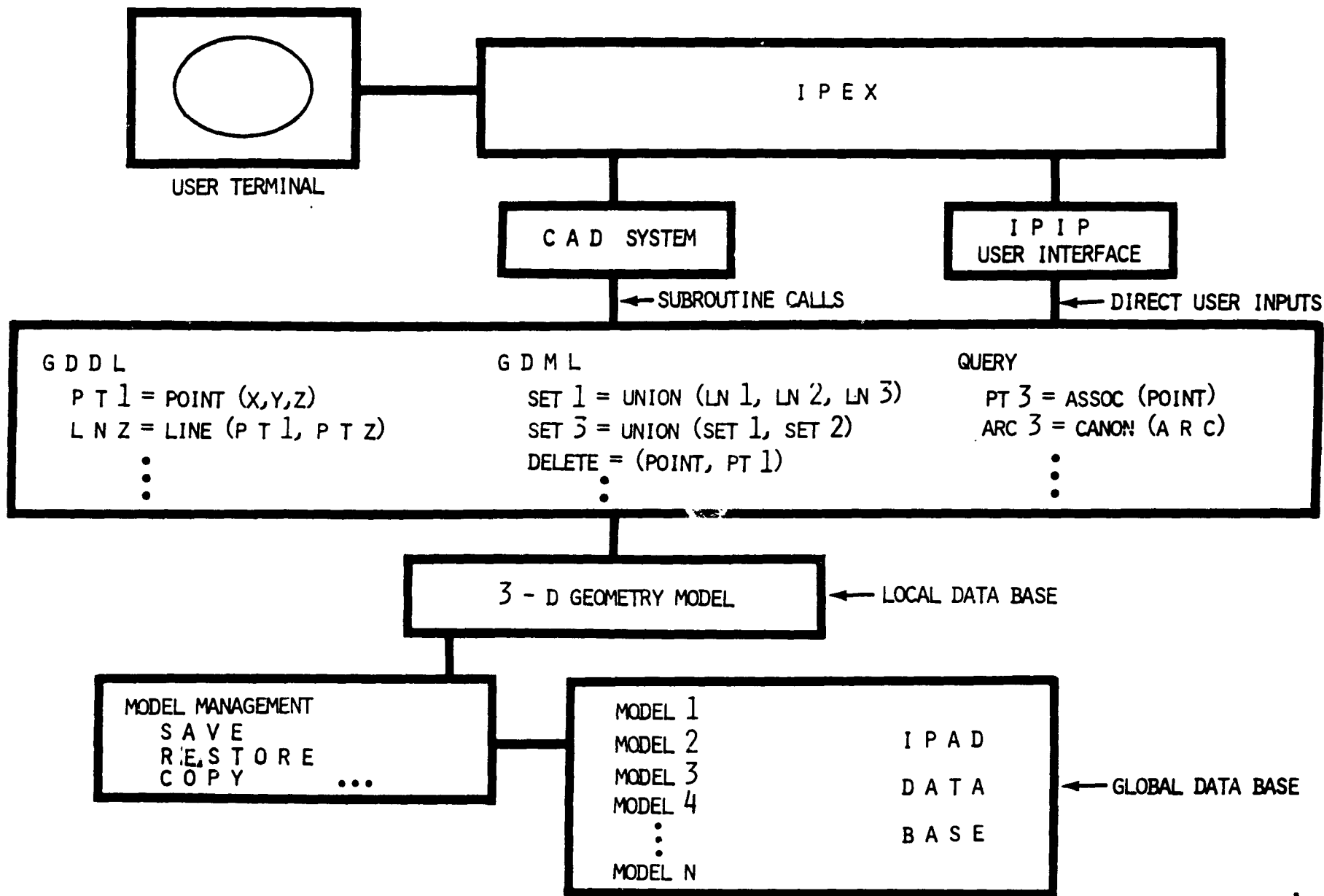
## GEOMETRY MODELING PROCESS

The various elements of the IPAD system and the geometry standard utilities are shown in relation to the geometry modeling process.

A user, through his terminal and the host system, is attached to the IPAD executive IPEX. Through IPEX the user has 1) access to IPIP for direct access to GDDL, GDML, Query and Model Management activities in the Local IPAD D.B. or the Global IPAD D. B., and 2) access to the IPAD CAD system and the IPAD geometry standard utility for constructing, manipulating, editing and managing 3D geometry models. During the modeling process, the model will be in the Local IPAD D.B. However, the model management utilities of IPIP provide for functions between the Local and Global Data Bases. Finally, the various geometry models of interest to a community of users are stored in the Global IPAD D.B.



GEOMETRY MODELING PROCESS

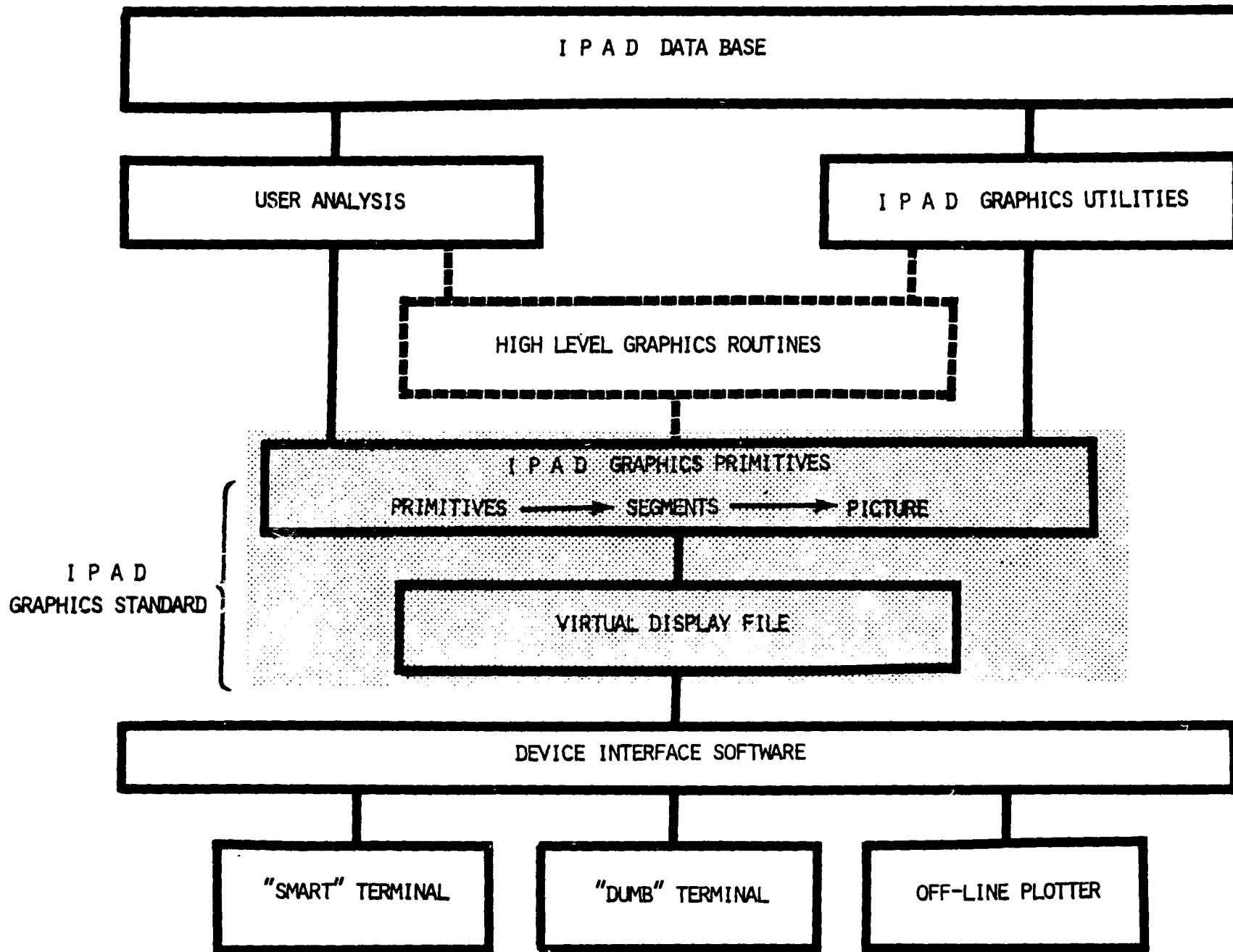


## IPAD GRAPHIC STANDARD

This chart illustrates the various elements that are utilized when displaying pictures of models which have been created, and illustrates in addition, the location of the IPAD graphic standard elements. The user would utilize, from the IPAD data base, various analyses, graphics utilities, and high-level graphics routines to construct, through the use of the graphics primitives, a set of pictures, finally building up a virtual display file. This display file could be saved for other postprocessing needs. The display file is passed to the device interface software. The display file could be passed directly to the smart terminal. In the case of dumb terminals, the device interface software would map the display file into the routines associated with displaying the picture. Similar processes would take place to off-line plotting devices.

The core primitives are the simplest graphics tools. Primitives include: Input, output, segments, attributes, view transformations, and control. They embody the concept of portability and graphics standardization. The graphics primitives are designed to allow easy creation and component modification of graphic displays. Primitives are not designed to modify the user's data structures directly when CRT changes are made. The responsibility for modifying data structure resides with the application program responsible for the data structure (e.g., CAD). However, "hooks" are provided by the primitives to allow a program to propagate changes made on the CRT in the data structure produced by the application program.

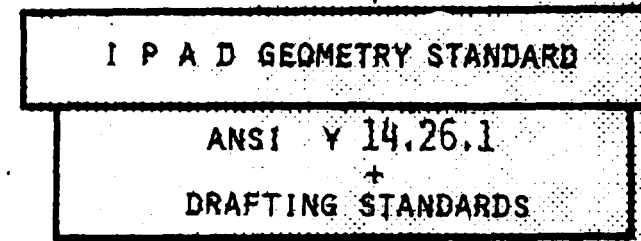
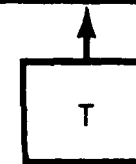
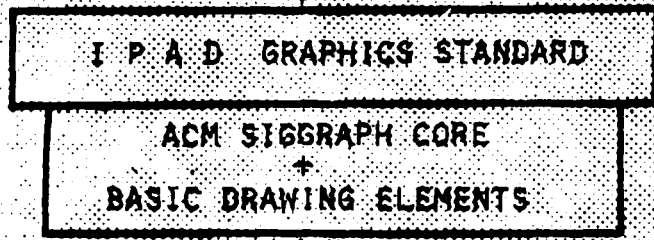
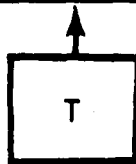
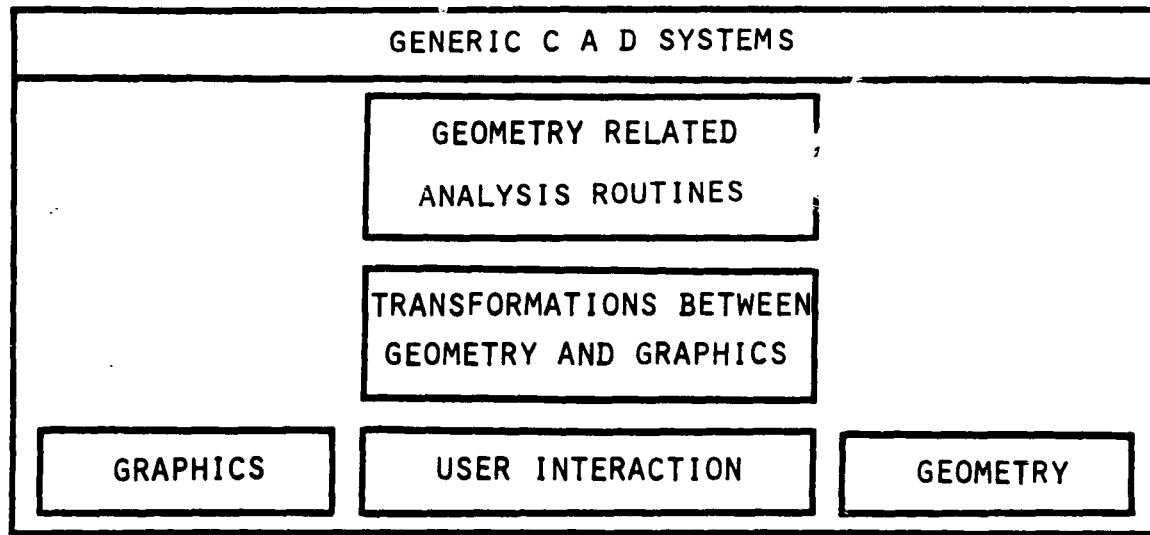
I P A D GRAPHICS STANDARD



## GEOMETRY AND GRAPHICS STANDARDS IN CAD SYSTEMS

Generically, a CAD system has such major elements as geometry-related analysis routines, transformation capability between the geometry and the graphics routines, provision for user interaction data management, and contains procedures for handling both geometry and graphics. Typical of such systems are CADD, AD2000, and CADAM. Each CAD system has its own unique method of handling geometry. Therefore, communication between CAD/CAM systems and related D.B.'s become a major problem. The IPAD geometry standard will provide a common basis to which each can be interfaced and thus reduces the number of translators required. Such systems are characteristically used to accept data from a user and to produce either models, geometric models of particular entities of interest and also to display pictures of those models. Modeling process uses geometry standards. In this picture we show that the IPAD geometry standard is intended to encompass the work to date of the ANSI Y14.26.1 committee, plus additional items such as drafting standards, which were mentioned earlier. Similarly, there is an IPAD graphic standard which is based primarily on the work of an ACM SIGGRAPH and augmented by basic drawing elements. It is the intent of the IPAD program to develop an IPAD geometry standard based upon the ANSI work and an IPAD graphics standard, based upon ACM SIGGRAPH work.

GEOMETRY AND GRAPHIC STANDARDS IN C A D SYSTEMS



## FUTURE USE OF IPAD GEOMETRY AND GRAPHICS STANDARDS

IPAD graphics standard has the potential of being adopted by such standards bodies as the ACM SIGGRAPH and the ANSI committees. In the future we would expect that systems would be designed and built with this standard as a basis and that for the interim, the existence of the IPAD standards would expedite the integration of such systems into an IPAD environment.

From the point of existing systems, two different strategies are available to us. With respect to geometry, we have the option of translating, as shown on the previous slide, between the IPAD geometry standard and the geometry standard of the particular commercial CAD system in use, thus creating an interface. Or, directly replacing those particular geometry portions of the commercial CAD system and associated data management. In the case of graphics, we anticipate that it will be necessary to replace the graphics routines directly with the IPAD graphics primitives. The geometry and graphics associated routines in AD2000 are being investigated at our development site, to determine the relative effort to interface or replace.

# FUTURE USE OF IPAD GEOMETRY AND GRAPHICS STANDARDS

## FUTURE SYSTEMS

- o DESIGN AND BUILD WITH STANDARDS AS A BASIS.
- o EXPEDITE INTEGRATION INTO AN IPAD ENVIRONMENT.

## EXISTING SYSTEMS

### GEOMETRY ASPECTS

- (1) INTERFACE TO  
OR
- (2) REPLACE WITH
  - o IPAD GEOMETRY DATA
  - o MANAGEMENT UTILITY AND ASSOCIATED DATA BASE

### GRAPHICS ASPECTS

- o REPLACE WITH IPAD GRAPHICS PRIMITIVES

## QUESTIONS THAT MIGHT BE DISCUSSED IN PANELS

### PANEL 1: REQUIREMENTS

1. How accurate must be the surface location, slope and curvatures to give acceptable aerodynamic calculation results?
2. Spline methods (linear or higher order interpolation) introduce some degree of artificial waviness. At what point does this introduce significant errors in aerodynamic calculation (or measurement)?
3. Real aerodynamic shapes usually have discontinuities in the surface such as sharp edges, corners, gaps and inlet/exhaust holes. How precisely do these need to be specified?
4. Aerodynamic calculations often involve several iterations or cases that call for minor adjustments in surface shape, flow conditions or paneling density/distribution. What is a "reasonable turnaround time" between aerodynamic analyses? This question could be stated as: What "turnaround time" would cause aerodynamic analysts or researchers to abandon or hardly use an available computerized geometry method? How much input and re-input would be inhibiting?
5. The original aerodynamic shape specification can come from a number of sources; drawings at several levels of detail, lists of coordinates, systems of equations or coefficients, actual wind tunnel models or aircraft. Should a surface representation system accommodate all these sources? What checking methods are needed?
6. Is it time to discuss standardization?



STALEY /

University of Connecticut  
Department of Mechanical Engineering  
Computer-Aided Design Laboratory

Mathematical Techniques for Surface Description  
NASA / Ames Workshop  
Aircraft Surface Representation for Aerodynamic Computation  
March 1,2 1978

Scott M. Staley  
Dr. Phillip P. White  
Dr. Richard E. Garrett  
University of Connecticut  
Storrs, Connecticut

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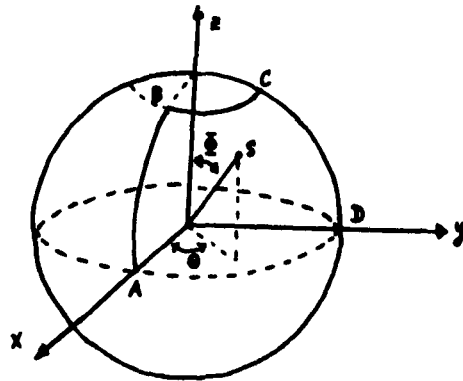
STALEY 2.

### Analytical Surface Description

Parametric representation of unit spherical surface

$$\begin{aligned} X &= \cos \theta \sin \Phi \\ Y &= \sin \theta \sin \Phi \\ Z &= \cos \Phi \end{aligned}$$

Two parameters  $\theta, \Phi$  required to generate surface in 3-D



Vector parametric equation

$$\bar{S} = (\sin \Phi \cos \theta) \bar{e}_1 + (\sin \Phi \sin \theta) \bar{e}_2 + (\cos \Phi) \bar{e}_3$$

Parametric tangents

$$\frac{\partial \bar{S}}{\partial \theta}, \quad \frac{\partial \bar{S}}{\partial \Phi}$$

Twist vectors, (Cross derivatives)

$$\frac{\partial^2 \bar{S}}{\partial \theta \partial \theta}, \quad \frac{\partial^2 \bar{S}}{\partial \theta \partial \Phi}$$

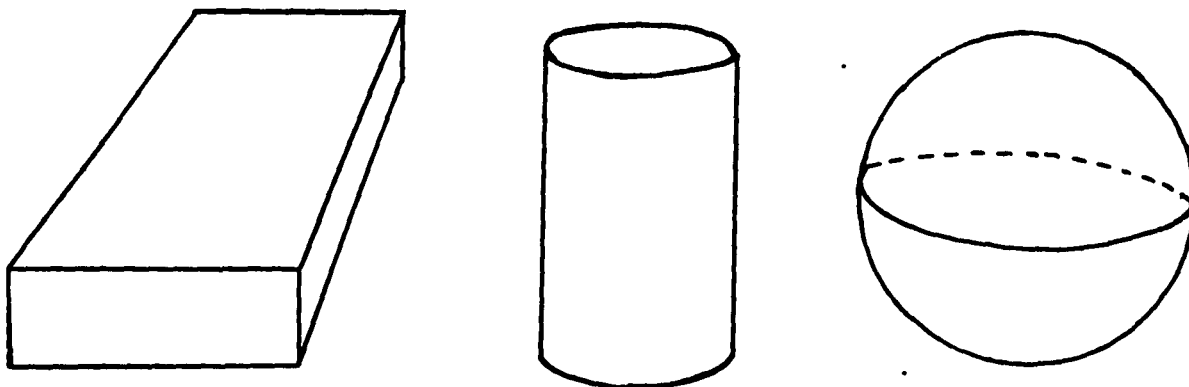
Surface normals (Cross product of two tangent vectors)

$$\bar{N} = \frac{\partial \bar{S}}{\partial \theta} \times \frac{\partial \bar{S}}{\partial \Phi}$$

STALEY 3.

Analytical Surface Description

Some PADL primitives



Sample composite object

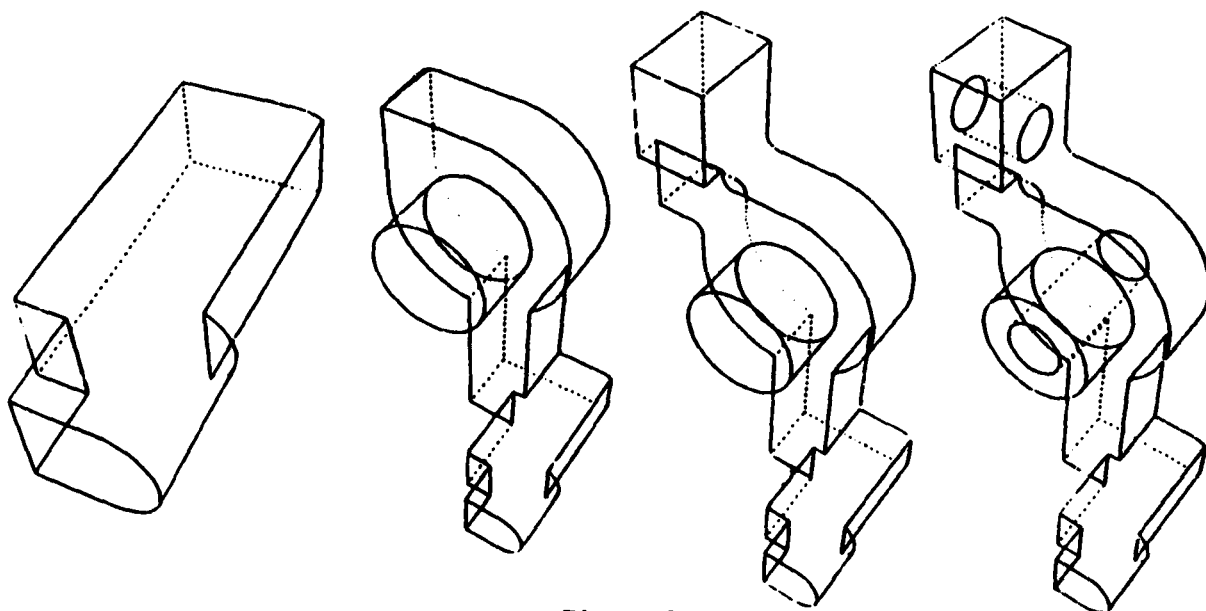


Figure 1

## Analytical Surface Description

### ADVANTAGES

Exact mathematical description

No storing large quantities of data points

Secondary surface properties easily derived

i.e. surface areas, volumes, curvatures, etc.

No interpolation schemes necessary

### DISADVANTAGES

Limited class of surfaces addressable

Mathematics of composite objects relatively complex

Problems not yet solved include boundary conditions,

smoothness, oblique angle intersections, fillets

### DESIGN SYSTEMS / UTILITY

PADL system (Part and Assembly Description Language)

Discrete part description

## Bilinear Surface Description

## MATHEMATICS

$$Q(u,w) = [(1-u) \ u] \begin{bmatrix} P(0,0) & P(0,1) \\ P(1,0) & P(1,1) \end{bmatrix} \begin{bmatrix} 1-w \\ w \end{bmatrix}$$

## ADVANTAGES

Simple to construct/implement

Points on surface linear combination of patch endpoints

User not involved with parametric tangents, etc.

## DISADVANTAGES

Not a flexible multi-purpose technique

A single patch is not a curved surface

No more than first order continuity anywhere

## Lofted or Ruled Surface Description

## MATHEMATICS

$$Q(u,w) = P(u,0) (1-w) + P(u,1) w$$

## ADVANTAGES

General Scheme

Can accommodate different curve types (polynomial, spline, etc)

## DISADVANTAGES

Contains curves on only two sides of patch

Linear interpolation scheme in one direction

$C^0$  fairness across patch boundaries

## Linear Coons' Surface

## MATHEMATICS

$$Q(u,w) = \begin{bmatrix} (1-u) & u \end{bmatrix} \begin{bmatrix} P(0,w) \\ P(1,w) \end{bmatrix} \begin{bmatrix} P(u,0) & P(u,1) \end{bmatrix} \begin{bmatrix} 1-w \\ w \end{bmatrix} \\ - \begin{bmatrix} (1-u) & u \end{bmatrix} \begin{bmatrix} P(0,0) & P(0,1) \\ P(1,0) & P(1,1) \end{bmatrix} \begin{bmatrix} 1-w \\ w \end{bmatrix}$$

## ADVANTAGES

Allows curve on all four sides of patch

Supports different curve descriptions

Linear blending easy to implement

## DISADVANTAGES

Some curve types could be involved mathematically

Linear blending functions determine internal

surface shape (regardless of curve type)

## Overhauser-Coons' Surface

## MATHEMATICS

$$Q(u,w) = P(u,0)B_0(w) + P(0,w)B_1(u) + P(u,1)B_2(w) + P(1,w)B_3(u) \\ - P(0,0)B_0(u)B_0(w) - P(1,0)B_1(u)B_0(w) \\ - P(0,1)B_0(u)B_1(w) - P(1,1)B_1(u)B_1(w)$$

where:  $B_0(t) = 1 - 3t^2 + 2t^3$

$$B_1(t) = 3t^2 - 2t^3$$

are the 'Blending Functions'

and the  $P(u,w)$  are the Overhauser curves forming the patch boundaries



### Overhauser-Coons' Surface

#### ADVANTAGES

- Improved algorithm for fast computation
- Facilitates the use of 'Shaping Tools'
- Better local control than cubic curve techniques

#### DISADVANTAGES

- Large node displacement may cause spurious wiggles
- Adding a point to curve affects 3 curve segments
- Moving a point affects 4 neighboring curve segments
- Normally 12 adjacent patches are affected by the displacement of a single point in common to 4 patches
- Complex data structure/data handling facilities
- Storage requirements - data points and tangents
- $C^1$  fairness across patch boundaries

#### DESIGN SYSTEM / UTILITY

- Three Dimensional Design System -- J. Brewer (1977-Purdue)
- Total software implementation (no special hardware required)

## Bicubic Surface Description

## MATHEMATICS

$$Q(u,w) = \begin{bmatrix} R_1(u) & R_2(u) & R_3(u) & R_4(u) \end{bmatrix} P \begin{bmatrix} B_1(w) \\ B_2(w) \\ B_3(w) \\ B_4(w) \end{bmatrix}$$

where  $R_i(t)$  are the cubic 'Blending Functions'

$$\begin{bmatrix} B_1(t) & B_2(t) & B_3(t) & B_4(t) \end{bmatrix} = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

and  $P$  is the boundary condition matrix

corner coordinates	w-tangent vectors
u-tangent vectors	twist vectors

## Bicubic Surface Description

## ADVANTAGES

Well proven and widely used method

## DISADVANTAGES

Not readily adaptable to surface 'Shaping Tools'  
Three quantities (position, tangent vectors, twist vectors)  
all must be worked with to manipulate surface shape  
Hard to have intuitive feel for surface shape control  
Calculation difficulty is high (matrix inversion)  
Poor local curve control  
Must split curve to represent knuckles  
 $C^2$  fairness  
Large storage requirements  
Spurious wiggles from parametric cubics

## DESIGN SYSTEM / UTILITY

NASA / Ames system

HULLDEF -- Naval Ships Engineering Center

Planned Design

### Bezier Curve and Surface Description

#### MATHEMATICS

##### Curves

$$R(s) = \sum_{i=0}^n \bar{Q}_i(s) \bar{P}_i$$

where  $\bar{Q}_i(s) = \binom{n}{i} s^i (1-s)^{n-i}$

$\bar{P}_i$  = polygon vertices

##### Cartesian Product (Tensor Product) Surface

$$B_{m,n}(s,t) = \sum_{i=0}^m \sum_{j=0}^n \bar{Q}_i(s) \bar{Q}_j(t) \bar{P}_{i,j}$$

## Bezier Curve and Surface Description

### ADVANTAGES

Low storage requirements -- polygon points  
High order curve and surface fairness  
Intuitive user interface to surface control  
    tangent and twist vector control parameters  
    manipulated by placement of polygon points  
Interactive curve approximation shown effective  
Ab initio surface design capabilities  
Variation diminishing properties

### DISADVANTAGES

Local curve control poor  
Concatenating Bezier curves and surfaces not well developed  
Using high degree polynomials, some smoothness lost  
    computation costs increase proportionately

### DESIGN SYSTEM / UTILITY

UNISURF System -- Regie Renault

### B-Spline Curve and Surface Description

#### MATHEMATICS

##### Curves

$$C(t) = \sum_{k=0}^n P_k N_{k,n}(t)$$

where  $P_k$  = polygon vertices  
 $N_{k,n}$  = basis functions

the N matrix

$$\begin{bmatrix} N_{i,1} & N_{i-1,2} & \dots & N_{i-k+1,k} \\ & N_{i,2} & & N_{i-k+2,k} \\ & & N_{i,3} & \vdots \\ \emptyset & & & N_{i,k} \end{bmatrix}$$

##### Cartesian Product Surface

$$Q(u,w) = \sum_i \sum_j P_{i,j} N_{i,k}(u) M_{j,l}(w)$$

## B-Spline Curve and Surface Description

### ADVANTAGES

Well conditioned for curve order less than 20  
Local basis s.t. at every point only  $k$  basis  $\neq 0$   
Low storage requirements -- polygon points  
B-Spline formulation contains Bezier as a special case  
Good user control handles for manipulating surface  
    No. and placement of polygon vertices  
    Multiple (repeated) polygon vertices  
    Order of curve  $2 \leq k \leq$  no. of vertices  
Ab Initio curve and surface design  
Follows polygonal form more closely than Bezier curve  
Good local curve control  
Variation diminishing property

### DISADVANTAGES

Not well developed as a curve fitting technique  
Calculation difficulty moderate to high

### DESIGN SYSTEM / UTILITY

University of Utah System -- J.H. Clark (1974)

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STACEY 21

STALEY 12

SUMMARY

In conjunction with research being conducted by the Mechanical Engineering Department at the University of Connecticut in the area of three dimensional model generation, a review of the literature has been conducted. The topics of primary interest were (1) Mathematical techniques for three dimensional surface representation and design and (2) State of the art in three dimensional computer model generation. This presentation to the NASA / Ames workshop on Aircraft Surface Representation for Aerodynamic Computation is a summary of the investigation into topic (1) above.

S.M. Staley  
P.R. White  
R.E. Garrett

March 1978

**Presentation Summary:**

**Visual 3D Interaction  
with Parabolic Blending**

**D. C. Anderson  
Purdue University**

**presented at**

**Workshop on Aircraft Surface Representation  
for Aerodynamic Computation**

**NASA - Ames Research Center  
March 1-2, 1978**

*1978  
ANDERSON*



Introduction

Curve and surface algorithms have received ever-increasing attention during recent years. Bezier and Riesenfeld introduced algorithms that allow more intuitive control of shape than the earlier developed Coons formulation. A lesser known parametric curve description, known as parabolic blending, was developed by A. W. Overhauser in 1968 at Ford Motor Company. This formulation offers unique advantages to interactive curve and surface manipulation because it is based solely on coordinates on the curves, and not parametric derivatives.

Formulation of Overhauser Curves from Parabolic Blending.

$$c(t) = (1-t)p(r) + tq(s)$$

Parabolic blending consists of a parametric blend of two parabolas p(r) and q(s).

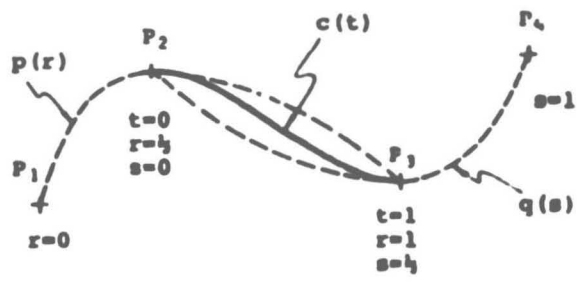


Figure 1 An Overhauser Curve

p(r) and q(s) are plane parabolas constructed from the first three points, and the second three, respectively.

The curve is a blend of these parabolas between the inner two points.

$$p(r) = [r^2 \ r \ 1] B$$

$$q(s) = [r^2 \ r \ 1] C$$

Each parabola can be expressed as a quadratic in its parameter.

$$c(t) = [t^3 \ t^2 \ t \ 1] A$$

These can be combined via a linear relationship between  $r$  and  $t$ , and  $s$  and  $t$ , resulting in a cubic space curve.

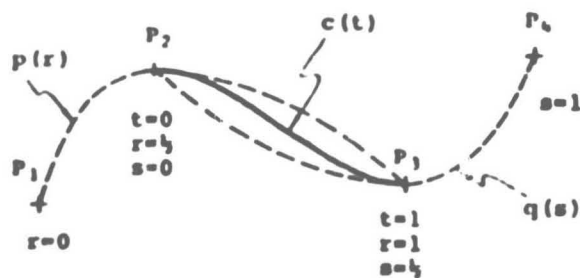
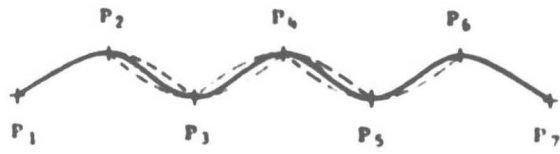


Figure 1 An Overhauser Curve

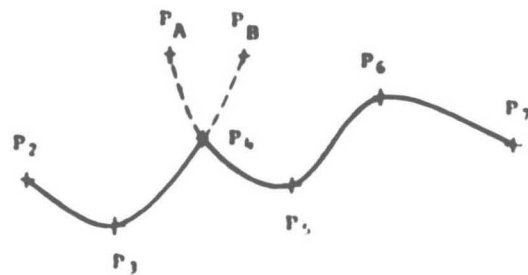
$$c(t) = [t^3 \ t^2 \ t \ 1] \begin{bmatrix} -1/2 & 3/2 & -3/2 & 1/2 \\ 1 & -5/2 & 2 & -1/2 \\ -1/2 & 0 & 1/2 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \end{bmatrix}$$

ANDERSON - 2

By arbitrarily assigning a value of  $r = 1/2$  at  $t = 0$ , a compact, easy to construct formulation is found, depending only on the space coordinates on the curve.



A series of blended curves is constructed easily by sequencing the selection of the four points. First derivative continuity is maintained as a consequence of the  $c(t)$  formulation.



If a discontinuity in the first derivative is desired, off-curve points can be introduced. In this manner, these points allow flexible shape control similar to Bezier's design points.

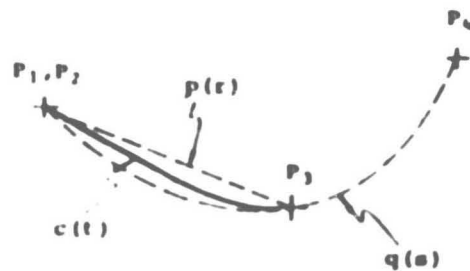
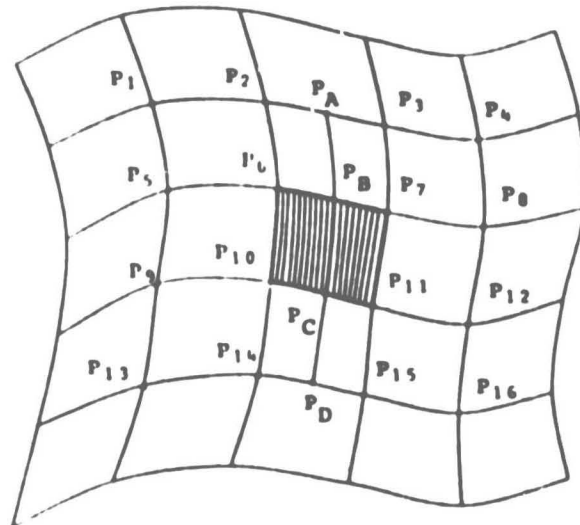


Figure 4 An Overhauser Curve with Two Coincident Points

This formulation also allows two points to be coincident without numerical difficulties.

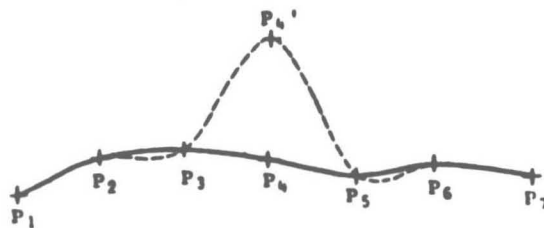


A surface can be constructed from Overhauser curves by several methods. Overhauser suggested that sets of four points on "parallel" curves be used to form a parabolic "blend" across an interior patch. The "traces" could be calculated in the opposite parametric direction, or the two could be averaged if desired. In any case, the surface shape depends upon sixteen adjacent coordinates.

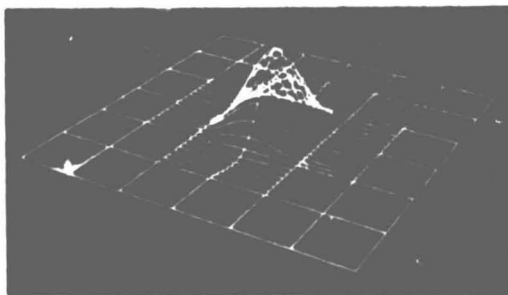
Interaction

Overhauser curves and surfaces were added to an interactive 3D design system being developed in the Computer-Design and Graphics Laboratory in the School of Mechanical Engineering at Purdue University. The system also allowed Coons' bicubic surfaces to be interactively manipulated using an Imlac PDS-1 refresh display connected to a PDP 11/40 minicomputer.

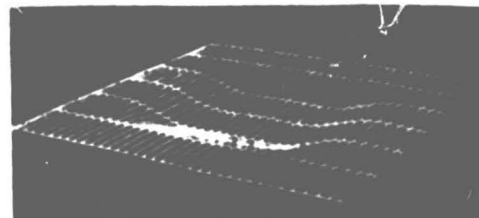
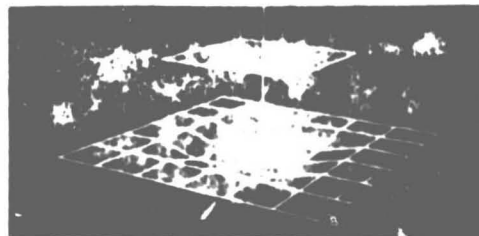
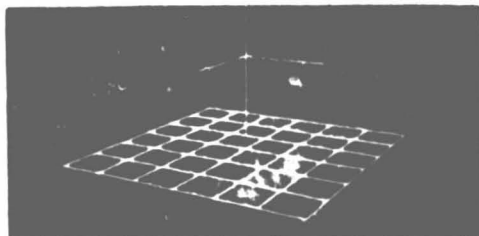
ANDERSON 7



An Overhauser Curve is constructed by placing points in 3 space with a dynamic 3D cursor. The curve is manipulated by "picking-up" a point and dragging it. Affected segments of the curve are intensified by the system. New points can be easily added to the curve in the same manner.



Surfaces are shaped in a similar manner as points are moved.

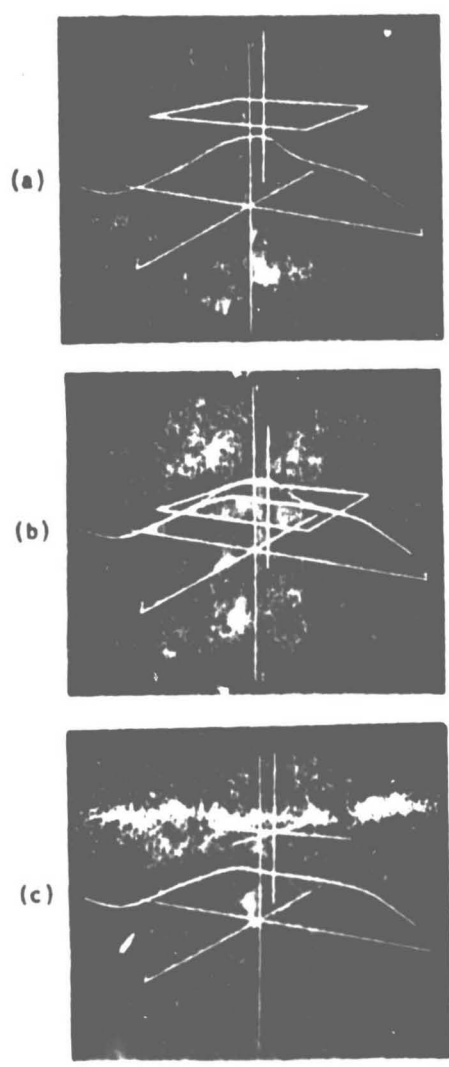


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ANDERSON - 5

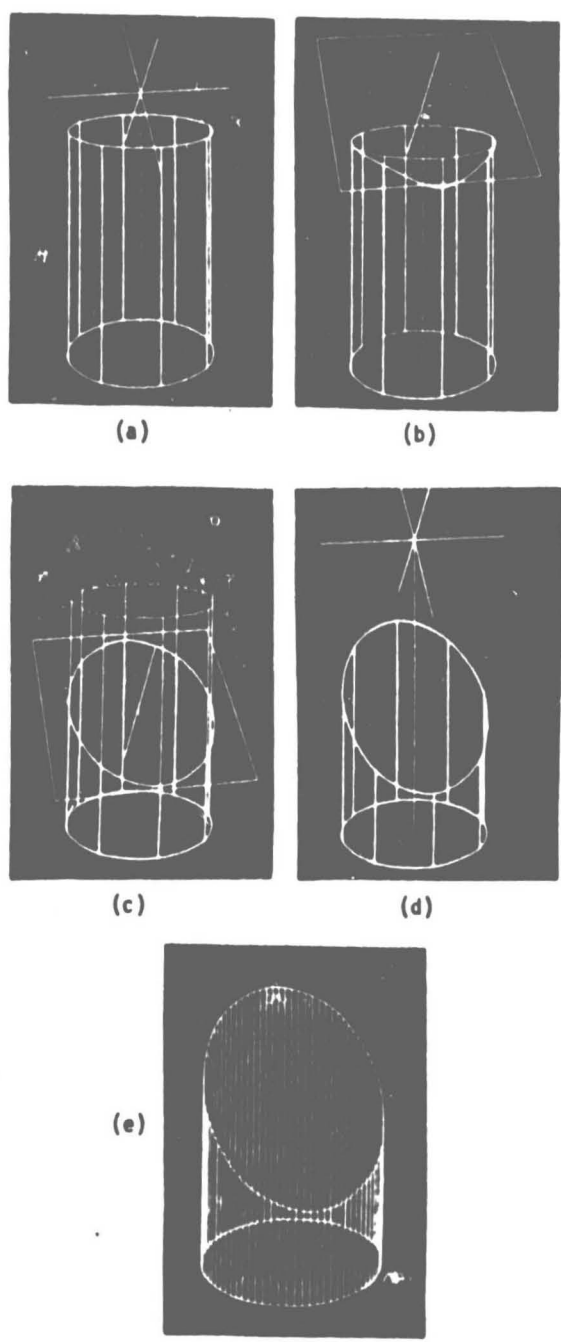
A group of points forming a curve or surface can be manipulated using a shaping tool, such as a plane. The 3D plane is defined by the designer, and points "stick" to it as it moves in space. This illustrates one flexibility afforded by the Overhauser formulation.

The ten minute film shows the 3D design system in action, including the manipulation of Coons' and Overhauser curves and surfaces.



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An Overhauser curve is created using the 3D cursor, and a planar shape tool is used to "flatten" the curve.



A cylinder consisting of eight Overhauser surfaces is generated and truncated with the planar shaping tool.

POINT THINKING FOR GRAPHICAL DISPLAYS

TIM RAU, LANGLEY RESEARCH CENTER

MARCH 1-2, 1978

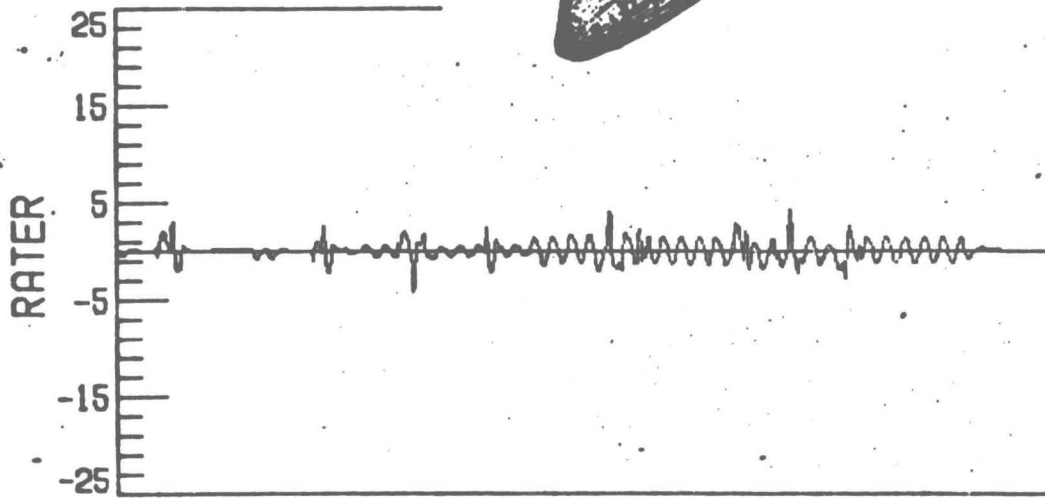
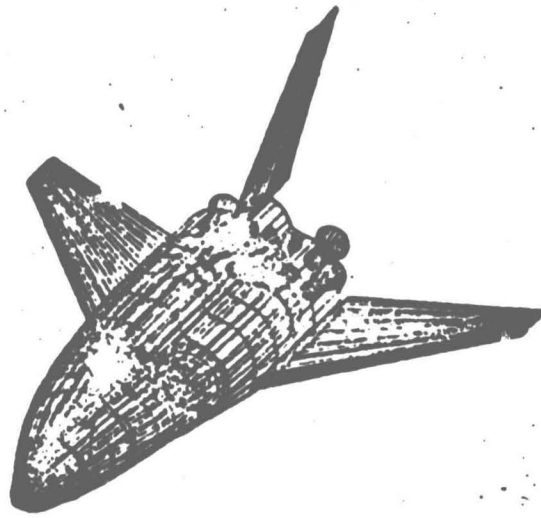
Rau 1



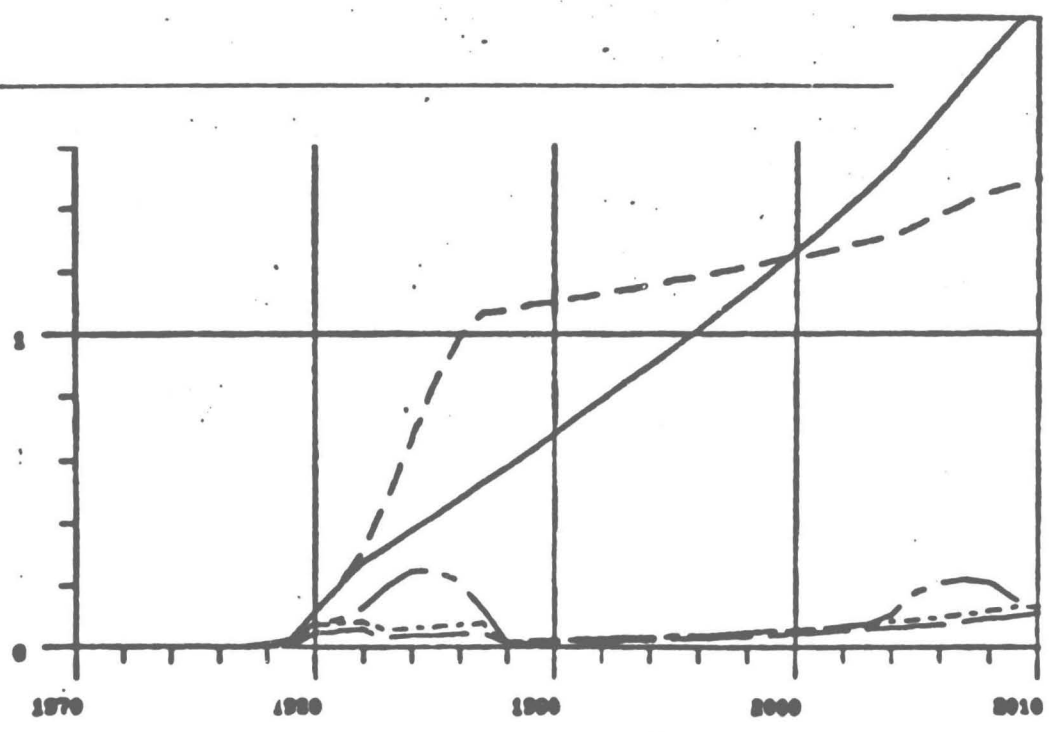
## REPRESENTATIVE GRAPHICAL DISPLAYS

Graphical displays can take many different shapes and forms. The ultimate goal is to obtain as high a quality representation of the actual data as possible as cheaply and quickly as we can. In doing this, we should consider the ultimate potential of the plotting device as well as the data itself.

RAU 2



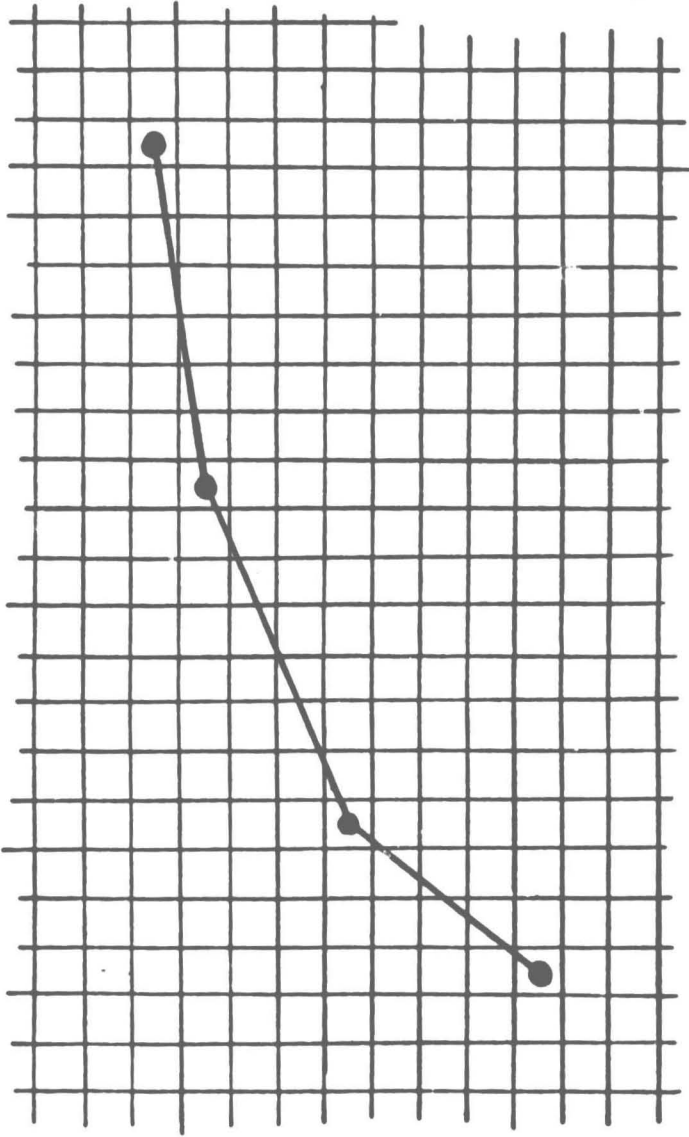
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Reopresentive graphical displays

### RASTER SPACE-LINE PLOTTING CONCEPT

All raster-oriented plotting devices use some sort of a curve approximation method. The raster space can be thought of as an  $n \times m$  grid of points to which the plotter can position itself. The plotter then draws in straight line segments between node points. Some plotters use methods breaking down such segments into subsegments, if necessary.



Plotting device raster space  
Line plotting concept

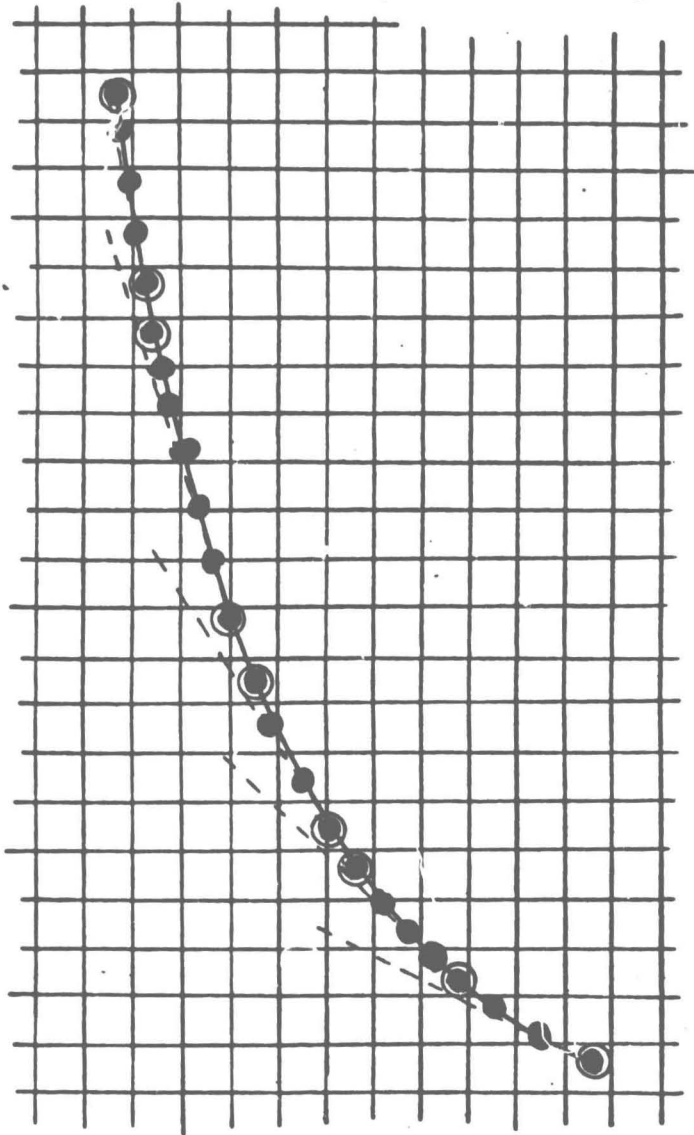
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3

### POINT-THINNING CONCEPT

A curvilinear line may be broken down into line segments at the programming level rather than the plotting device level. This is especially beneficial in working with very dense data representations, since many calls to the actual plotting routines may then be bypassed. In this example, a reasonable curve representation could be specified with just nine calls (circled points) to the plotting routines.



Plotting device raster space

Point-thinning concept

RAU/LARC

6

4

## FORTRAN IMPLEMENTATION OF POINT-THINNING LOGIC

FORTRAN code implementing a point-thinning technique is illustrated by the DO loop as shown. Input x-y data to be plotted is provided in the XLOC and YLOC arrays. The AMULT factor is the number of rasters per unit of plotting length, e.g., 200 rasters per inch for most CALCOMP devices. The IFIX function converts a floating point number to the integer mode. The CALPLT routine is the actual plotting routine. In its call, the third parameter specifies pen up (=3) or pen down (=2).

## FORTRAN IMPLEMENTATION OF POINT-THINNING LOGIC

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```

DIMENSION ALLOC(...), YLOC(...)
LOGICAL FIRST, LAST

C      * * * INITIALIZE THE PROCEDURE .. FORCE THE FIRST POINT
FIRST = .F.
LAST = .F.

C      * * * START THE PLOT LOOP WHEN THE X-Y COORDINATES ARE IN THE
C      * * * ALLOC AND YLOC ARRAYS RESPECTIVELY.
DO 1000 I = 1, LAST
C      * * * SAVE THE LAST POINT LOCATION
XNPI = XN
YNPI = YN

C      * * * GET THE NEW POINT AND SCALE IT
XN = ( ALLOC(I) - UNGX ) * SCALX
YN = ( YLOC(I) - UNGY ) * SCALY

C      * * * SET THE INDICATOR FOR THE LAST POINT
IF ( I .EQ. LAST ) LAST = .T.
IF ( .NOT. FIRST ) GO TO 100
FIRST = .T.
SLOPE = 0.0

C      * * * SAVE DATA ABOUT THIS PLOTTED COORDINATE
INSET = XN
IXSET = IFIX ( AMULT * XN + 0.5 )
IYSET = IFIX ( AMULT * YN + 0.5 )

C      * * * CALL THE ACTUAL PLOTTING ROUTINE
CALL CALPLT ( XN, YN, 3 )
GO TO 1000
100 CONTINUE
IF ( .NOT. LAST ) GO TO 200
C      * * * LAST POINT .. CHECK FOR DISCONTINUITY
IF ( IFIX ( AMULT * ( YN - SLOPE * ( XN - INSET ) ) + 0.5 ) .NE.
1 IYSET ) GO TO 300
IXPI = IXSET
IYPI = IYSET
GO TO 400
200 CONTINUE
C      * * * CHECK FOR THE NEED TO PLOT
IF ( IFIX ( AMULT * ( YN - SLOPE * ( XN - INSET ) ) + 0.5 ) .EQ.
1 IYSET ) GO TO 1000
C      * * * COMPUTE THE REVISED SLOPE
IF ( ABS ( XN - XNPI ) .LT. 1.E-14 ) GO TO 300
SLOPE = ( YN - YNPI ) / ( XN - XNPI )

300 CONTINUE
IXNI = IFIX ( AMULT * XNI + 0.5 )
IYNI = IFIX ( AMULT * YNI + 0.5 )
IF ( ( IYNI .EQ. IYSET ) .AND. ( IXNI .EQ. IXSET ) ) GO TO 400
C      * * * PLOT THE NEW POINT AS WELL
CALL CALPLT ( XNPI, YNPI, 2 )

400 CONTINUE
C      * * * SAVE DATA ABOUT THIS PLOTTED COORDINATE
XNSET = XN
IXNSET = IFIX ( AMULT * XN + 0.5 )
IYNSET = IFIX ( AMULT * YN + 0.5 )
IF ( ( IYNI .EQ. IYSET ) .AND. ( IXNI .EQ. IXSET ) ) GO TO 1000
C      * * * PLOT THE POINT AT LAST
CALL CALPLT ( XN, YN, 2 )
1000 CONTINUE

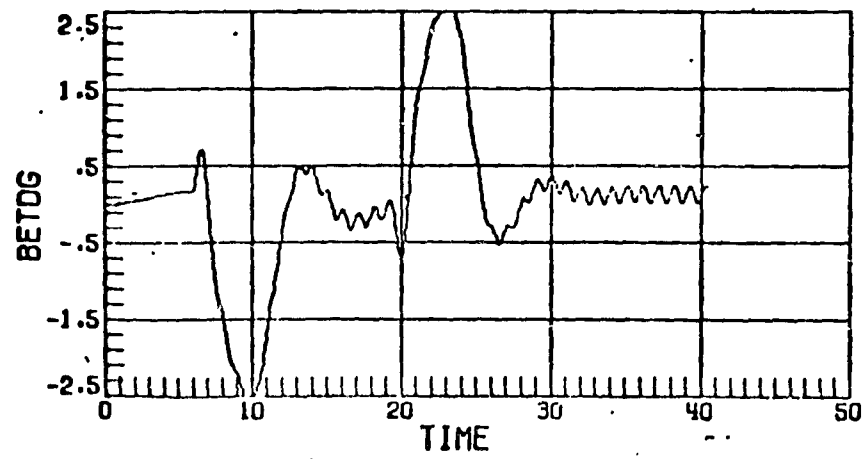
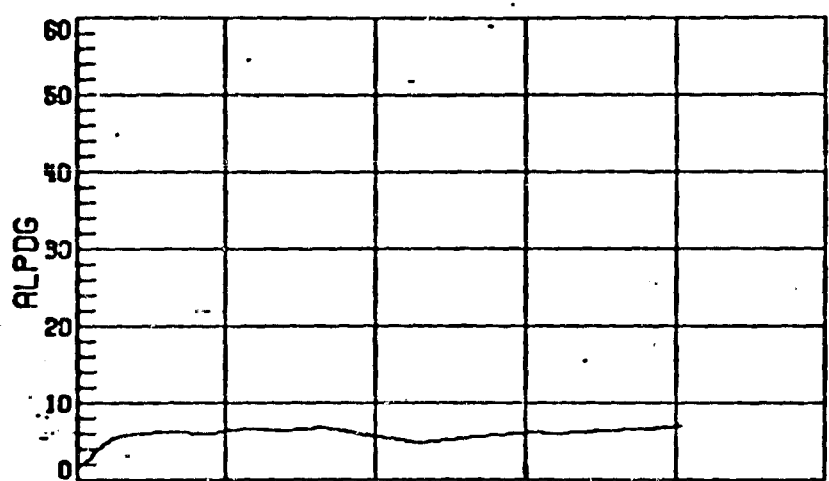
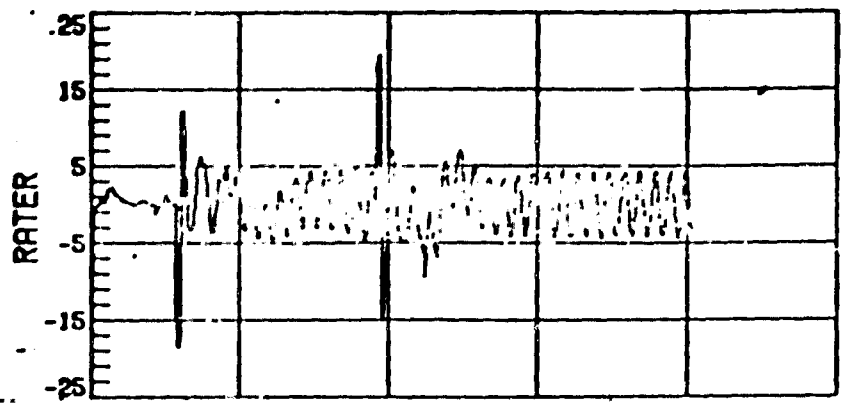
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FORTRAN implementation of point-thinning logic

### TYPICAL POINT-THINNING PROGRAM OUTPUT

The point-thinning logic has been implemented in an independent plot program used to plot from real-time analysis runs in the batch mode. In this example, there are twenty-five data points per second. Thus somewhat over 1000 points were examined for each curve. Obviously some curves are more active than others and required more data points to be plotted. Visual comparison with methods plotting every point showed no difference in curve representation.



Typical point-thinning program output

## RESULTS AND CONCLUSIONS

Typical results from the real-time data plotting program showed that about 90 percent of the points could be skipped in the actual plotting process. This resulted in significantly reduced CPU time and reduced I/O activity. Similar benefits are anticipated for interactive graphics applications.

## RESULTS AND CONCLUSIONS

- o NORMALLY MORE THAN 90 PERCENT OF THE DATA POINTS COULD BE IGNORED.
- o CPU TIMES WERE REDUCED TO ABOUT 30 PERCENT OF THEIR FORMER REQUIREMENTS IN THE PLOTTING PHASE.
- o RESULTING PLOT VECTOR FILES (INCLUDING TITLES, GRIDS, ETC.) WERE REDUCED IN SIZE BY OVER 50 PERCENT.
- o THE METHOD NEEDS TO BE APPLIED TO THE INTERACTIVE GRAPHICS DISPLAYS. COMPUTER RESPONSE SHOULD IMPROVE DUE TO BETTER CPU UTILIZATION AND REDUCED PLOT VECTOR FILE SIZE.

PARAMETRIC CUBIC SURFACE  
REPRESENTATION

BY

DAVID P. ROLAND

NASA SURFACE REPRESENTATION WORKSHOP 1-2 MARCH 1978  
AMES RESEARCH CENTER MOFFETT FIELD, CALIFORNIA

ROLAND /

Foil 2

Ames Research Center has developed a geometry system oriented towards interactive computer graphics, to interface to linearized panel aerodynamics programs. This system provides a geometric representation of realistic aircraft configurations from which analytical mathematical models can be created. Various configurations can be assembled quickly from independent geometric components.

D. P. Roland

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## GEOMETRY SYSTEM GOALS

- \* GEOMETRY DEFINES PANELLING
- \* ASSEMBLE CONFIGURATIONS QUICKLY
- \* DATA FORMAT USEFUL FOR INTERACTIVE GRAPHICS

ROLAND 2

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Foil #3

Parametric cubic equations were selected as the data format because they had several important features:

- \* a single mathematical format can be used to represent curves and surfaces of all kinds.
- \* parametric equations do not experience numerical difficulties with infinite slopes.
- \* it is a mature technology with a large base of software available both in industry and within NASA.

D. P. Roland

## FEATURES OF PARAMETRIC CUBICS

- \* SINGLE FORMAT FOR ALL CURVES/SURFACES
- \* HANDLES INFINITE SLOPES
- \* MATURE TECHNOLOGY
- \* SOFTWARE AVAILABLE IN INDUSTRY

ROLAND3

Foil #4

It has been recognized that parametric surfaces have some limitations. The ability to specify slope continuity in the general case and higher order derivatives continuity was lacking. The maximum number of sides in a patch is four and some waviness occurs within a surface. However, it has been determined that these restrictions will not impact the requirements of the aerodynamics programs employed.

D. P. Roland

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## LIMITATIONS OF PARAMETRIC CUBICS

- \* NO GENERAL SLOPE CONTINUITY
- \* NO HIGHER ORDER CONTINUITY
- \* MAXIMUM OF 4 SIDES PER PATCH
- \* WAVINESS POSSIBLE WITHIN SURFACES

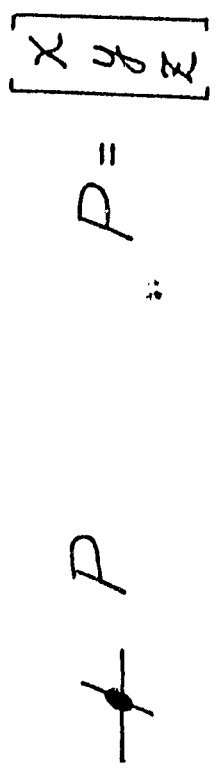
Foil #5

The geometric entities utilized in this system are the point, the parametric cubic curve and the bicubic surface patch. A point in three-space is a triple of the component coordinates. A curve in three-space has each coordinate defined as a cubic polynomial of the parameter  $u$ . Similarly for a surface, which is a bicubic in  $u$  and  $w$ . Since the parameters are limited to the range  $0 - 1$ , each entity is bounded and has a sense of direction.

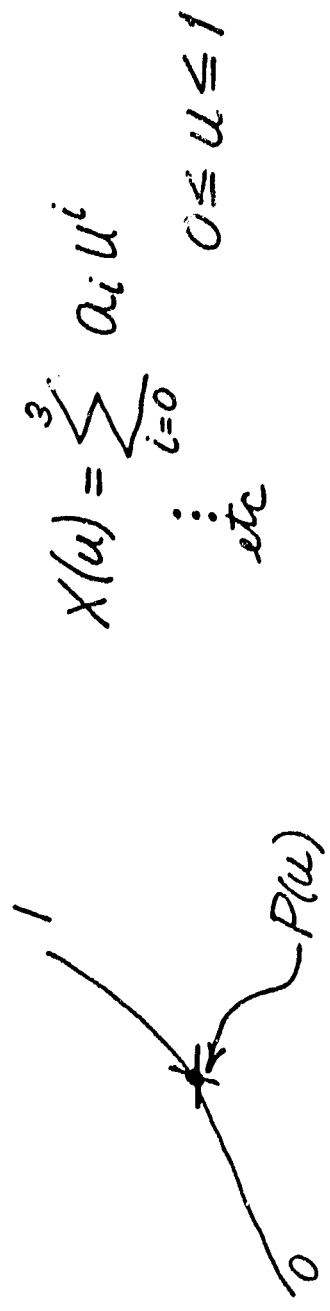
D. P. Roland

# PARAMETRIC CUBIC GEOMETRY ENTITIES

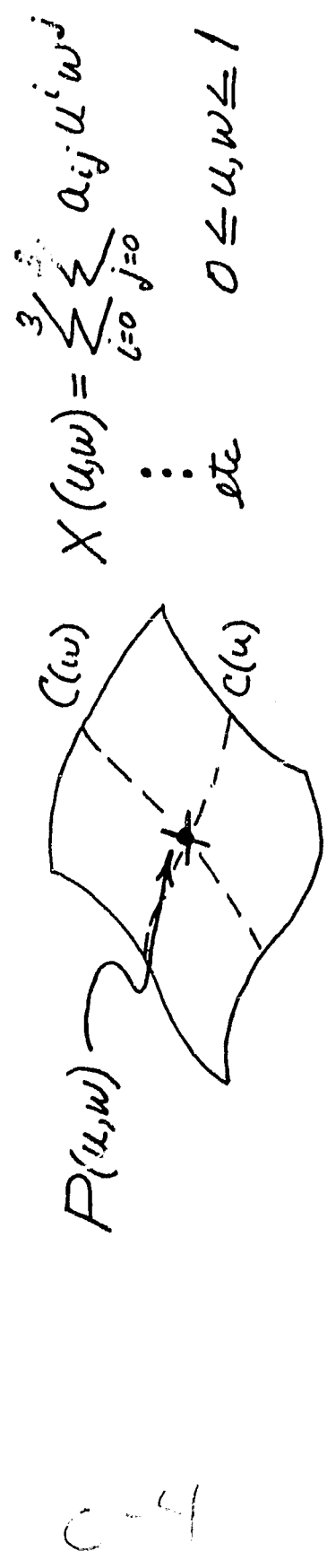
\* A POINT



\* A CURVE



\* A SURFACE



Foil #6

The format of parametric cubic equations is well-suited to matrix notation. In the algebraic form, it is computationally efficient, although the coefficients are difficult to interpret. In the geometric form, the coefficients become the end or corner points and the parametric tangent vectors, from which the slope at the ends can be determined by division. This form is quite useful to the engineer as a simple reference for position and slope continuity.

I. P. Roland

## CONVENIENT FORMATS

\* ALGEBRAIC MATRIX FORMAT \*

$$P(u) = [u^3 \ u^2 \ u \ 1] \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix}$$
$$P(u, w) = [u] [A] [w]^T$$

\* GEOMETRIC MATRIX FORMAT \*

$$P(u) = [F_1(u) \ F_2(u) \ F_3(u) \ F_4(u)] \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}$$
$$P(u, w) = [F(u)] [B] [F(w)]^T$$



Foijl #7

Parametric cubic approximations of other commonly used curves can be created via straightforward techniques. A conic approximation is developed by the beginning and end points, slopes and heel point. Rho determines the type of conic created:  $0 \leq .5$  is an ellipse;  $.5$  is a parabola (which is exact, not approximate);  $.5 \leq .75$  is a hyperbola. The circle approximation is a special case of the conic having the correct end points and slopes, and the midpoint on the circle. The graphical layout describing the point of  $u = .5$  can be used to quickly define the curve from its coefficients or to approximate even hand-drawn curves. This technique is also applicable to space curves.

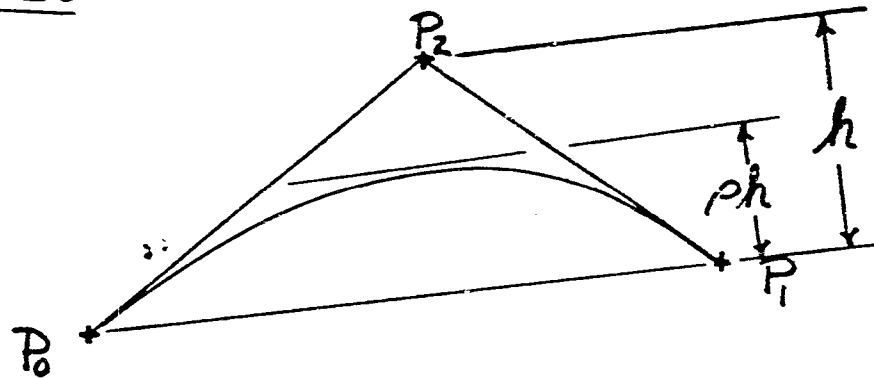
H. P. Roland

## CREATE CURVES

\* CONIC APPROXIMATION

$$P_0' = 4\rho(P_2 - P_0)$$

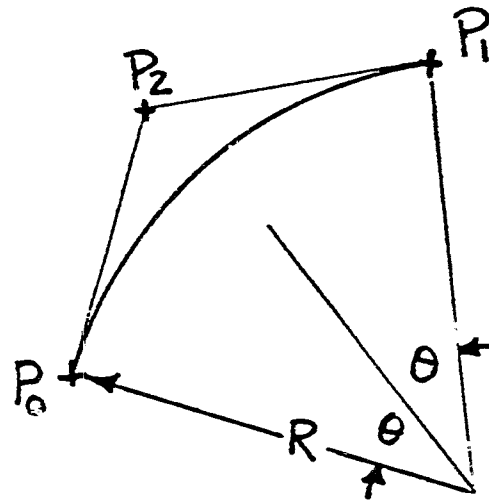
$$P_1' = 4\rho(P_1 - P_2)$$



\* CIRCULAR APPROXIMATION

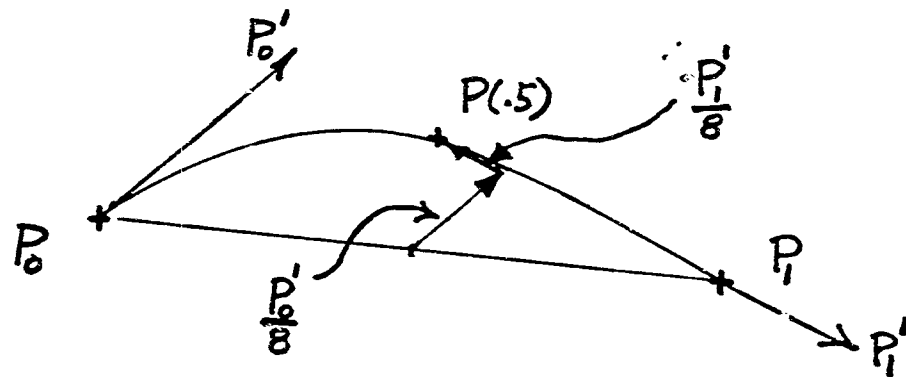
$$P_0' = \psi dP_0' \quad \psi = \frac{4R(1 - \cos\theta)}{\sin\theta}$$

$$P_1' = \psi dP_1'$$



\* GRAPHICAL LAYOUT

$$P(.5) = \frac{P_0 + P_1}{2} + \frac{P_0' - P_1'}{8}$$



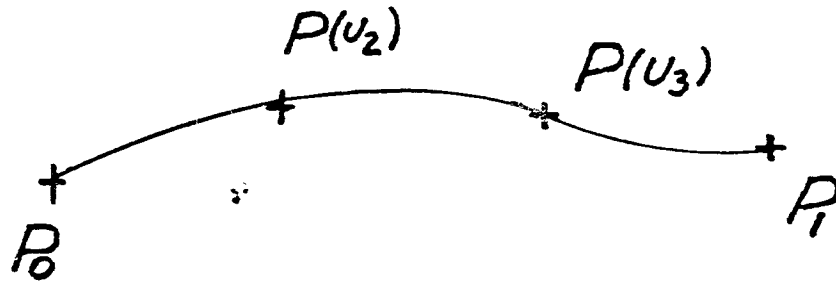
Foil #8

General space curves can be defined analytically via a four-point transformation. Complex shapes are defined as piecewise continuous segments. Slope continuity can be specified if required. Segmented curves with curvature continuity can be created with spline fitting techniques.

D. P. Roland

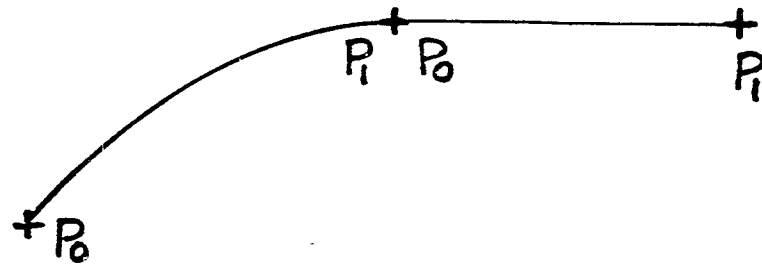
## CREATE CURVES

\* THROUGH 4 POINTS



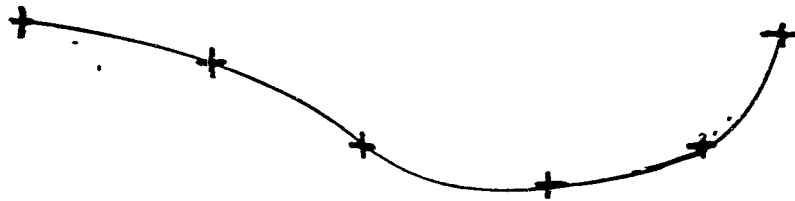
\* SEGMENTED CURVES

POSITIONAL CONTINUITY ALWAYS  
SLOPE CONTINUITY IF REQUIRED



\* SPLINE FIT

CURVATURE CONTINUITY

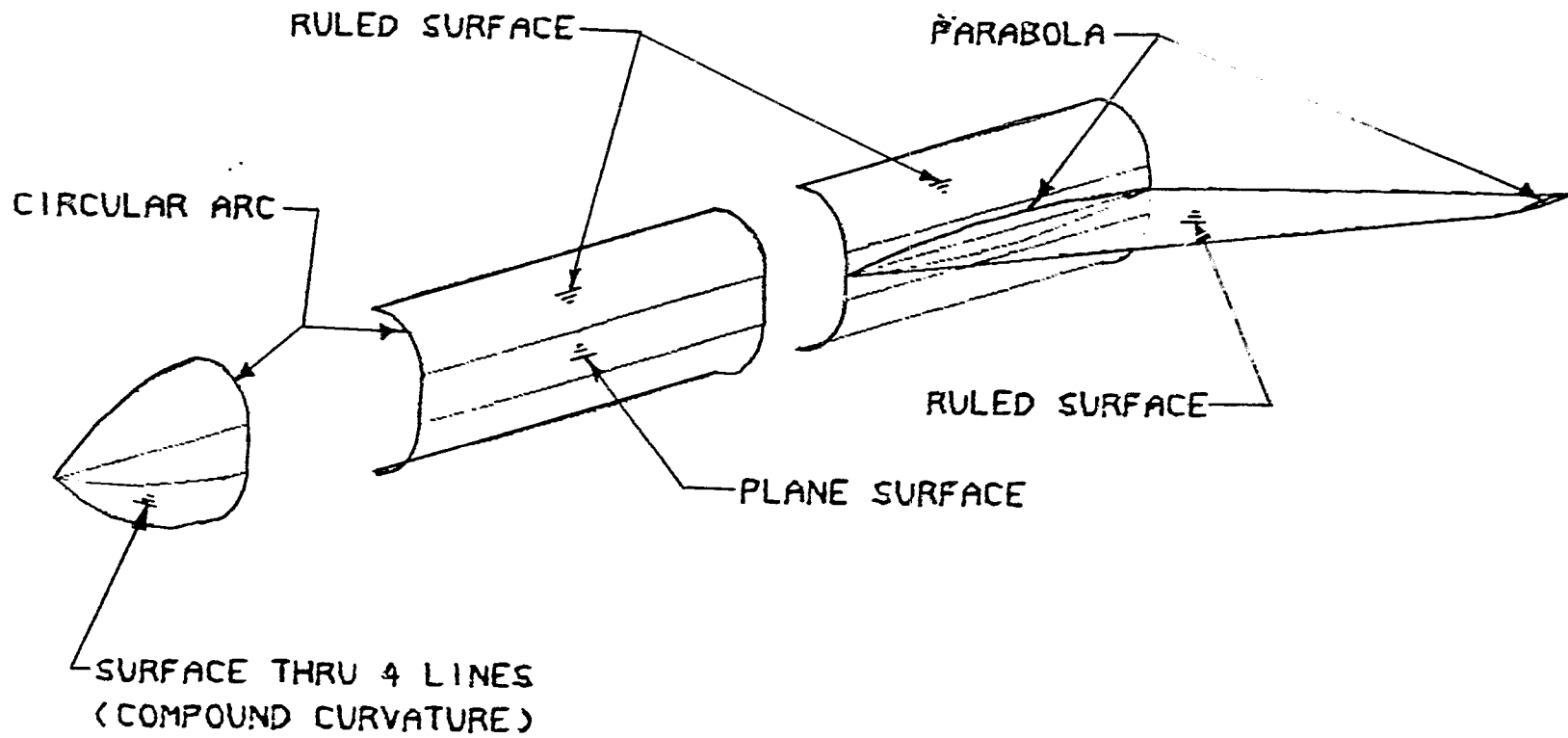


Foil #9

Many aircraft surfaces are specified analytically. This wing-body configuration (with/without canard) has been used at NASA Langley for a series of wind tunnel tests, and it is currently being used to verify the advanced panel aerodynamic codes at NASA Ames. It has been modelled as a set of components utilizing parametric bicubic surface patches. The surfaces were created from the analytical description of the geometry in the Langley report.

D. P. Roland

# CREATING SURFACES (WITHOUT SPLINES)



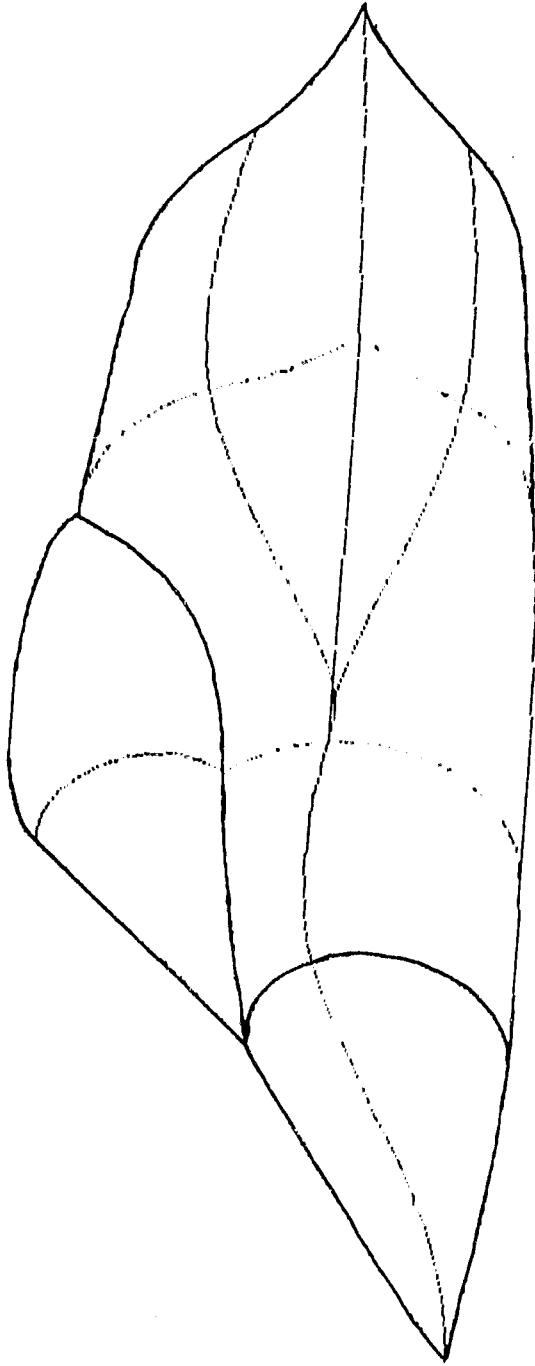
Foil #10

In other areas, complex compound surfaces may only be defined as cross-sections on a drawing. A tension-spline fit program is utilized to create patch networks from digitized cross sections that have positional continuity and regions of curvature continuity while simultaneously creating apparent slope discontinuities.

D. F. Roland

CREATING SURFACES

TENSION SPLINE-FIT SURFACE





Foil ~~10~~ 11

The parametric cubic form is useful in interactive graphics because a limited set of software suffices for geometric shapes. The patch form allows each entity to be stored on disc as a separate record. Large numbers of patches need not be kept in core. Transformations on the patches are simple matrix multiplications. The surfaces can have their edges connected and new patches created between patches.

D. F. Roland

## USEFUL IN INTERACTIVE GRAPHICS

- \* SINGLE SET OF SOFTWARE
- \* EACH ENTITY HANDLED SEPARATELY
- \* ABILITY TO MODIFY COMPONENTS  
TRANSLATE, ROTATE, SCALE, SUBDIVIDE
- \* ABILITY TO CONNECT COMPONENTS  
CONNECT BOUNDARIES  
CREATE RULED SURFACES  
FILLET BETWEEN COMPONENTS

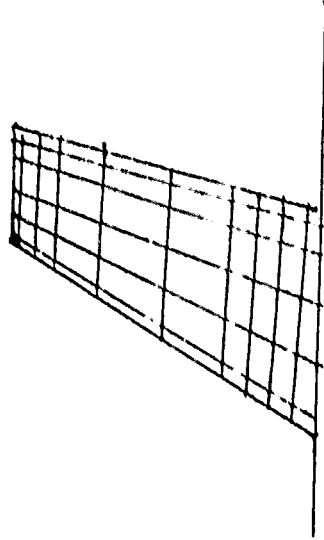
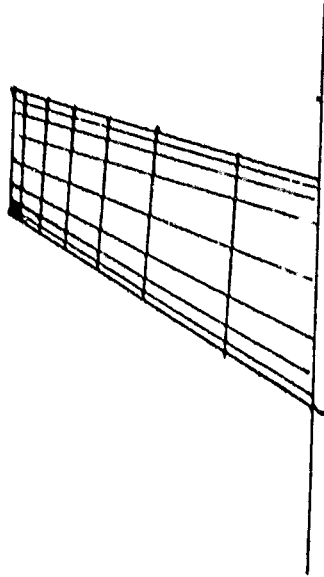
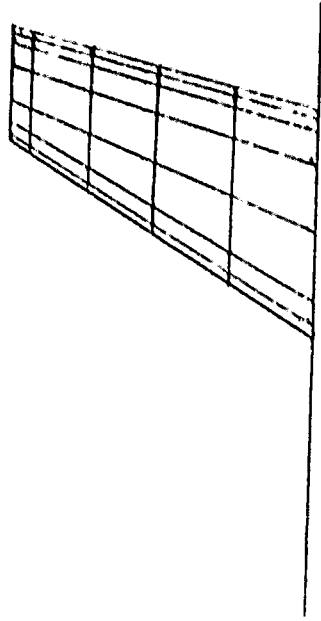
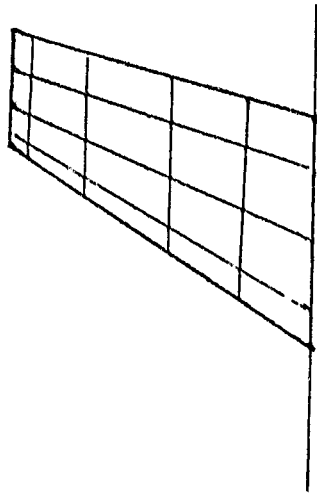
Foil ~~117~~-

The final product of the system is the panel definitions. Panel edges are created by specifying the number and distribution of parameter values at which points are to be extracted from the parametric equations. Equal, sine, cosine, half cosine, or user defined spacings of the parameters may be specified.

D. P. Roland

# USAGE OF SURFACES

CONVERSION INTO AERODYNAMIC PANELLING



280 31/1/78 12

Foil ~~14~~ 13

Another use of the geometric definition is to create the inputs to Level I aerodynamic programs. These include surface areas and body volumes. The ability to intersect the surfaces with plane equations is useful for cross sectional distributions. If the pressure data is made into a surface analog, plane intersections provide isobars for display. The intersection between surfaces can be computed to locate the interface of components.

D. F. Roland

## EVALUATING SURFACES

- \* SURFACE (WETTED) AREA.
- \* VOLUME
- \* PLANE INTERSECTIONS  
CROSS SECTIONAL AREA DISTRIBUTION  
PRESSURE SURFACE ISOBARS
- \* SURFACE-SURFACE INTERSECTIONS

Foil ~~13~~ 14

In conclusion, parametric cubic geometry is a useful technique for defining realistic aircraft configurations for linear panel aerodynamic methods. The limitations do not currently impact the requirements and improved methods will be developed.

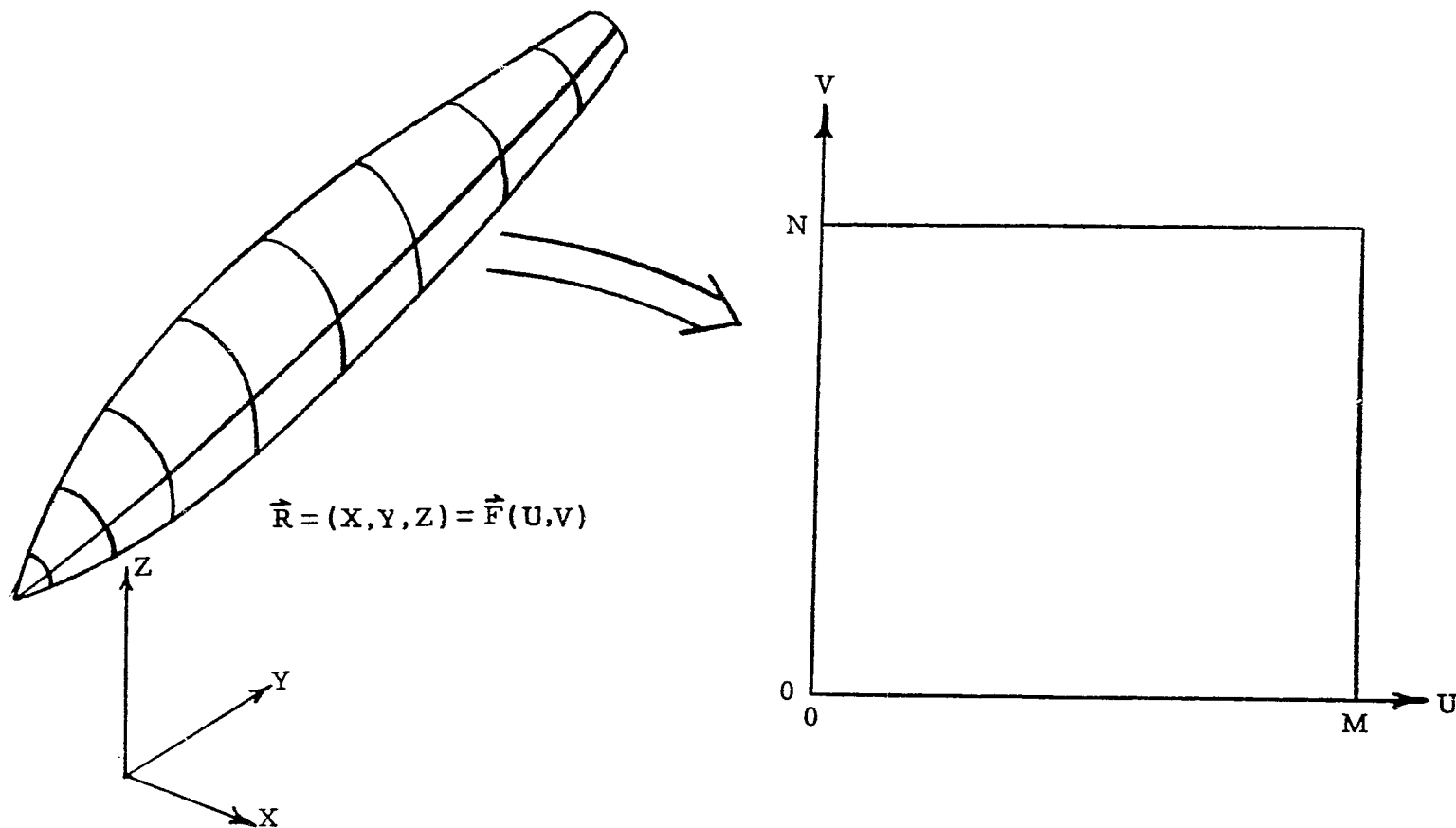
U. P. Roland

CONCLUSIONS - PARAMETRIC CUBIC GEOMETRY IS:

- \* USEFUL NOW
- \* CAPABLE OF DEFINING REALISTIC CONFIGURATIONS
- \* MEETS THE REQUIREMENTS OF CURRENT ACTIVITIES
- \* IMPROVED METHODS ARE COMING

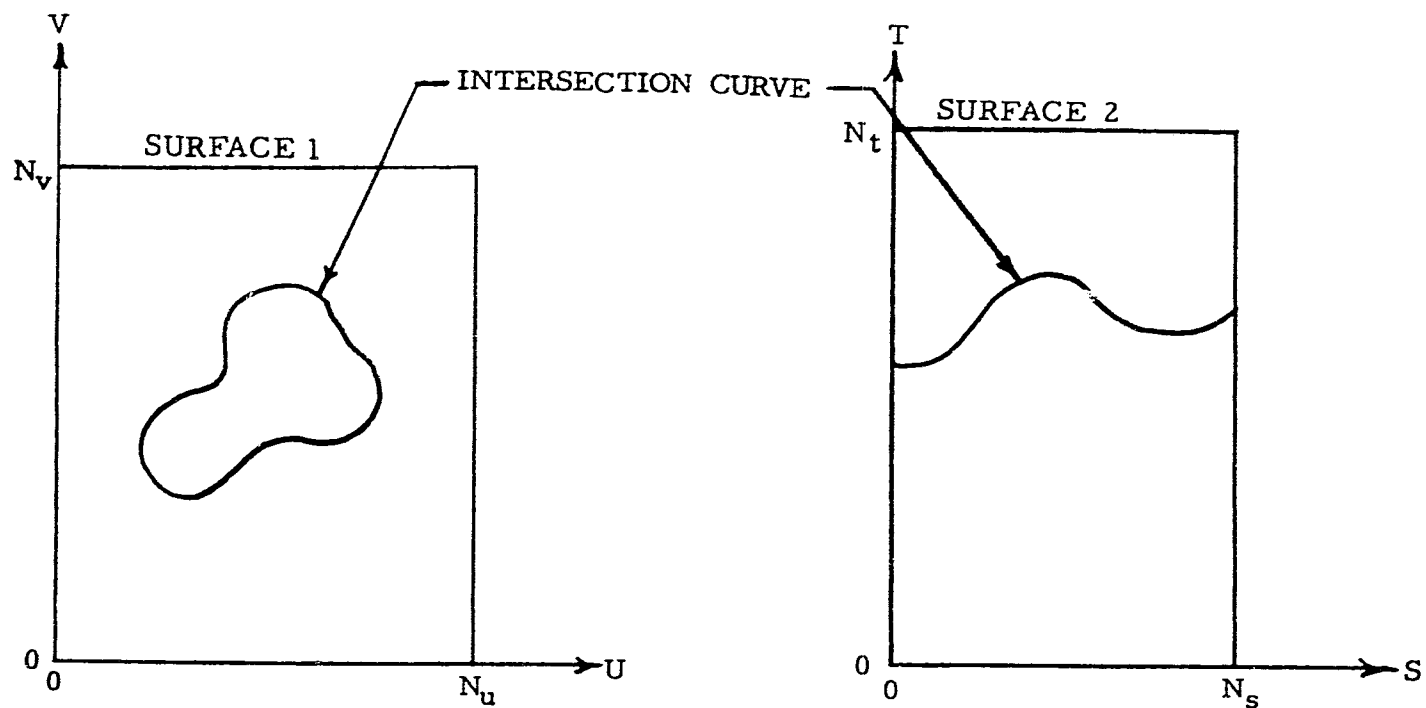
ROLAND 14





WITHIN THE CONTEXT OF THE INTERSECTION PROBLEM, A SURFACE IS DEFINED TO BE THAT PORTION OF THE BOUNDARY OF A PHYSICAL OBJECT THAT IS MAPPED INTO A RECTANGULAR REGION IN PARAMETER SPACE.

TIMMER 1

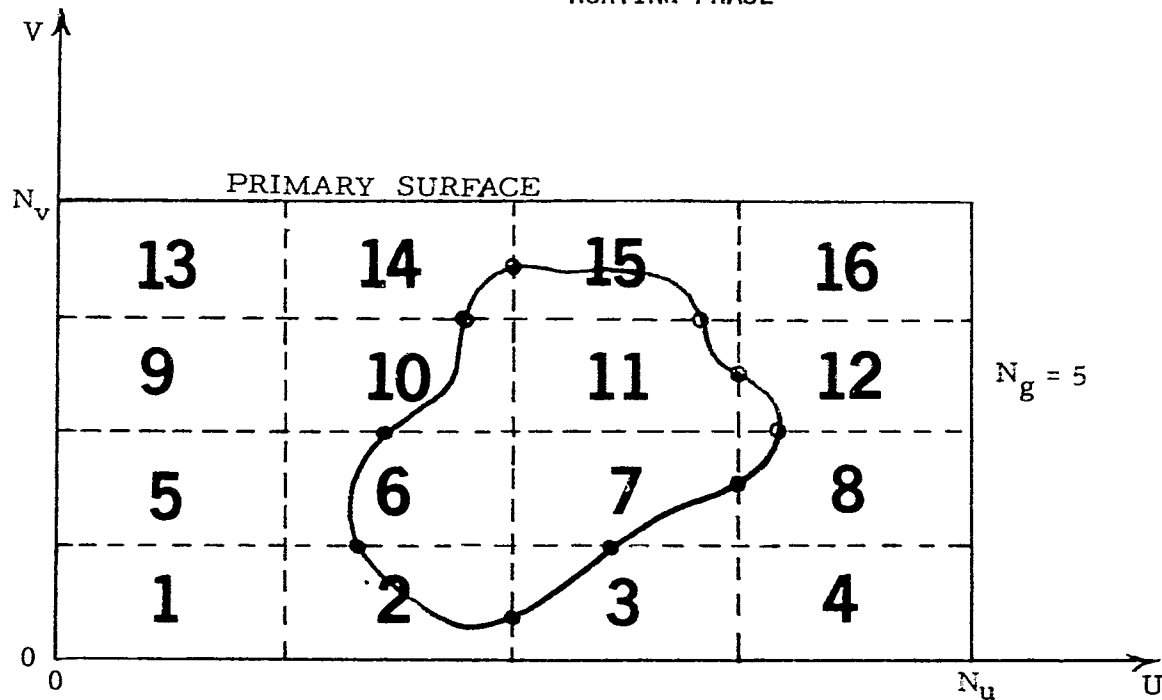


$$\vec{G}(u, v, s, t) = \vec{r}_1(u, v) - \vec{r}_2(s, t) = 0$$

- THREE EQUATIONS IN FOUR UNKNOWNS
- SOLUTION MAY BE EXPRESSED AS  $\vec{r}(\sigma)$ , OR EQUIVALENTLY  $\{u(\sigma), v(\sigma), s(\sigma), t(\sigma)\}$  WHERE  $\sigma$  IS SOME ARC LENGTH RELATED PARAMETER

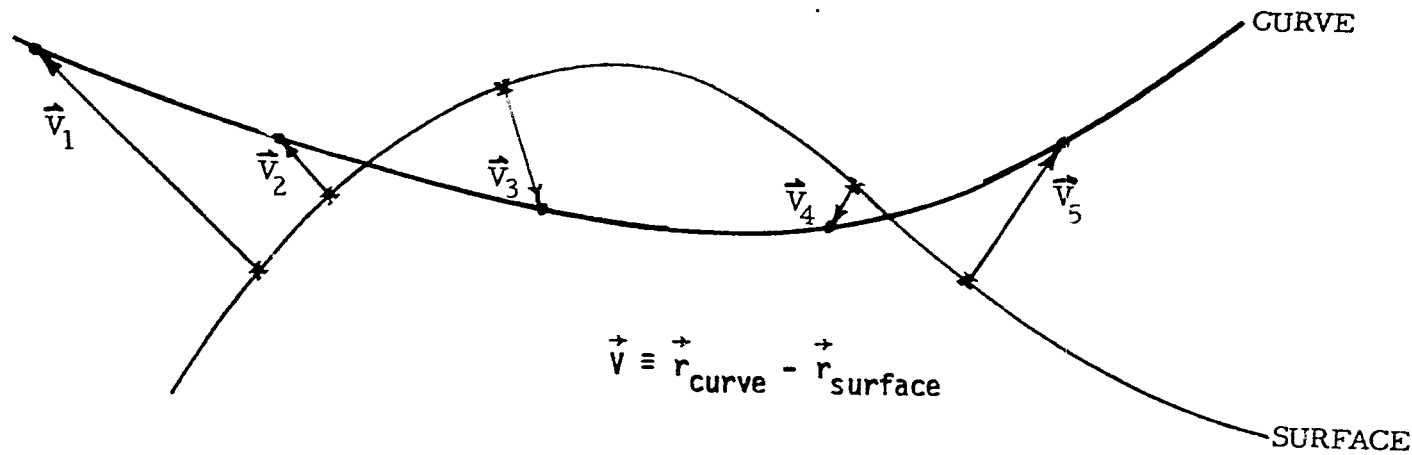
TIMMER 2

### HUNTING PHASE

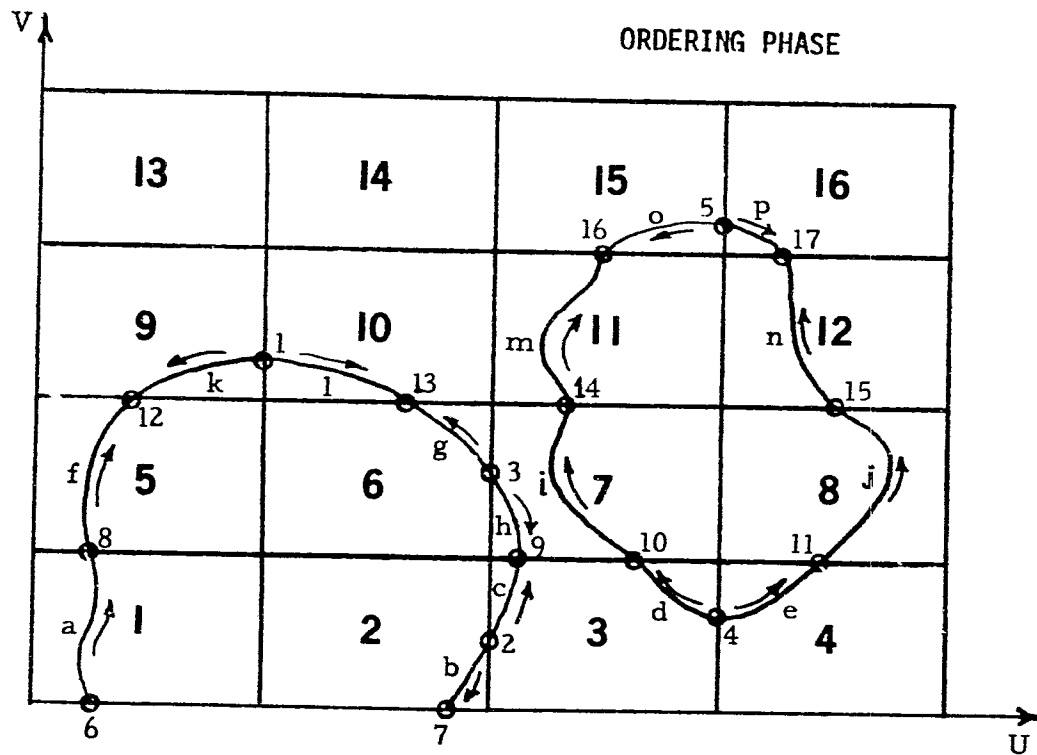


- THE HUNTING GRID IS ESTABLISHED ON THE PRIMARY SURFACE BY  $N_G$ .
- EACH LINE IN THE GRID IS A CURVE DEFINED BY EITHER  $u$  OR  $v$  BEING CONSTANT.
- THE INTERSECTION OF A CURVE WITH THE SECONDARY SURFACE IS FOUND BY SOLVING THE CONSISTENT SET OF EQUATIONS  $\vec{G}(v,s,t) = 0$  OR  $\vec{H}(u,s,t) = 0$ .
- THE SOLUTIONS OF THESE SETS OF EQUATIONS PROVIDE THE INITIAL CONDITIONS FOR THE TRACING PHASE.

### CURVE-SURFACE INTERSECTION CALCULATION



- CURVE CRAWLING PROCEDURE TESTS  $\vec{v}_i \cdot \vec{v}_{i+1} \equiv \phi_i$
- THE POINT ON THE SURFACE (X) APPROXIMATES THE CLOSEST POINT ON THE SURFACE TO A GIVEN POINT ON THE CURVE (•).



LOOP 1: a,f,-k,l,-g,h,-c,b

LOOP 2: -n,-j,-e,d,i,m,-o,p

NOTE: MINUS SIGNS INDICATE A REVERSED DIRECTION FOR THE SEGMENT

TIMMER 5

HALSEY 1

1. Generation of Input Data for a Three-Dimensional Potential-Flow Program

This talk describes work performed at Douglas Aircraft Company under contract to NASA Langley to develop a geometry package to simplify the task of preparing the input data for a potential-flow program. The particular program for which the geometry package was developed is the three-dimensional lifting version of the Douglas Neumann program, which was developed by John Hess under Navy sponsorship and which is in use at numerous companies, universities, and government agencies. The geometry package is sufficiently general, however, to be of use in other applications. A major portion of the expense involved in using the potential-flow program is consumed by the man-hours required to prepare the input data (virtually all of which is geometric data).

GENERATION OF INPUT DATA FOR A  
THREE-DIMENSIONAL POTENTIAL  
FLOW PROGRAM

Halsey/Hess  
Slide 1

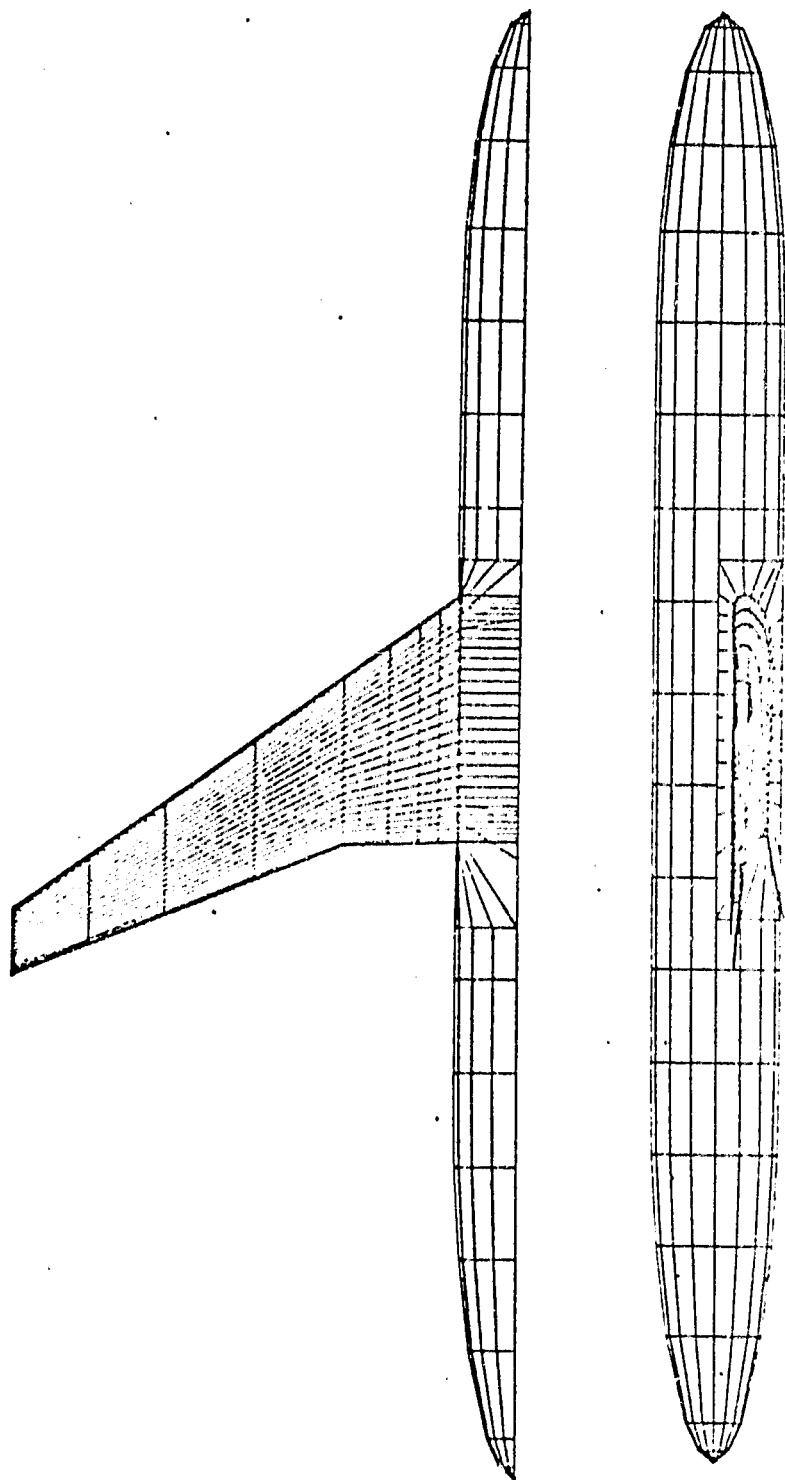
HALSEY 1

2. Typical Element Distribution for a Wing-Fuselage Case

Preparing the geometric input is so time-consuming because the potential-flow program requires a large number of points for good accuracy. A typical wing-fuselage case, shown here, required approximately 800 points.



TYPICAL ELEMENT DISTRIBUTION FOR A WING-FUSELAGE CASE  
(~800 ELEMENTS)



Halsey/Hess  
Slide 2

HALSEY 2

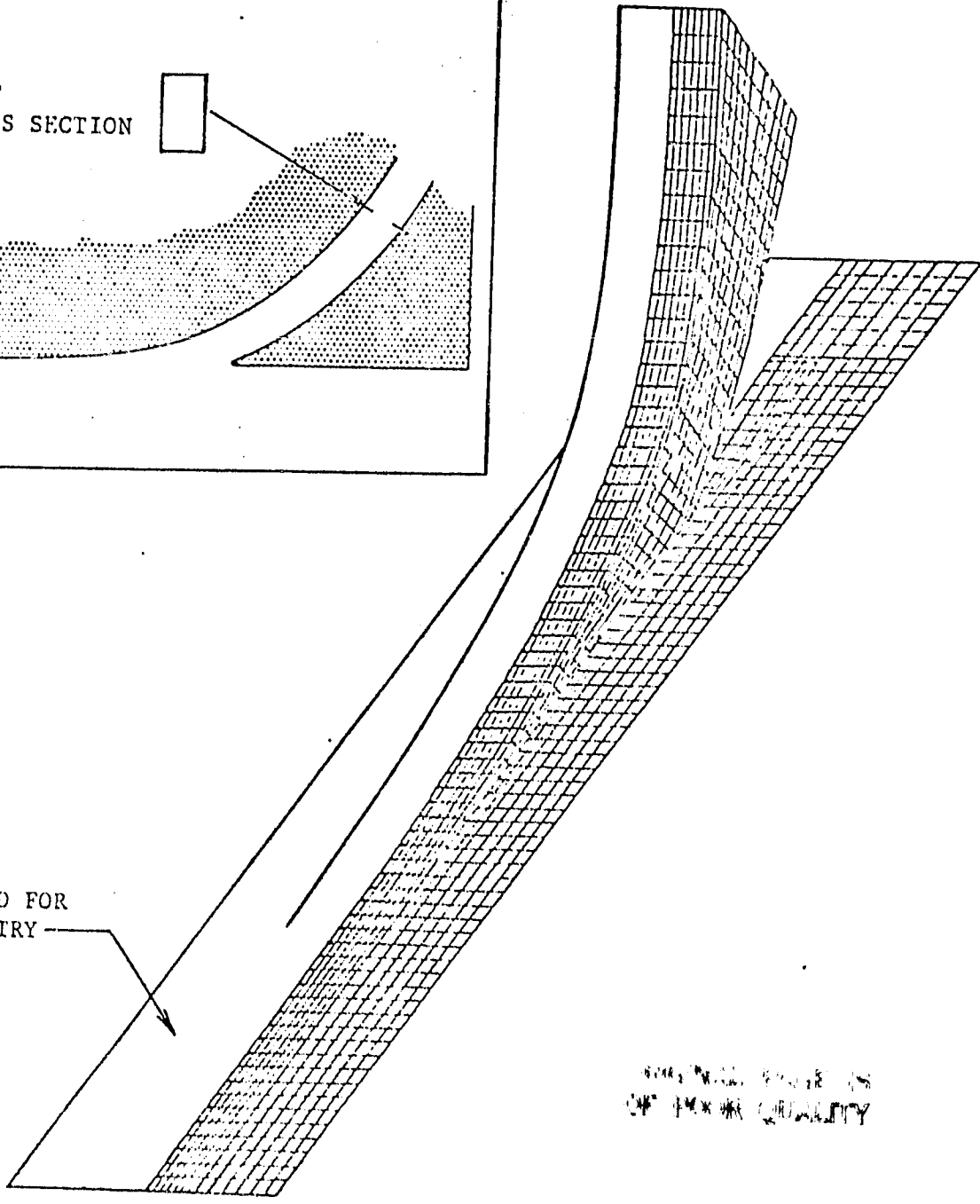
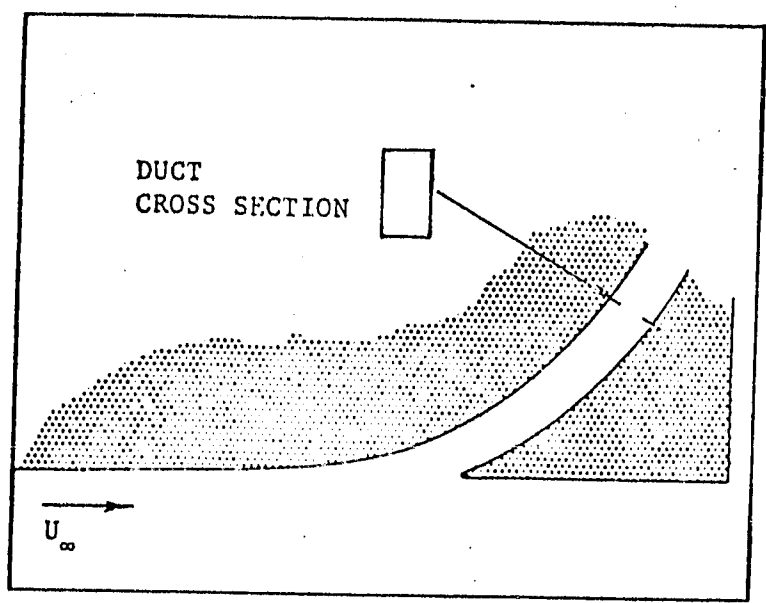
ORIENTAL TYPE  
OF POOR QUALITY

3. Elements Used by Bell Aerospace for a Flow Water Inlet or a Surface Effect  
Case

Many more points are sometimes required. For example, Bell Aerospace used the potential-flow program to analyze a flow water inlet on a surface effect ship. They had to increase the dimensions on all the proper variables to allow them to use approximately 7 3500 units.

m

ELEMENTS USED BY BELL AEROSPACE FOR A  
FLUSH WATER INLET ON A SURFACE  
EFFECT SHIP (~3500 ELEMENTS)



ACCOUNTED FOR  
BY SYMMETRY

QUALITY OF MESH IS  
OF HIGH QUALITY

4. Factors Which Influence Point Spacing Requirements

In addition to sheer number of points, the user must take care in the way he distributes the points. On a wing, for example, the proximity of leading or trailing edges, the tip or root, breaks in the planform or any other corners, all influence the point spacing which should be used. On more general bodies, regions of high curvature or any factor which causes the solution (either the source density or the velocity) to vary rapidly, have to be considered.

## FACTORS WHICH INFLUENCE POINT SPACING REQUIREMENTS

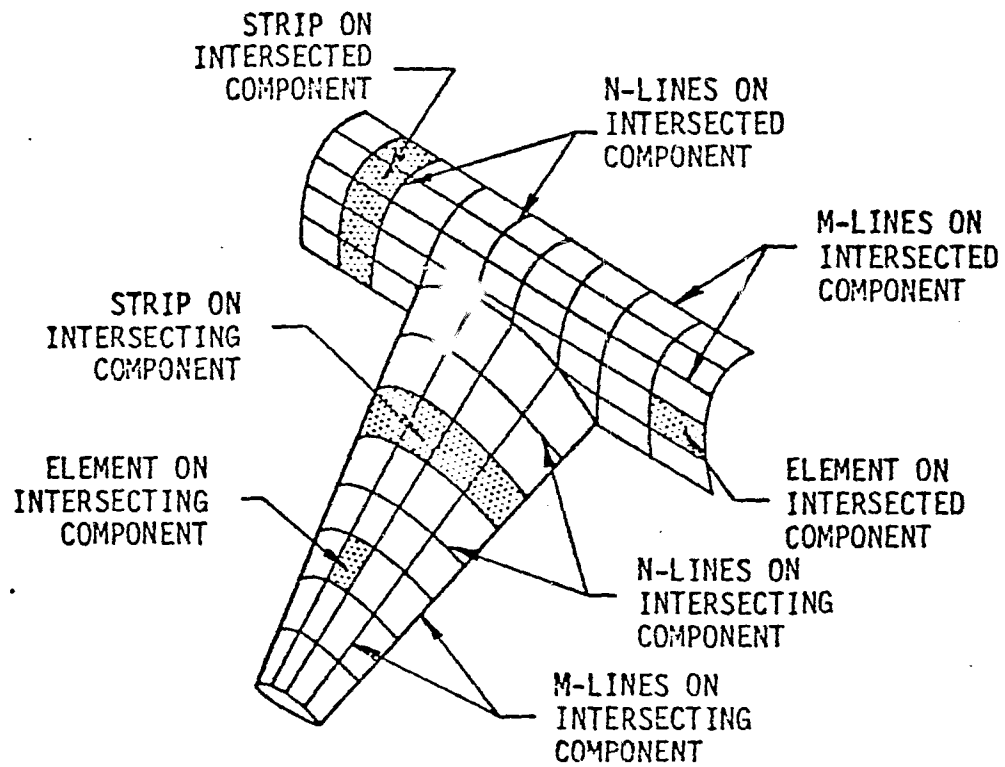
- o LEADING EDGES
- o TRAILING EDGES
- o CORNERS
- o PLANFORM BREAKS
- o AREAS OF HIGH CURVATURE
- o REGIONS OF RAPID VARIATION OF SINGULARITY STRENGTH OR SURFACE VELOCITY

5. Definition of Frequently Used Terms

In addition, the user must organize the points in a manner consistent with the logic of the potential-flow program. This slide illustrates some of the logical considerations and also defines some terms to be used later in this talk. A general configuration, such as an aircraft, is divided into a number of simpler components, such as a wing or a fuselage, or a portion of one of these. Each component is defined by specifying points on a section curve, then on an adjacent section and so on, until all sections have been defined. Points on a section curve are ordered as if one were traversing the perimeter of the section (not generally fore-and-aft). Such section curves are designated N-lines. The curves connecting corresponding points on the N-lines are designated M-lines. The area bounded by two adjacent N-lines is termed a strip and the area bounded by two N-lines and two M-lines is termed an element.

11

# DEFINITION OF FREQUENTLY USED TERMS



6. General Features of the Geometry Package

This geometry package simplifies the user's job in several ways. First, it greatly reduces the number of points for which the user must specify the coordinates. It is often possible to reduce this number by an order of magnitude, or more, from the number required for an accurate potential-flow solution. Second, it reduces the care that he must devote to spacing the points, since it provides a number of automatic spacing options. Third, the very difficult task of calculating intersection curves (if any) between the components is done automatically. Finally, if there are intersections, some repaneling is done to obtain compatible paneling distributions between adjacent components.



## GENERAL FEATURES OF THE GEOMETRY PACKAGE

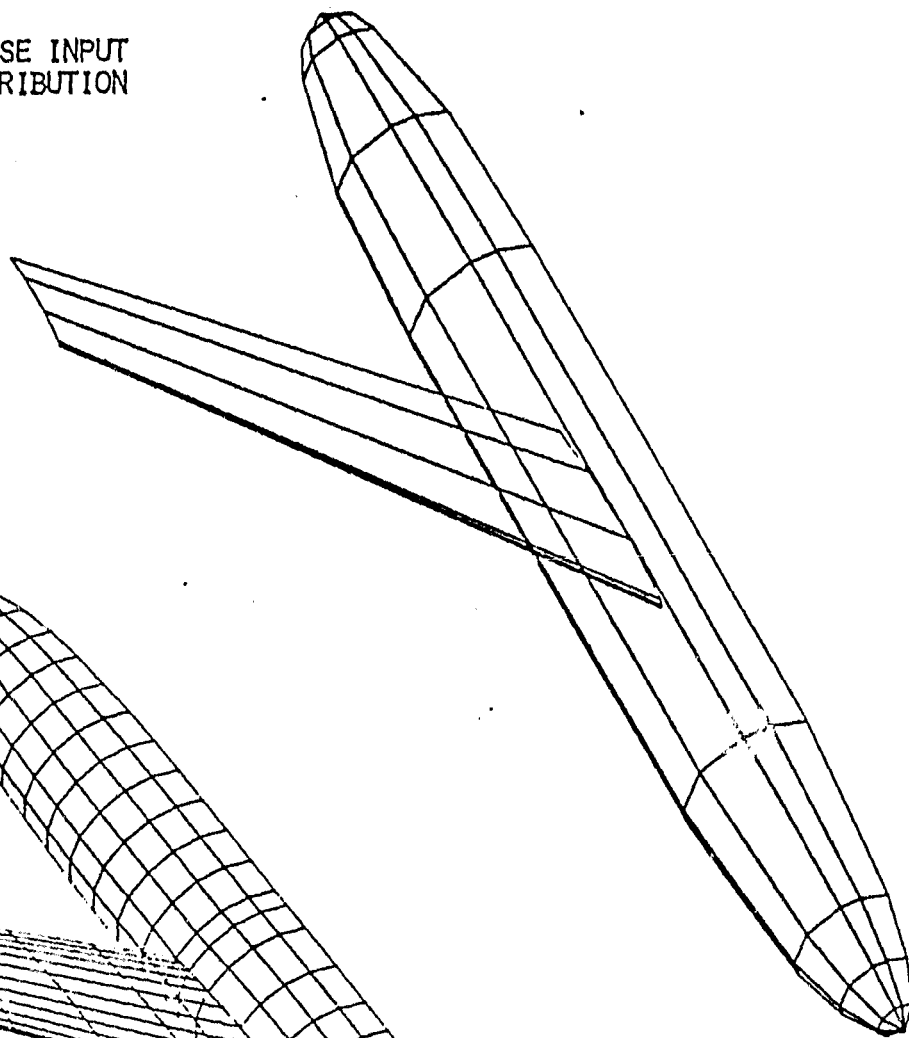
- o INITIAL GEOMETRY DATA CAN BE VERY SPARSELY DEFINED
- o GEOMETRY DATA AUGMENTED AND REDISTRIBUTED (SEVERAL OPTIONS)
- o INTERSECTION CURVES CALCULATED (USING P.C. PATCHES)
- o FINAL REPANELING MAKES ADJACENT ELEMENTS LINE UP ACROSS INTERSECTION CURVES

7. Use of the Geometry Package for a Wing-Fuselage Configuration

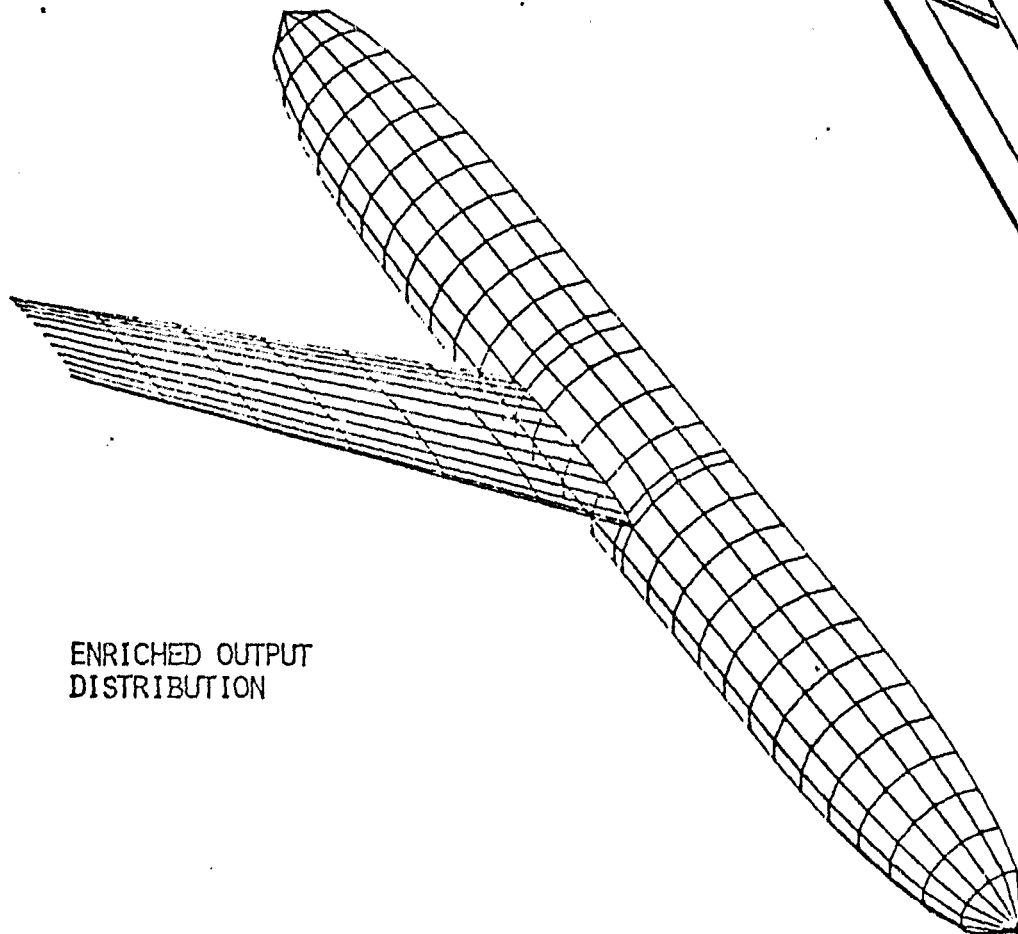
This is a typical example of what the geometry package can do. Because of the simplicity of the configuration, a very small number of points is sufficient to define the geometry. The geometry package has added and redistributed points in both chordwise and spanwise directions on the wing and in both axial and circumferential directions on the fuselage. It has also found the wing-fuselage intersection curve and matched the spacing of the points across the intersection curve.

# USE OF THE GEOMETRY PACKAGE FOR WING-FUSELAGE CONFIGURATION

SPARSE INPUT  
DISTRIBUTION



ENRICHED OUTPUT  
DISTRIBUTION



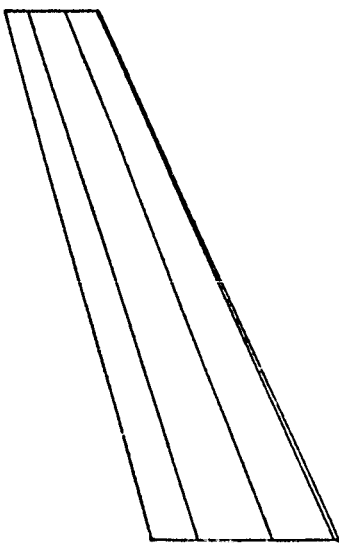
#### 8. Paneling of Isolated Components

The first operation performed by the geometry package is the paneling of isolated components. In this operation, the program takes the sparse input data and augments it to a specified number of points distributed according to one of several possible spacing algorithms. At this stage intersections are completely ignored; each component is paneled as if it were completely independent of the others (except that proximity of other components should be considered before deciding on the desired spacing algorithm and a desire for continuity between adjoining components may dictate that these adjoining components be paneled using the same algorithm).

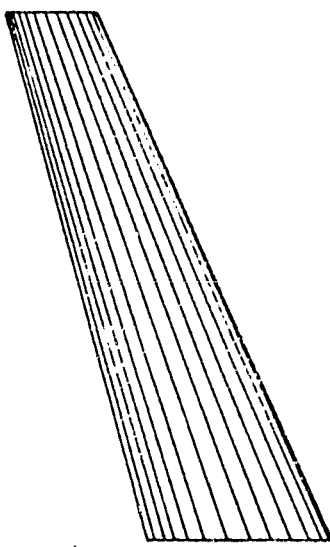
This slide shows a wing in various stages of the paneling operation. Initially, it is defined by a small number of points on just two N-lines (tip and root). The program first distributes points on the initial N-lines and then adds more N-lines. The adding of N-lines is accomplished by redistributing points on the M-lines. Thus, the entire paneling procedure is accomplished by two sets of interpolations on curves; no general surface-fitting is required.

PANELING OF ISOLATED COMPONENTS

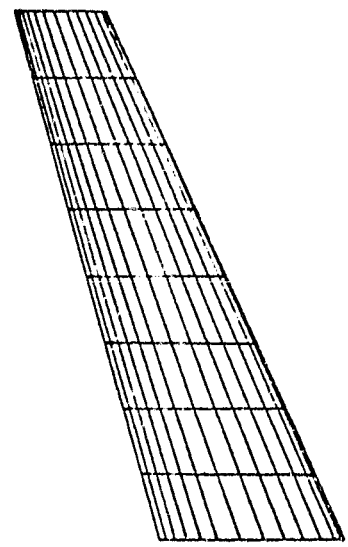
INITIAL ELEMENT DISTRIBUTION



DISTRIBUTION AFTER CHORDWISE REPANELING



DISTRIBUTION AFTER SPANWISE REPANELING



9. Interpolation Procedure for General Curves in Space

The interpolation procedure is slightly unusual. Cubic splines were initially used, but with the very sparse defining data (which generally may not have been smoothed) the waviness could get out of control. The method finally chosen can be very accurate, but it is very simple to implement and less likely than a true spline to cause problems. This is because a slight waviness introduced in one portion of a curve cannot propagate to other portions of the curve.

The independent variable of the interpolation is the straight-line arc length between the defining points (normalized by the total length of the curve). When normalized in this manner, the straight-line arc length is a very good approximation to the true arc length, which is perhaps the most general quantity that can be chosen as the independent variable. Separate calculations are performed to interpolate  $x$ ,  $y$ , and  $z$  coordinates versus arc length. In each interpolation, the first derivatives of the dependent variable ( $x$ ,  $y$ , or  $z$ ) with respect to straight-line arc length are first found by taking a weighted average of the angles of the straight-line segments. These are then used, together with the coordinate values, to determine the coefficients of cubic interpolating polynomials.

10. Comparison of Curve-Fit Methods

## INTERPOLATION PROCEDURE FOR GENERAL CURVES IN SPACE

- o THE STRAIGHT-LINE ARC LENGTH BETWEEN INPUT POINTS (NORMALIZED BY THE TOTAL LENGTH) IS THE INDEPENDENT VARIABLE.
- o SEPARATE INTERPOLATIONS ARE USED FOR (X VS. S), (Y VS. S) AND (Z VS. S).
- o PROCEDURE FOR EACH INTERPOLATION:
  - o FIND THE 1ST DERIVATIVES OF THE FUNCTION AT THE INPUT POINTS BY TAKING A WEIGHTED AVERAGE OF THE ANGLES OF THE STRAIGHT-LINE SEGMENTS.
  - o FIT A CUBIC CURVE OVER EACH SEGMENT (GIVEN 2 POINTS AND 2 FIRST DERIVATIVES ON EACH SEGMENT)
- o THIS IS NOT A TRUE SPLINE METHOD SINCE THE 2ND DERIVATIVES ARE DISCONTINUOUS.
- o RESULTS ARE CONSISTENTLY LESS WAVY THAN RESULTS OF A TRUE SPLINE METHOD (PERHAPS BECAUSE THE INDEPENDENT VARIABLE IS NOT A CONTINUOUSLY VARYING QUANTITY)

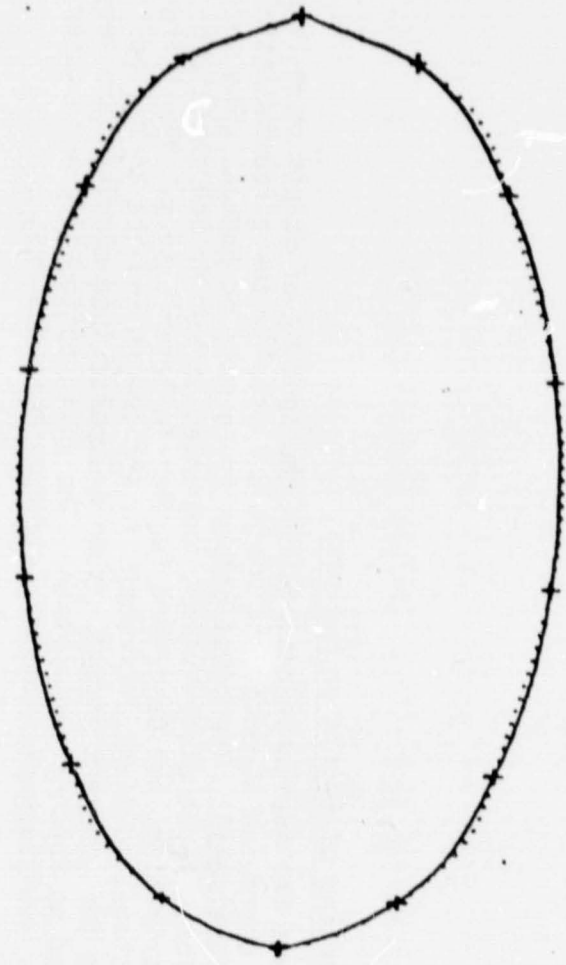
10. Comparison of Curve-Fit Methods

The reduced waviness of this interpolation procedure, compared to a spline method, can be seen in this case, interpolation on an elliptical cross section. Both methods are fairly inaccurate at the aft end of the curve (for the very sparse input data given) because no condition of periodicity has been imposed.



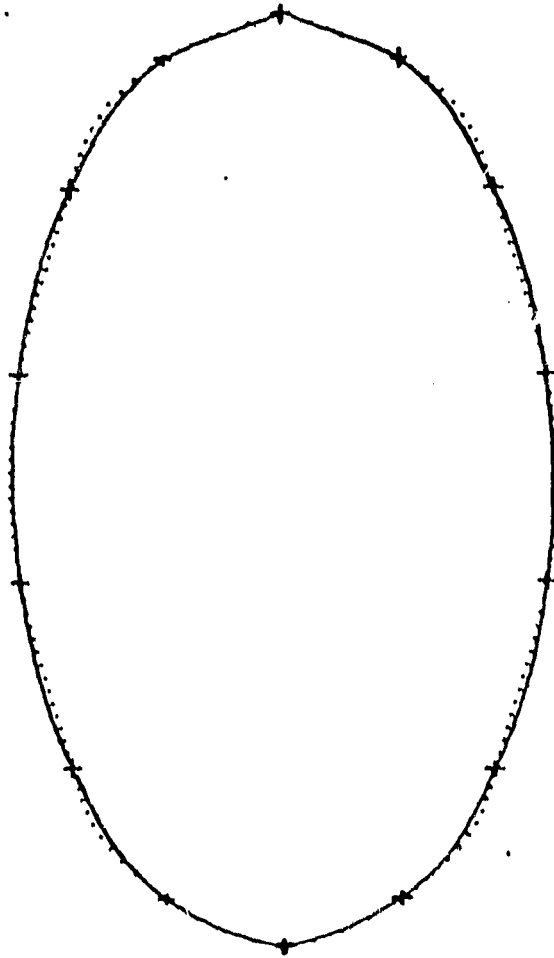
COMPARISON OF CURVE-FIT METHODS

+ INPUT POINTS  
— INTERPOLATED POINTS (PRESENT METHOD)  
• INTERPOLATED POINTS (SPLINE METHOD)



COMPARISON OF CURVE-FIT METHODS

+ INPUT POINTS  
— INTERPOLATED POINTS (PRESENT METHOD)  
• INTERPOLATED POINTS (SPLINE METHOD)



#### 11. Options for Spacing of Points on M-Lines

This slide shows the available options for the spacing of points on M-lines (i.e., in the chordwise direction on wings and usually the circumferential direction on fuselages). The first option is to make no change. The second and fifth options, input distribution, augmented in number and curvature-dependent distribution, are described further in later slides. The third and fourth options, constant increments in arc length and the so-called cosine spacing (or constant increments on a superscribed circle), are very common and need no further explanation. The sixth option allows the user to specify any arbitrary arc-length distribution he desires.

OPTIONS FOR SPACING OF POINTS ON N-LINES  
(CHORDWISE PANELING ON A WING)

1. INPUT DISTRIBUTION, UNALTERED
2. INPUT DISTRIBUTION, AUGMENTED IN NUMBER
3. CONSTANT INCREMENTS IN ARC LENGTH
4. COSINE SPACING
5. CURVATURE-DEPENDENT DISTRIBUTION
6. USER-SPECIFIED DISTRIBUTION

## 12. Curvature-Dependent Spacing Method

A method in which the point spacing is a function of the local surface curvature should be useful, since the results of the potential-flow method should vary rapidly in regions of high curvature. In this method, the spacing is linearly dependent on the absolute value of the curvature and some control over the variation of the spacing over the curve is provided. Artificial curvature is added in the generally flat trailing-edge regions on lifting sections in order to bunch points there, as required by the potential flow method. The implementation of the method requires an iterative procedure in which the arc length values are initially estimated, the curvature at the center of each segment of the curve is calculated and then used (with the specified equation) to update the estimated arc-length distribution. Convergence generally requires only three or four iterations. Examples of the method for a lifting and a nonlifting section are shown in the slide.

# CURVATURE-DEPENDENT SPACING METHOD

$$\Delta s_i = [(1 - \Delta s_{\min}/\Delta s_{\max})(1 - k_i/k_{\max}) + \Delta s_{\min}/\Delta s_{\max}] \Delta s_{\max}$$

where

$\Delta s$  = ARC LENGTH BETWEEN ADJACENT POINTS

$k$  = CURVATURE (AT ELEMENT MIDPOINT)

o WHEN  $k_i = k_{\max}$  ,  $\Delta s_i = \Delta s_{\min}$

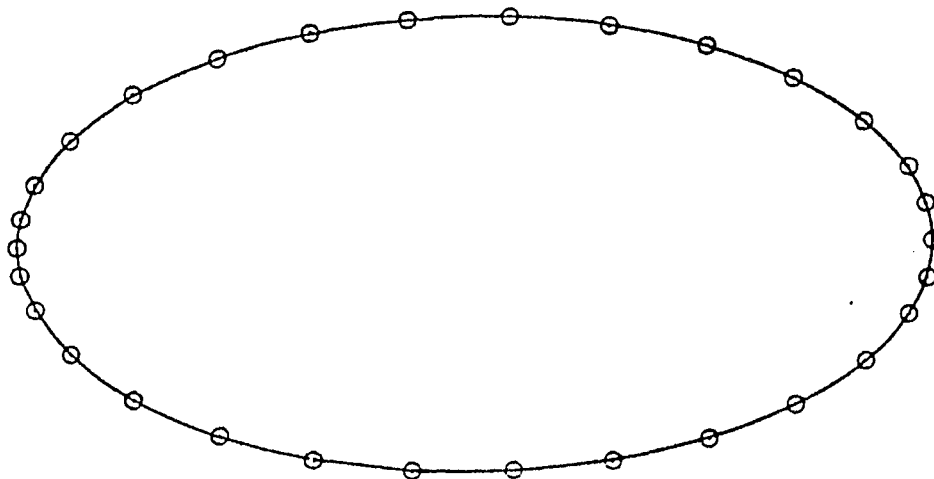
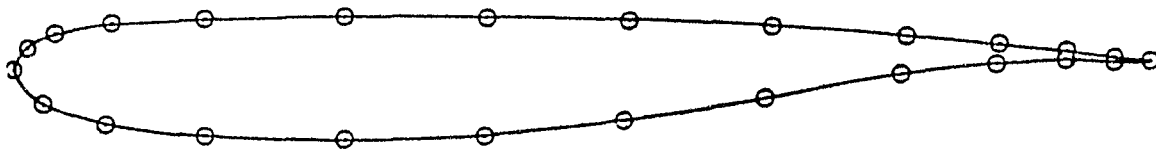
o WHEN  $k_i = 0$  ,  $\Delta s_i = \Delta s_{\max}$

o SPECIFY  $\Delta s_{\min}/\Delta s_{\max} = 0.25$

$\therefore \Delta s_i = [0.75(1 - k_i/k_{\max}) + 0.25] \Delta s_{\max}$

o SOLVE FOR  $\Delta s_i$  BY AN ITERATIVE PROCEDURE

## EXAMPLES

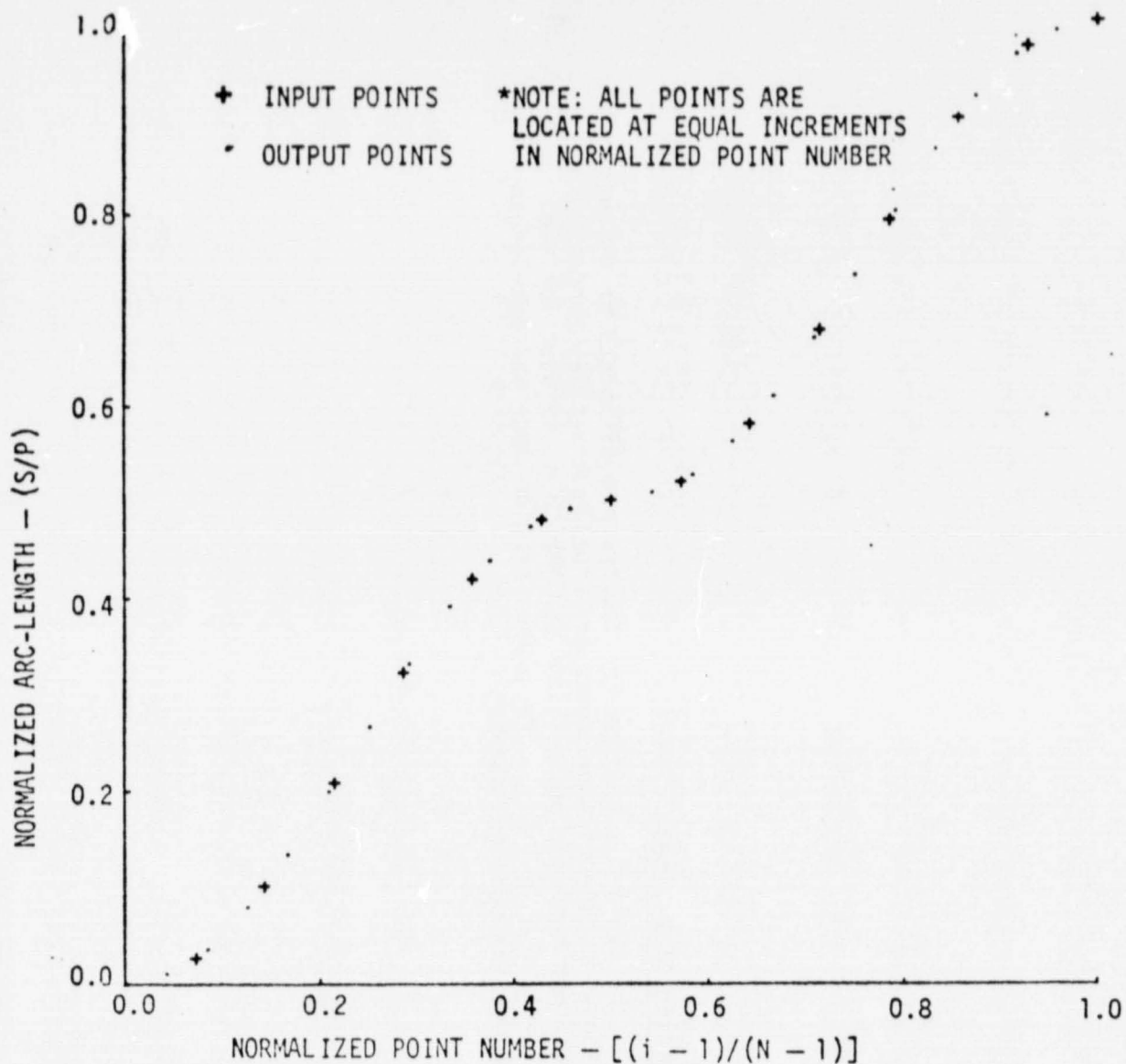


13. Method of Enriching Number of Points While Maintaining a Similar Distribution

It is impossible to provide an automatic point spacing method that will be appropriate for the large variety of cases which could be considered. This method provides a great deal of flexibility, however. The user must input properly distributed points, but he need not input an extremely large number of points.

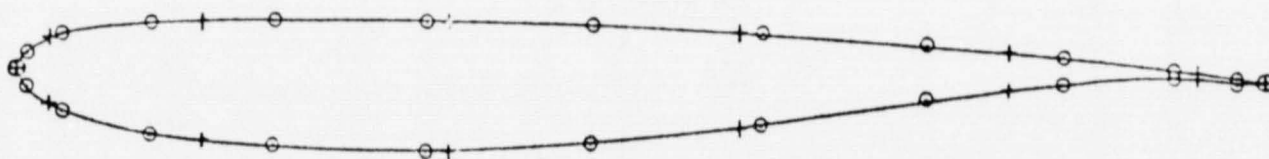
To enrich the number of points while maintaining a similar distribution to the input distribution, it is necessary to define a normalized point number (as shown) and construct a curve of arc length (at the input points) as a function of this normalized point number. Arc lengths at the output points are determined simply by interpolating on this curve to find the values corresponding to the output values of the normalized point number. An example of a section of a supercritical wing enriched from fifteen to twenty-five points is shown.

# METHOD OF ENRICHING NUMBER OF POINTS WHILE MAINTAINING A SIMILAR DISTRIBUTION



## EXAMPLE

+ INPUT POINTS (N = 15)      ⊙ OUTPUT POINTS (N = 25)





14. Options for Spacing of N-Lines

This slide shows the available options for the spacing of points on N-lines (i.e., in the spanwise direction on wings and usually the axial direction on fuselages). The four numbered options are similar to those used for the distribution of points on N-lines. The planar-section mode and arc-length mode require more explanation, however.

OPTIONS FOR SPACING OF N-LINES  
(SPANWISE PANELING ON A WING)

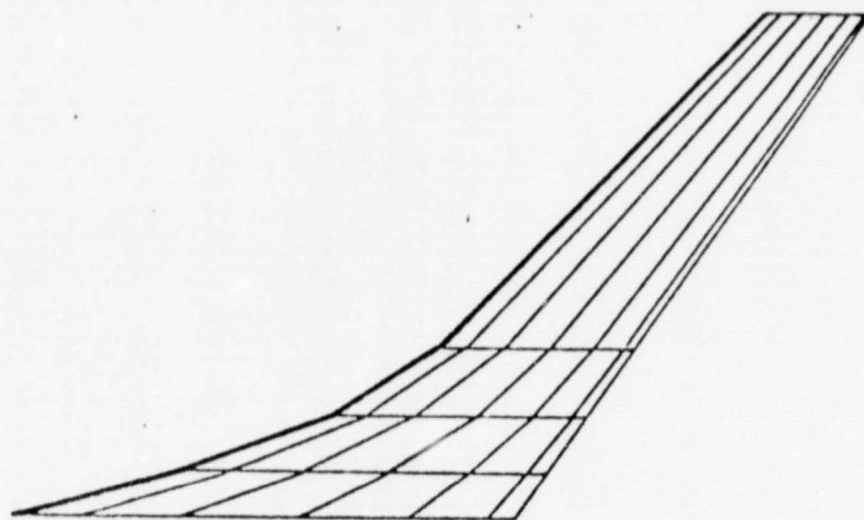
1. INPUT DISTRIBUTION, UNALTERED
  - 2.. INPUT DISTRIBUTION, AUGMENTED IN NUMBER
  3. CONSTANT INCREMENTS
  4. USER-SPECIFIED DISTRIBUTION
- 
- A. PLANAR-SECTION MODE
  - B. ARC-LENGTH MODE

15. Spanwise Redistribution of Elements on a Supercritical Wing

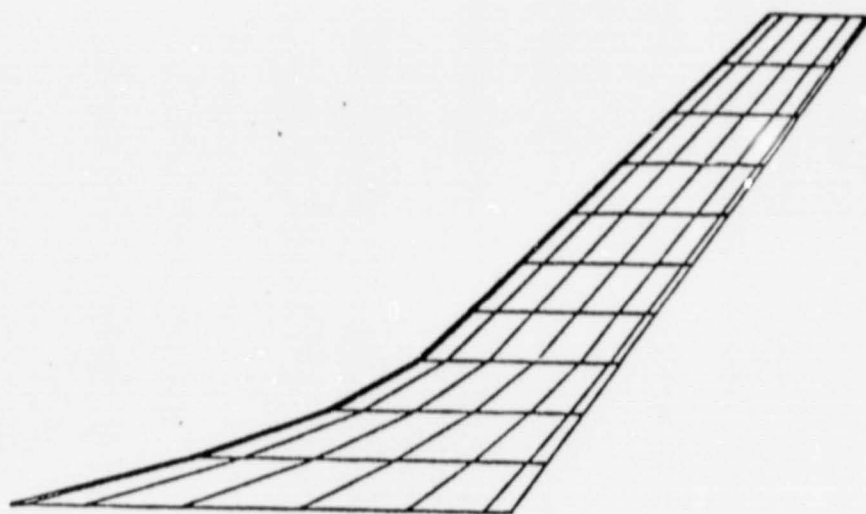
N-lines on this wing have been distributed using the planar-section mode of operation. In this mode, points on all N-lines, except possibly the first and last N-lines, lie in parallel planes. The specified distribution parameters refer to distances between the planes, rather than to arc lengths. This option is important for lifting components, such as wings, since the potential-flow program requires elements on lifting components to be trapezoidal. (Elements on nonlifting components, such as fuselages, may be more general quadrilaterals.)

16. Comparison of Planar-Section and Arc-Length Modes of Distribution

SPANWISE REDISTRIBUTION OF ELEMENTS ON  
A SUPERCritical WING



INITIAL ELEMENT  
DISTRIBUTION

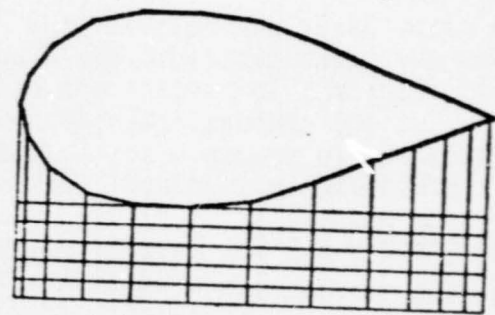


ELEMENT DISTRIBUTION  
AFTER REPANELING

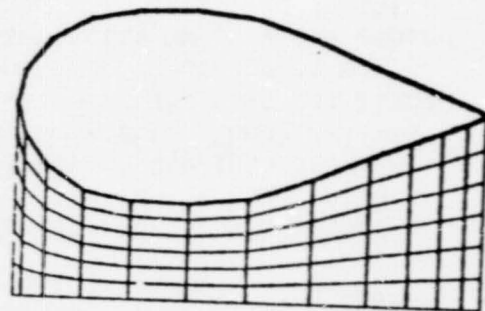
16. Comparison of Planar-Section and Arc-Length Modes of Distribution of N-Lines

In some cases, such as this strut on a thick wing, planar distributions of N-lines leave undesirable sparse areas. This is prevented by use of the arc-length mode of distributing N-lines. In this mode, the specified distribution parameters are the arc lengths along the M-lines and the distribution procedure is identical to the procedure for distributing points on N-lines.

COMPARISON OF PLANAR-SECTION AND ARC-LENGTH MODES  
OF DISTRIBUTION OF N-LINES -  
STRUT ON A THICK WING



(a) Planar-Section Mode.

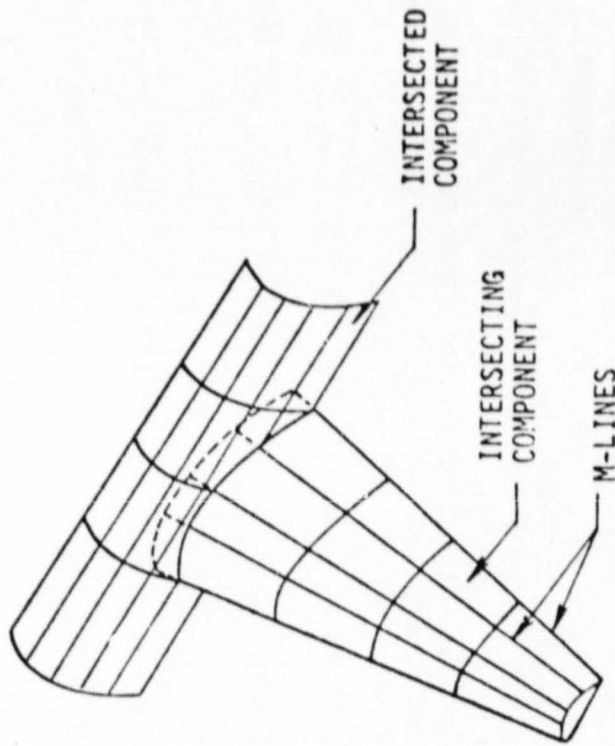


(b) Arc-Length Mode.

17. Assumptions of the Intersection Method

Having paneled the components as isolated bodies, the next step performed by the geometry package is the calculation of the curves of intersection (if any). This is not an absolutely general method, but the assumptions made are not too restrictive for the typical cases encountered in aerodynamic applications. First, it is assumed that a distinction can be made between intersecting and intersected components. The M-lines of the intersecting component pierce the elements of the intersected component. These M-lines must extend completely through the intersected component and must not blend in tangent to the surface of the intersected component. A component may intersect only one other component and may be intersected by only one other component. Intersecting and intersected components are identified in the input data.

# ASSUMPTIONS OF THE INTERSECTION METHOD



1. INTERSECTING AND INTERSECTED COMPONENTS CAN BE DISTINGUISHED.
2. EACH M-LINE ON THE INTERSECTING COMPONENT PIERCES AN ELEMENT OF THE INTERSECTED COMPONENT
  - (A) NOT TANGENT
  - (B) EXTENDS COMPLETELY INSIDE THE COMPONENT
3. EACH COMPONENT INTERSECTS ONLY ONE COMPONENT.
4. EACH COMPONENT IS INTERSECTED BY ONLY ONE COMPONENT.



#### 18. Steps in Calculating Intersection Curve

An intersection curve is defined as a series of intersection points between the M-lines on the intersecting component and the surface of the intersected component. For each M-line a search is conducted to determine which segment of the M-line intersects which element of the intersected component. For the purposes of this search, each element is represented by two triangular planes, but each M-line segment is assumed to be curved. When the intersected element is found, its geometric data is used to determine its parametric cubic patch coefficients. These are not stored permanently because of the large amount of redundancy in storing P.C. coefficients of patches with common boundaries. The final calculation of the intersection point requires the solution of three simultaneous nonlinear equations and is described in the next slide.

## STEPS IN CALCULATING INTERSECTION CURVE

FOR EACH INTERSECTING M-LINE:

1. SEARCH FOR THE INTERSECTED ELEMENT
2. FIND APPROXIMATE INTERSECTION POINT  
(ASSUMING PLANAR ELEMENTS)
3. FIND P.C. PATCH COEFFICIENTS OF ELEMENT
4. CALCULATE MORE PRECISE INTERSECTION  
POINT

19. Intersection of a Cubic Curve and a Parametric Cubic Surface

Knowledge of the P.C. patch coefficients of an element allows the equation of the surface to be written in terms of the parametric variables,  $u$  and  $w$ , as shown in this slide (equations for  $y$  and  $z$  coordinates are of exactly the same form as the equation shown for the  $x$  coordinates). Equations for the  $x, y,$  and  $z$  coordinates of points on the cubic curve are also known. Equating coordinate values on the curve and on the surface gives three nonlinear equations for the three unknowns ( $u, w,$  and  $s$ ). Solution by Newton's method, starting from an approximate solution obtained in the searching operation, generally converges in less than about six iterations.

# INTERSECTION OF A CUBIC CURVE AND A PARAMETRIC CUBIC SURFACE

- o REPRESENTATION OF SURFACE:

$$\begin{aligned}
 x_s = & w^3(A_x u^3 + B_x u^2 + C_x u + D_x) \\
 & + w^2(E_x u^3 + F_x u^2 + G_x u + H_x) \\
 & + w(I_x u^3 + J_x u^2 + K_x u + L_x) \\
 & + (M_x u^3 + N_x u^2 + O_x u + P_x)
 \end{aligned}$$

(AND SIMILAR EXPRESSIONS FOR Y AND Z COORDINATES)

- o REPRESENTATION OF CURVE:

$$x_c = Q_x s^3 + R_x s^2 + S_x s + T_x$$

- o 3 EQUATIONS:

$$x_s - x_c = 0$$

$$y_s - y_c = 0$$

$$z_s - z_c = 0$$

- o 3 UNKNOWNNS:

$$(u, w, s)$$

- o SOLVE BY NEWTON'S METHOD

20. Illustration of Intersection Method

Various analytic cases (involving spheres, cones, cylinders, and ellipsoids) have been used to verify the accuracy of the intersection method. Various cases involving realistic aircraft components have also been calculated. Few of these cases have sufficient character to be interesting to view graphically. A less realistic case that does have more character is, therefore, shown in this slide.

21. Use of the Geometry Package for a Wing-Fuselage Configuration

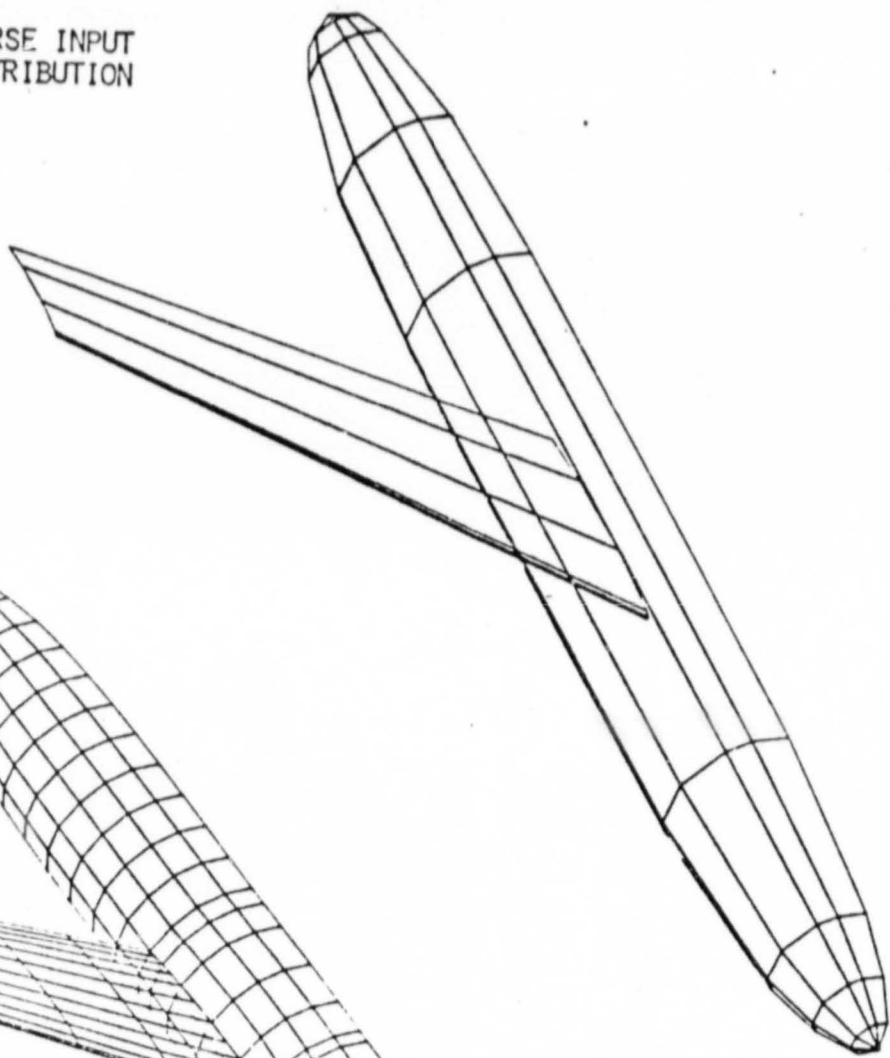
After calculating the intersection curves, some repaneling takes place. Various options for different sorts of cases are provided. In the interest of brevity, only the wing-fuselage case, perhaps the most common application of the geometry package, will be described. Most of the calculations in this portion of the method involve procedures very similar to those already described (for example, interpolating along curves or the intersection of curves and planes).

First, the intersection curve between the wing and the fuselage is made an N-line on the wing and all N-lines outboard of this are shifted to maintain a smooth distribution of N-lines. The area of the wing inside the fuselage becomes a single strip which functions as a means of making the vorticity continuous between left and right wings. Planar N-lines on the fuselage are passed through the leading and trailing-edge points on the intersection curve and both N- and M-lines are shifted on the forward and the after portions of the fuselage in order to maintain smooth point distributions. N-lines on the fuselage are passed through points on the intersection curve (either through every point or every other point) and then points on these N-lines are redistributed to provide a smooth distribution. The area covered by the wing is not paneled. This final repaneling breaks up a fuselage (assumed here to initially consist of only one component) into four components - one forward, one aft, one above, and one below the wing.

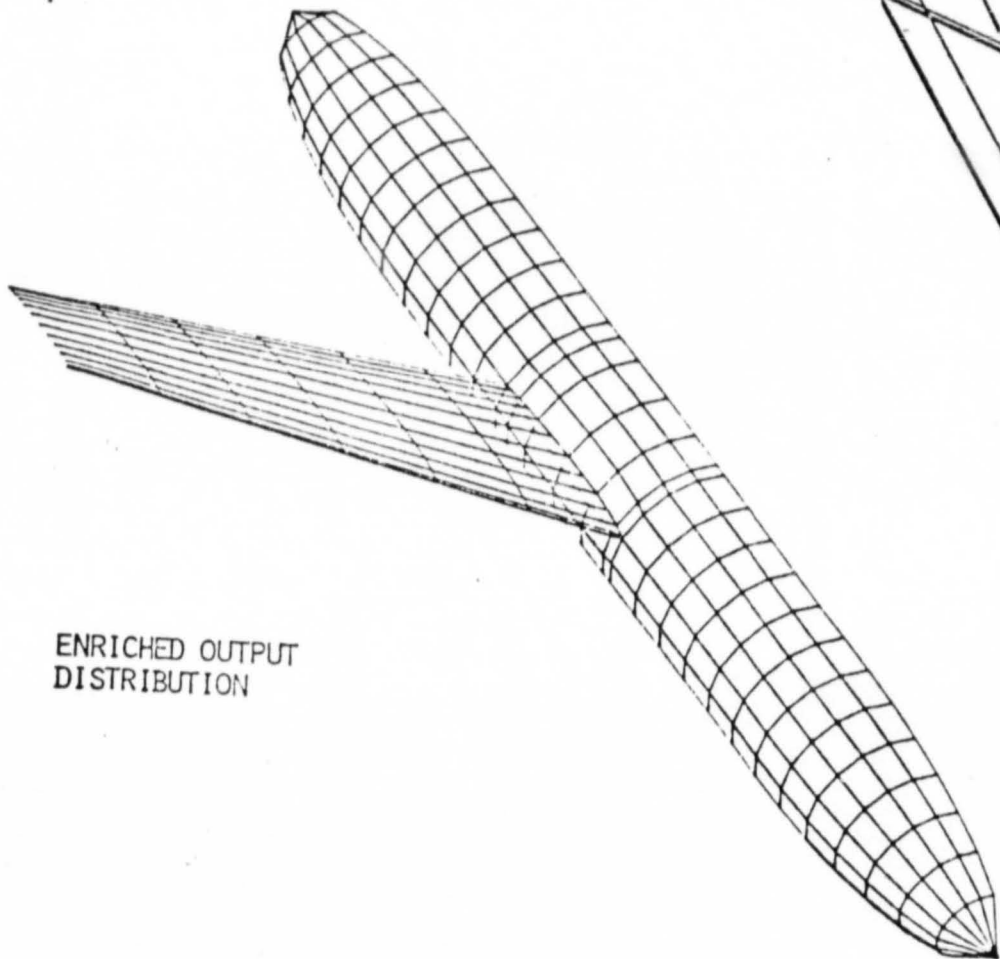
*HALSEY 21*

# USE OF THE GEOMETRY PACKAGE FOR WING-FUSELAGE CONFIGURATION

SPARSE INPUT  
DISTRIBUTION



ENRICHED OUTPUT  
DISTRIBUTION



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PANEL 2: METHODS

1. What are the unsolved (or not reported in the literature) mathematical problems:
  - (a) Intersections and blending of arbitrary splined surfaces?
  - (b) Filleting with arbitrary radius?
  - (c) Design/specification of surface from known aerodynamic solutions or pressure distributions?
2. Which method of surface representation are most conservative of computer storage and processing power?
3. Can we list the advantages and disadvantages of each method? There are several byproducts inherent in each approach. Can we summarize these?
4. Will "connectivity tables" that represent the relative location of various aircraft components become cumbersome?



DISCUSSION VUGRAPH 1.

This paper discusses an analytical method for computing a body fitted coordinate system for an arbitrary three-dimensional flow field. This research has been carried out at General Dynamics, Fort Worth Division under a continuing NASA/Ames Contract to extend General Dynamics 2-D/axisymmetric finite-difference flow field computation procedure to three dimensions.

A BODY ORIENTED MESH-GENERATION  
TECHNIQUE FOR 3-D FLOW FIELDS

BY

Ishwar C. Bhateley  
&  
Leroy L. Presley

PRESENTED AT

- 1) AIAA 6TH Minisposium, Arlington, Texas 25 February 1978
- 2) NASA Workshop on Aircraft Surface Representation for Aerodynamic Computation, March 1-2, 1978

BHATELEY - 3

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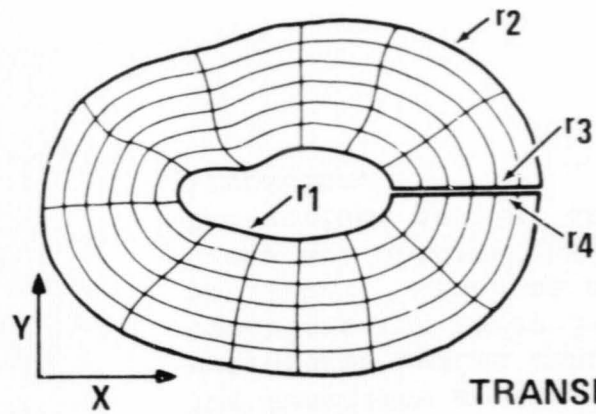
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## DISCUSSION VUGRAPH 2.

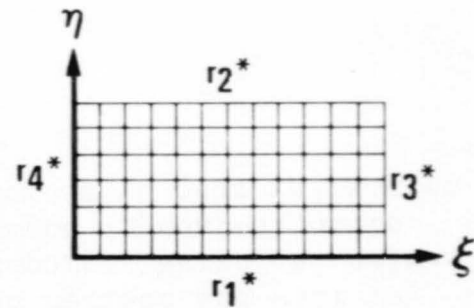
Extensive research has been done in developing two-dimensional body-fitted coordinate systems at Mississippi State University and the University of Cincinnati. Two transformation techniques for mapping an arbitrary doubly connected region into a rectangle are shown in this slide. In the first technique the inner and outer boundaries of the doubly connected region map into two opposite boundaries of the rectangular region. An arbitrary curve connecting the two boundaries in the physical plane maps into the other two sides of the rectangle in the transformed plane. In the second technique the inner boundary is mapped into a horizontal or vertical slit in the transformed plane, while the exterior boundary is broken into four arcs each of which maps into a side of the rectangle in the physical plane. The Laplace equations are used as the transformation functions. The functions on the right-hand side of the equations can be chosen such as to provide desired coordinate system control.

# TWO DIMENSIONAL METHODS FOR GENERATION OF BODY FITTED COORDINATES

PHYSICAL PLANE



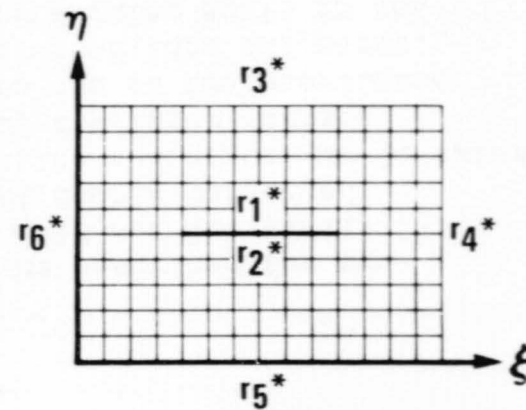
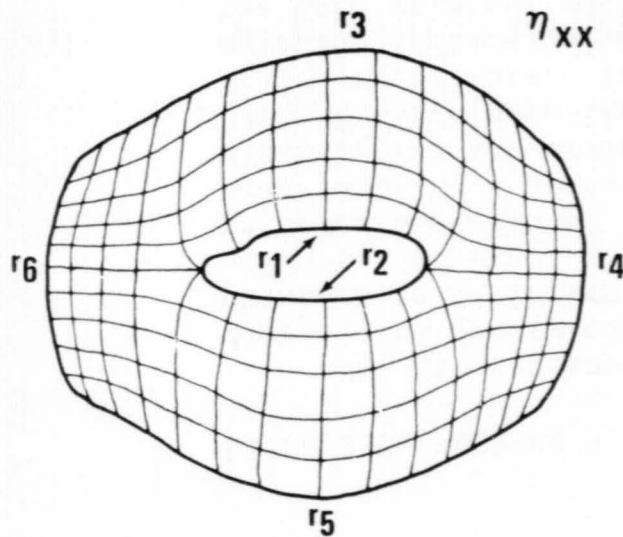
TRANSFORMED PLANE



TRANSFORMATION FUNCTION

$$\xi_{XX} + \xi_{YY} = P(\xi, \eta)$$

$$\eta_{XX} + \eta_{YY} = Q(\xi, \eta)$$



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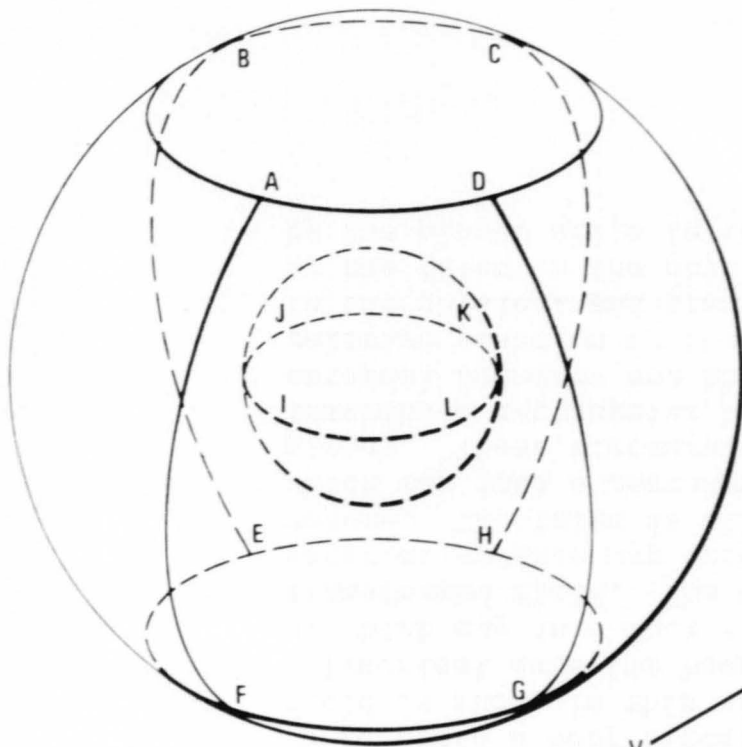
BHATELEY 2

### DISCUSSION VUGRAPH 3.

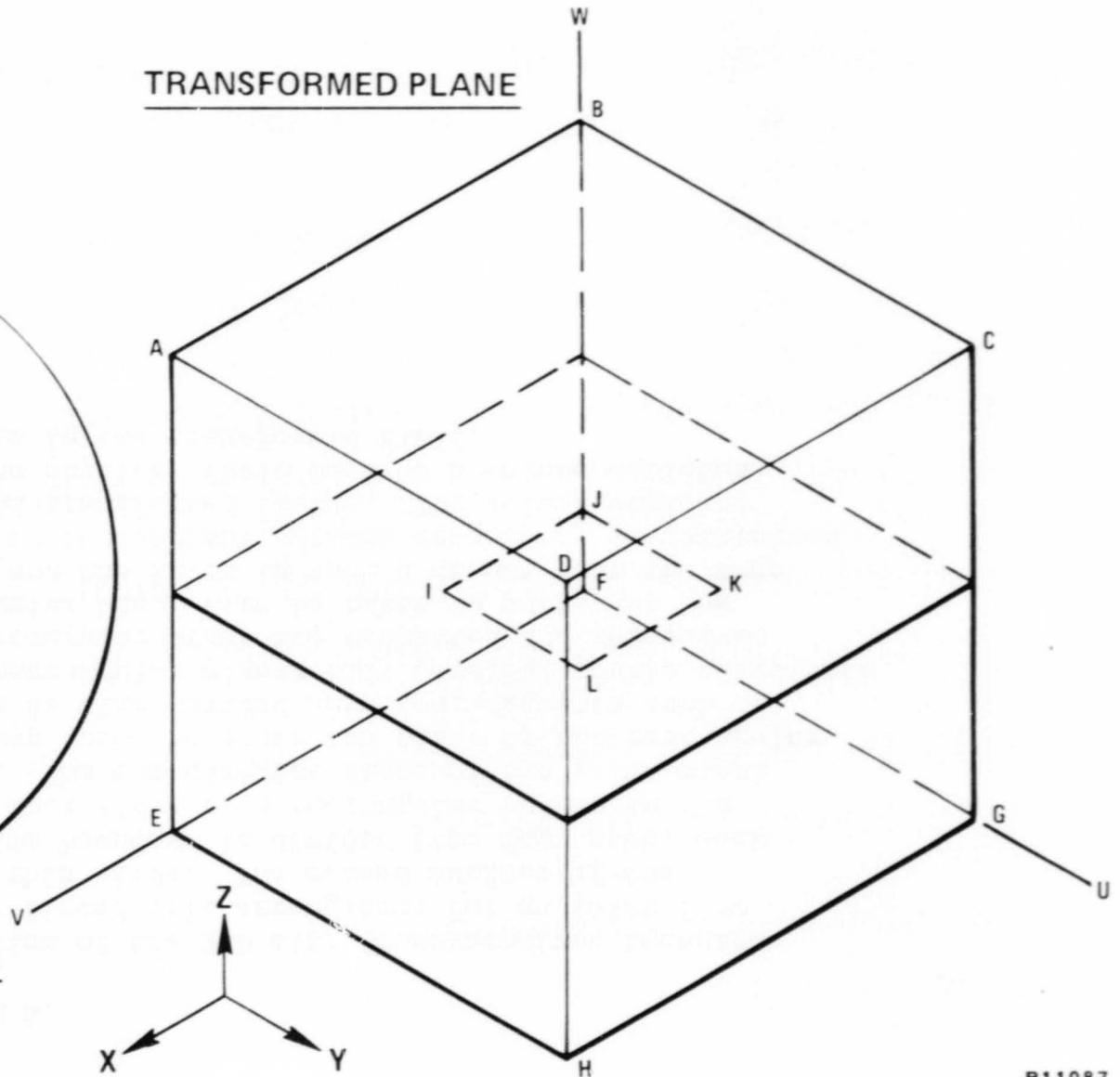
The first transformation technique described for two-dimensional doubly connected regions could not be readily extended to arbitrary three-dimensional doubly connected volumes. However, the slit transformation technique can be extended to three dimensions. In this approach, the inner surface transforms to a planar slit parallel to one of the coordinate planes, while the exterior surface is divided into six parts, each of which maps into a side of a rectangular solid in the transformed field. It is important that each part of the exterior surface and interior surface be approximately in the same relative position in the transformed plane as in the physical plane to obtain reasonable cell distribution. Again, the Laplace equations are used as transformation functions. The functions on the right-hand side can be used to provide coordinate system control. The inverse transformation equations for three 3-D flows have been derived and will be published soon as the contractors report. Numerical solutions are obtained using finite-difference approximation to the various partial derivatives and successive over relaxation iteration.

# THREE DIMENSIONAL SLIT TECHNIQUE FOR GENERATION OF BODY FITTED COORDINATES

PHYSICAL PLANE



TRANSFORMED PLANE



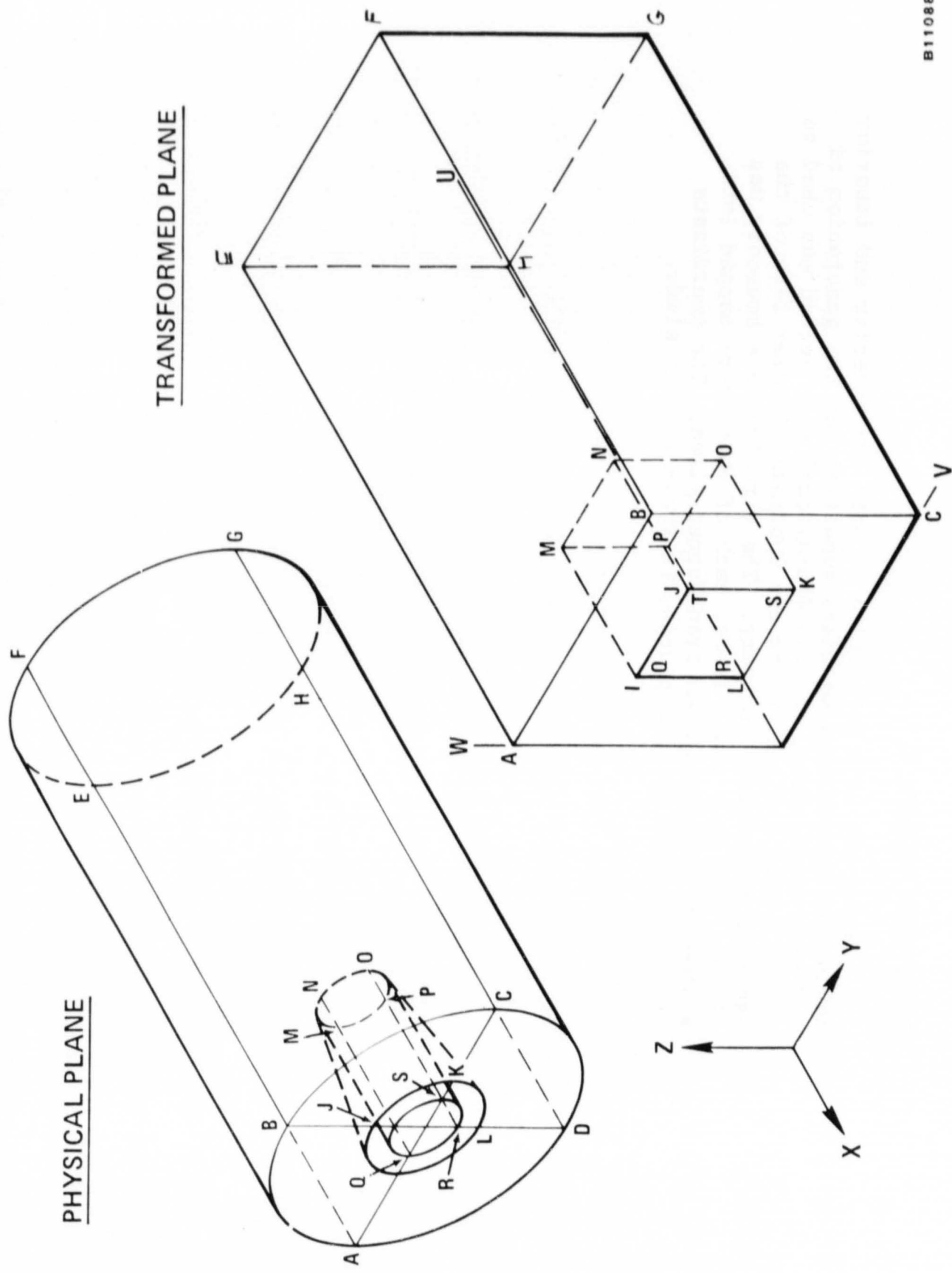
TRANSFORMATION FUNCTIONS

$$\begin{aligned}
 U_{XX} + U_{YY} + U_{ZZ} &= P(u,v,w) \\
 V_{XX} + V_{YY} + V_{ZZ} &= Q(u,v,w) \\
 W_{XX} + W_{YY} + W_{ZZ} &= R(u,v,w)
 \end{aligned}$$

#### DISCUSSION VUGRAPH 4.

The application of the 3-D slit transformation technique to generate a body fitted cell arrangement for an inlet flow field is shown in this slide. The curved surface of the cylindrical exterior boundary is divided into four parts each of which map into four sides of a rectangular volume in the transformed field. The two circular faces of the cylindrical exterior surface map into the other two sides of the rectangular volume. The inlet is also divided into four segments each of which map into a rectangular planar slit parallel to the coordinate planes. These rectangular areas are connected and themselves describe a rectangular box. Care is taken to partition the external boundary and the inlet in such a manner that the same relative position of the various surface components is maintained in the physical and transformed fields. The volume enclosed by the inlet in the physical field maps to a volume enclosed by the planar slits in the transformed field.

# SLIT TRANSFORMATION TECHNIQUE FOR INLET FLOW FIELD



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DISCUSSION VUGRAPH 5.

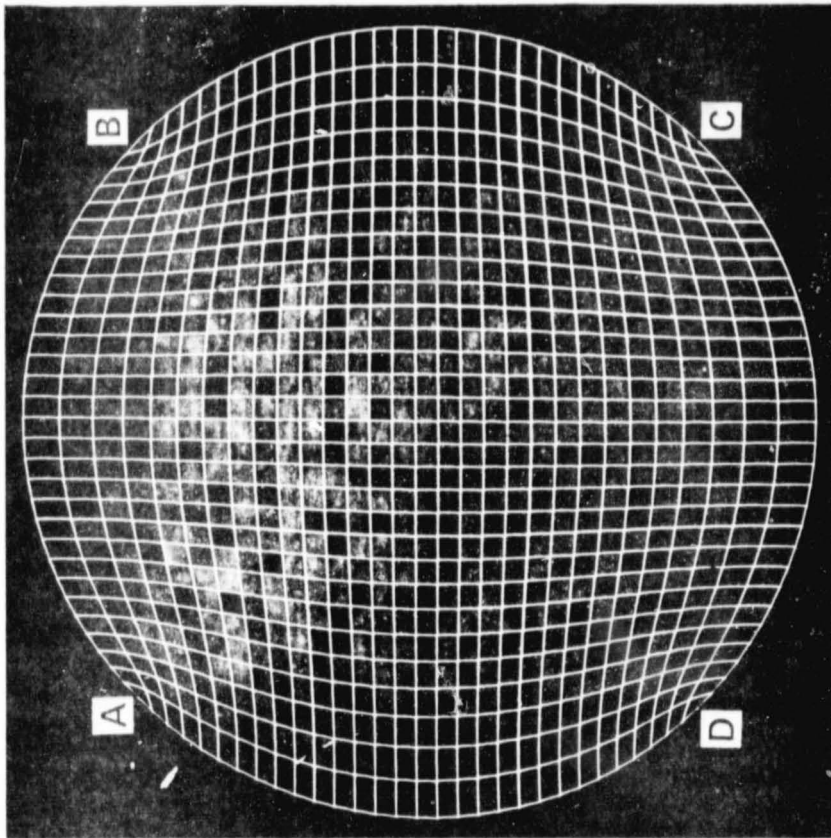
Since the cell definition on both the exterior and interior boundaries serves as a boundary condition for the generation of 3-D mesh arrangement, the two-dimensional slit method was used to obtain a cell definition for the upstream circular face of the exterior cylindrical boundary. The circular face boundary was divided into four equal areas, each of which were mapped into a side of a square in the transformed plane. The coordinate system obtained by this process is shown in this slide.



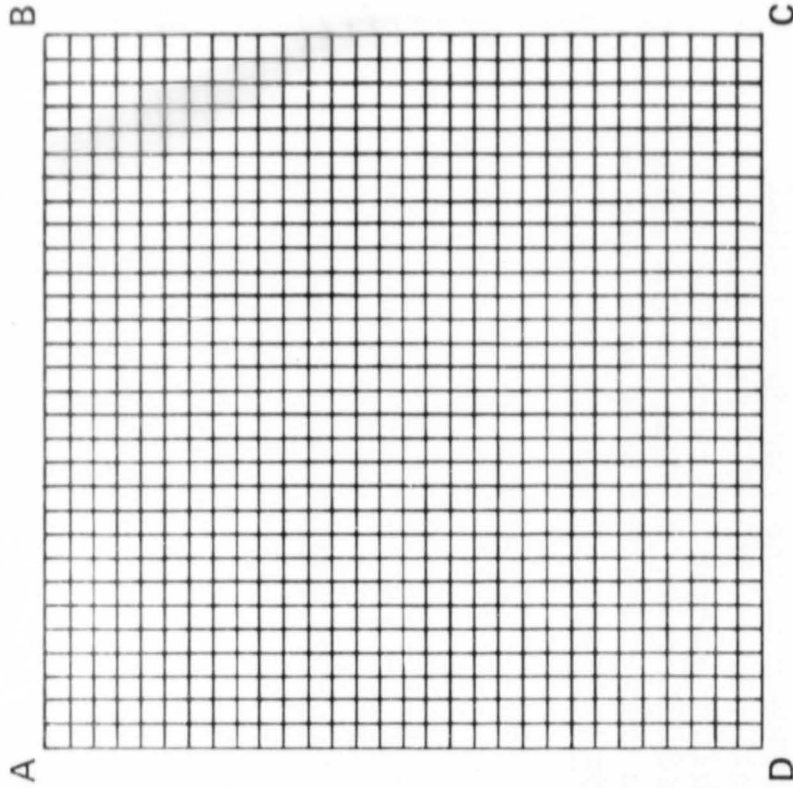
# STARTING SOLUTION FOR INLET FLOW FIELD UPSTREAM FACE

2-D SLIT TRANSFORMATION TECHNIQUE

PHYSICAL PLANE



TRANSFORMED PLANE



BHATELEY



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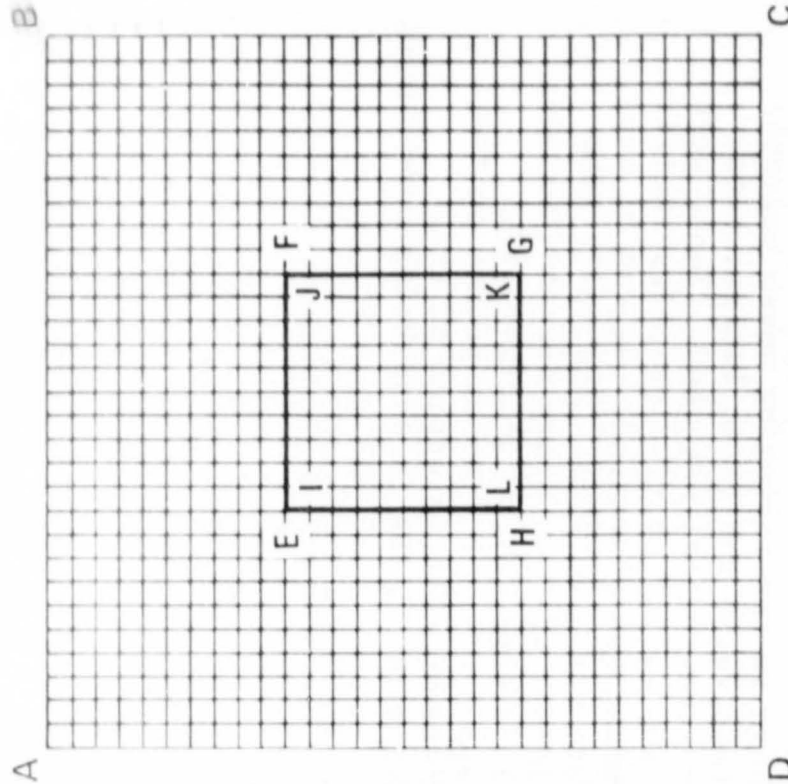
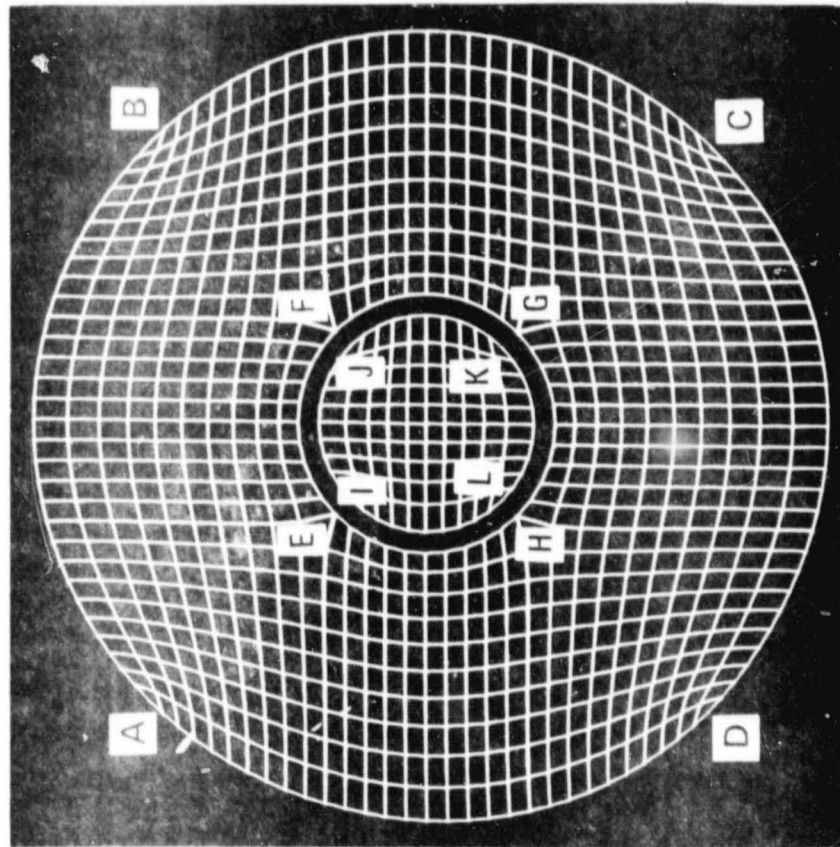
5

DISCUSSION VUGRAPH 6.

The starting solution on the downstream face of the exterior volume is also generated using the two-dimensional slit transformation technique. The circular exterior boundary is mapped into four sides of a square in the transformed plane. The annular inlet cross-sectional area is divided into four parts each of which map into four connected slits parallel to the coordinate axis forming an embedded square as shown in the slide. The resulting solution shown in this slide was used as a starting solution for 3-D cell generation program.

# STARTING SOLUTION FOR INLET FLOW FIELD DOWNSTREAM FACE

2-D SLIT TRANSFORMATION TECHNIQUE



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6

DISCUSSION VUGRAPHS 7 THROUGH 13.

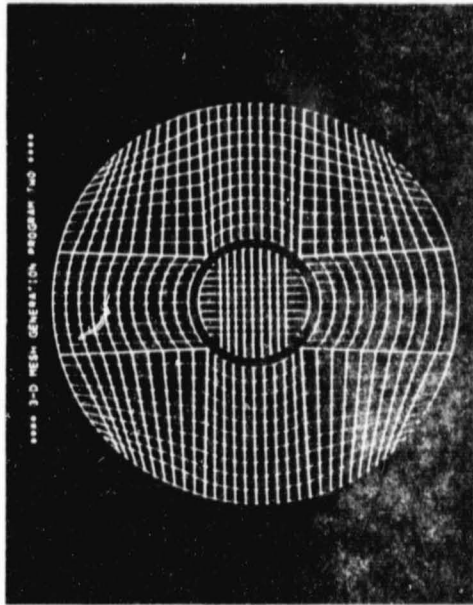
7

Typical starting intermediate and converged solutions for the 3-D circular-symmetric inlet flow field using the method discussed previously are shown in the following seven vugraphs. Cell arrangement for four transverse and three lateral cuts are shown. No coordinate system control was used. These solutions were generated using the GD interactive graphics facility. A 47 x 31 x 31 mesh arrangement was generated. As can be seen, a satisfactory cell structure was generated. The cells from one cut to the next were blended with no sharp discontinuities. Methods to improve the cell arrangement by incorporating coordinate system control and redistribution of points on the boundaries is being investigated. The extension of this technique to generalized 3-D flow fields is also being undertaken.

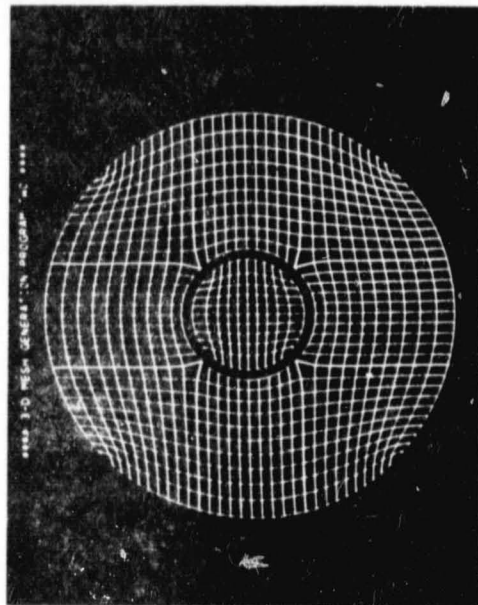
# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

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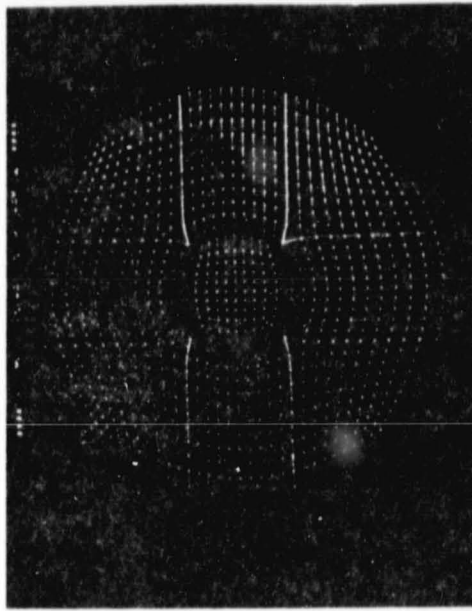
YF PLATE CUT NO. 1



Starting solution



Converged Solution (30 iterations)

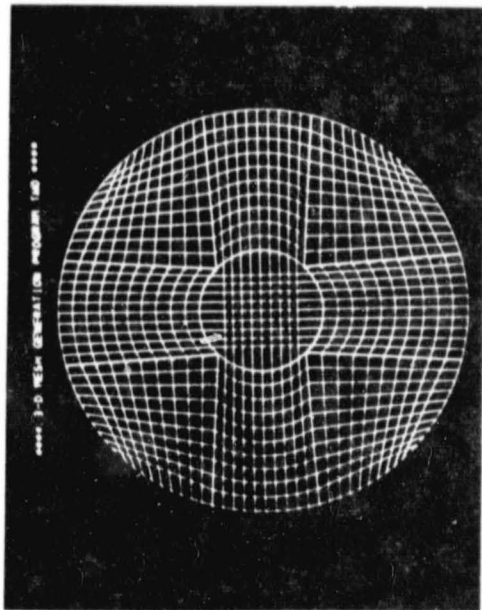


Intermediate solution (15 iterations)

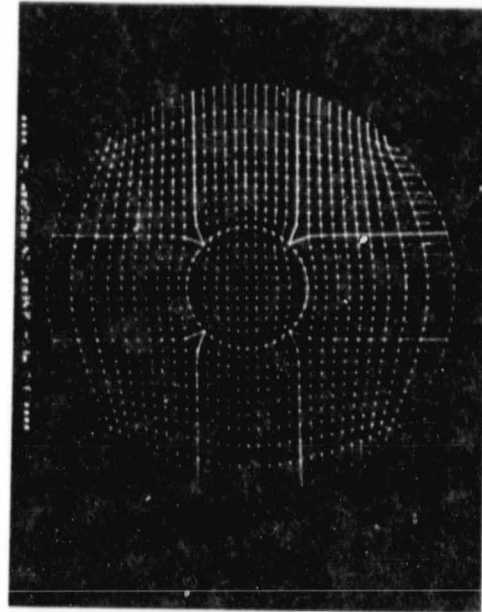
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# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

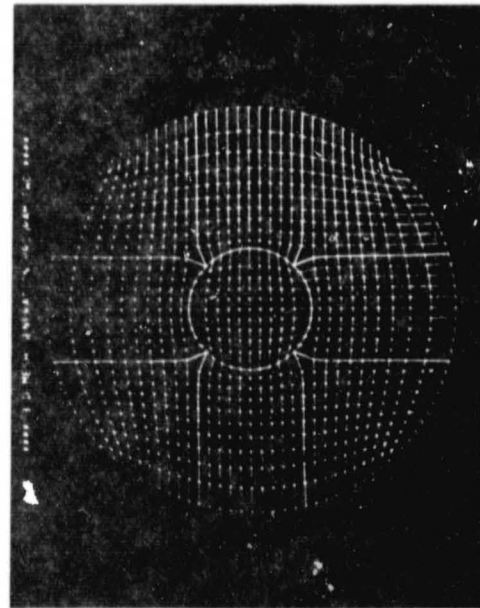
YZ PLANE CUT NO. 24



Starting Solution



Intermediate Solution (15 iterations)



Converged Solution (30 iterations)

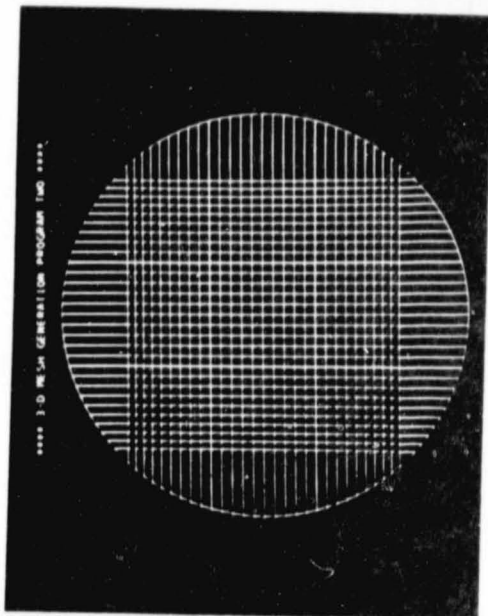
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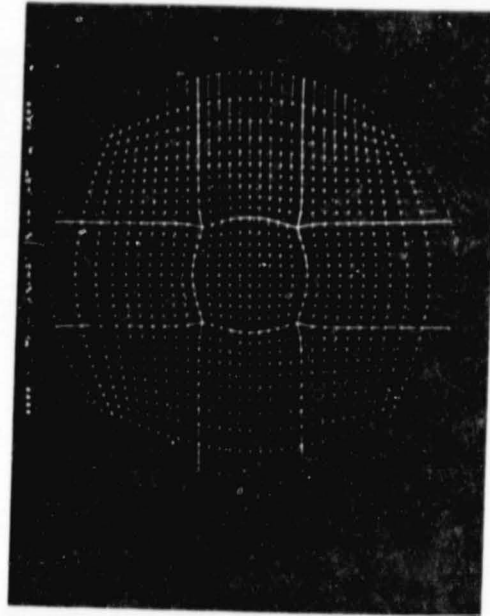
168

# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

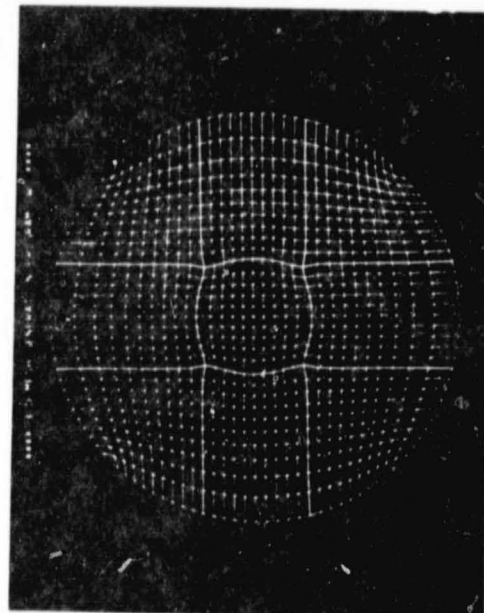
YZ PLANE CUT 20. 25



Starting Solution



Intermediate Solution (15 iterations)



Converged Solution (30 iterations)

Figure 9 Continued

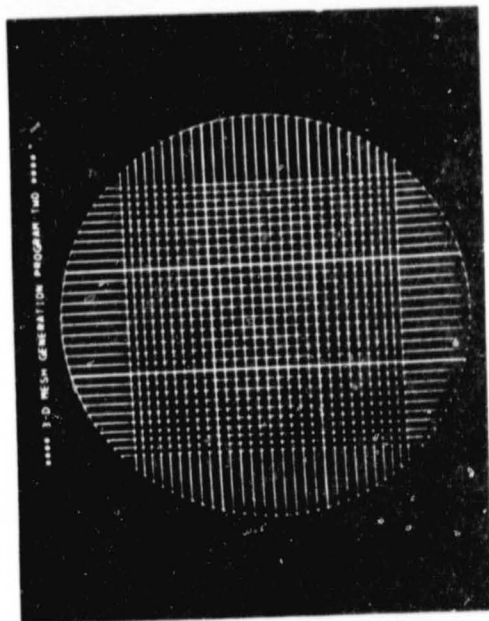
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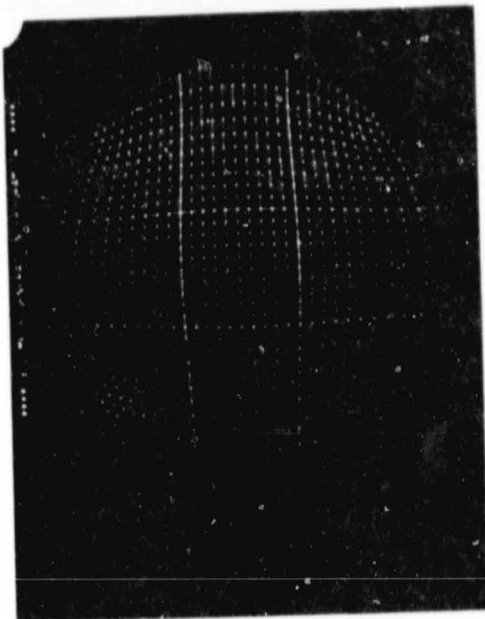


# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

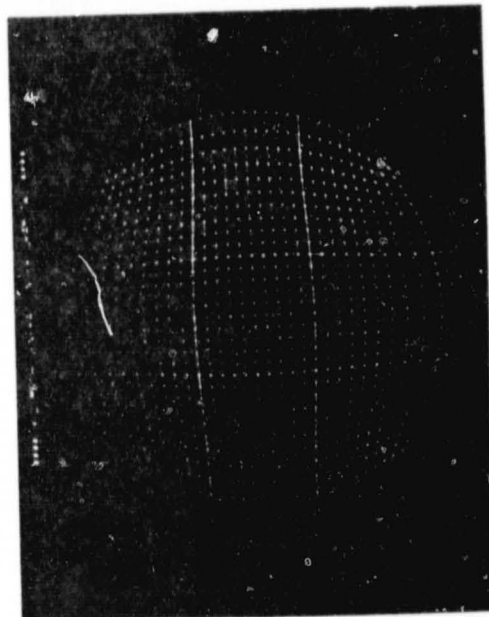
YZ PLANE CUT 30, 46



Starting Solution



Intermediate Solution (15 iterations)

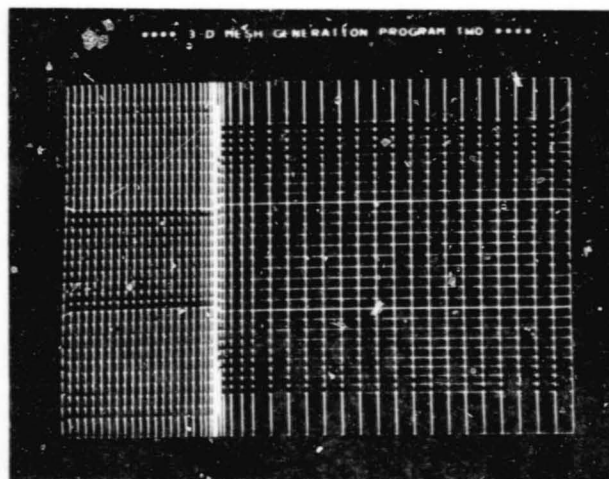


Converged Solution (30 iterations)

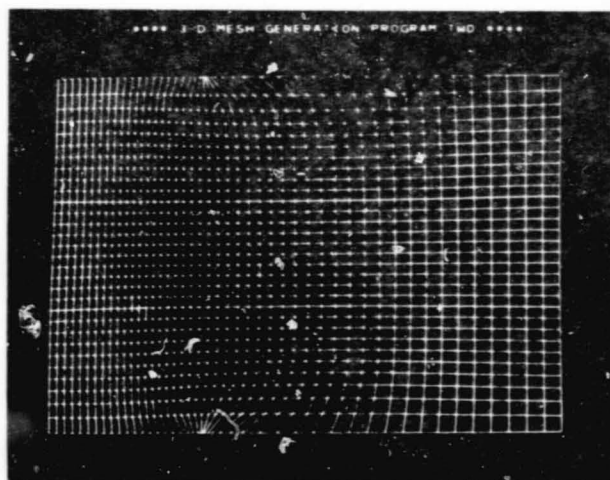
Figure 9 Continued

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# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

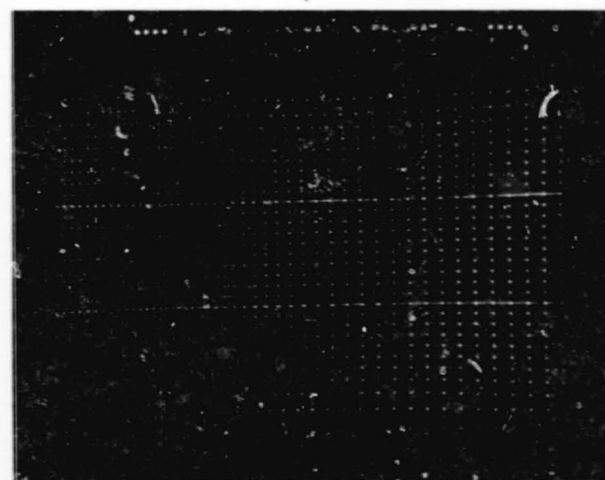


Starting Solution



Converged Solution (30 iterations)

XY PLANE CUT NO. 6



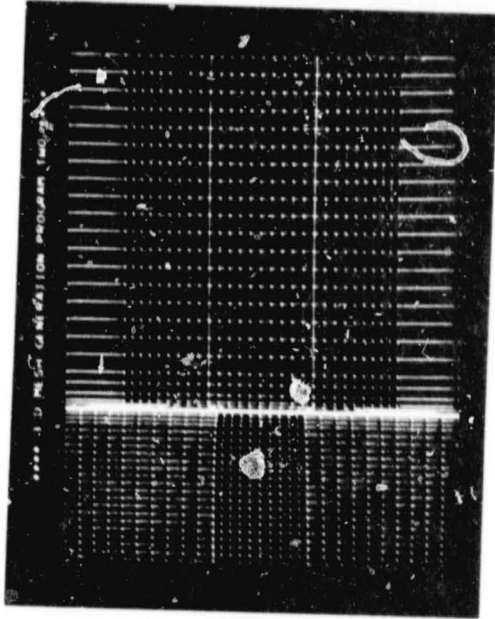
Intermediate Solution (15 iterations)

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# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

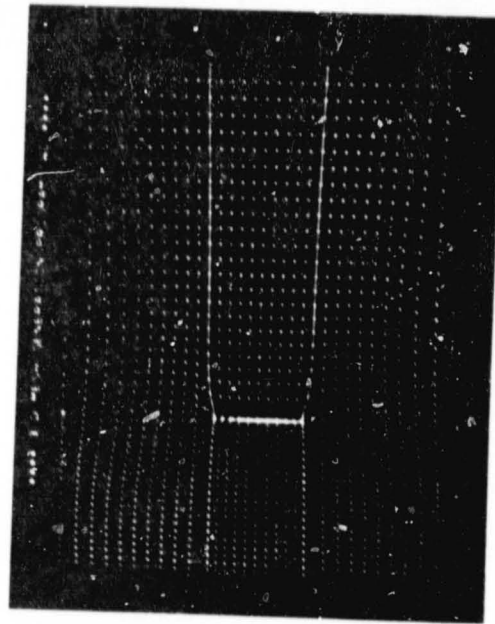
XY PLANE CUT NO. 11



Starting Solution



Intermediate Solution (15 iterations)

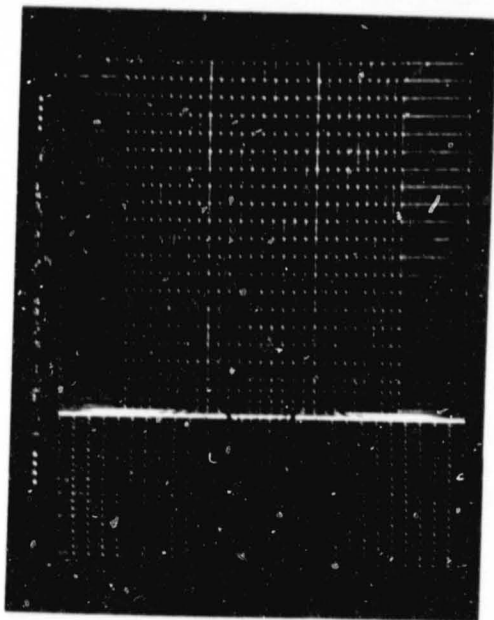


Converged Solution (30 iterations)

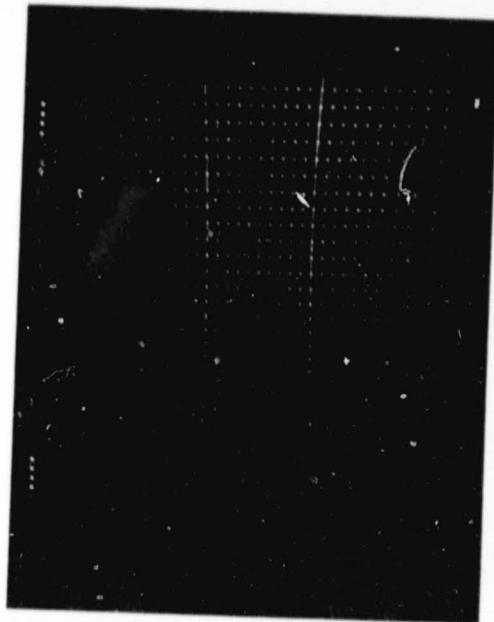
B11096

# COMPUTED MESH GEOMETRY FOR SYMMETRIC CIRCULAR INLET WITH ELLIPTIC LIP SHAPE

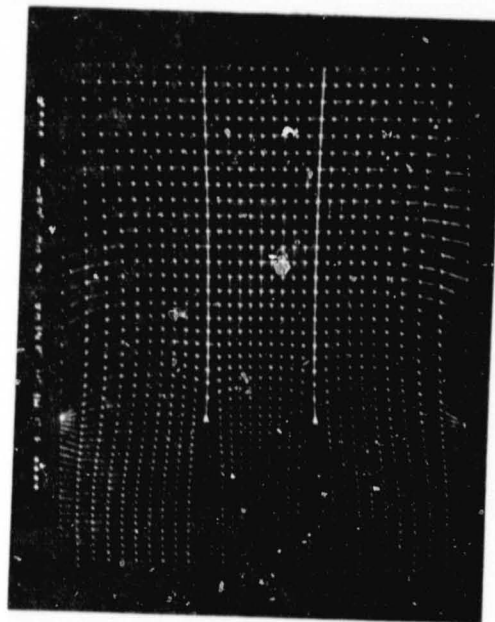
XY PLANE CUT NO. 14



Starting Solution



Intermediate Solution (15 iterations)



Converged Solution (30 iterations)

B11097

BHATELEY

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Title Page:

A primary problem in Computational Aerodynamics is obtaining flow field solutions about irregular geometries. An effective approach to this problem is to transform the governing equations and boundary conditions to a coordinate system where the problem is most easily attacked. For regular geometries there are analytical transformations which are most appropriately used, however, for the general case numerical approaches can be employed.

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RESEARCH CENTER  
WRIGHT-PATTERSON AIR FORCE BASE  
DAYTON, OHIO 45433

SMITH /

BOUNDARY FITTED CURVILINEAR COORDINATE  
SYSTEMS USING TENSION SPLINE  
FUNCTIONS

Figure 1:

Consider the physical domain for a simple two-dimensional aerodynamics problem such as the flow about an airfoil as shown at the top of this figure. Assume that it is desirable to numerically obtain the solution of the fluid flow about the airfoil using a rectangular uniform grid where the boundary of the airfoil  $\Gamma_1$  transforms to the unit interval  $s=0$  on the computational domain and the free stream boundary  $\Gamma_2$  transforms to the unit interval  $s=1$  on the computational domain. The cut in the physical domain  $\Gamma_3$  and  $\Gamma_4$  transforms to the unit intervals at  $t=0$  and  $t=1$  on the left and right sides of the computational domain. In order to solve a physical problem using the computational domain there must be a relationship between each point  $(x_i, y_i)$  in the physical domain and each point  $(t_i, s_i)$  in the computational domain. Also, the differential relation between corresponding points must be known.

SMITH 2

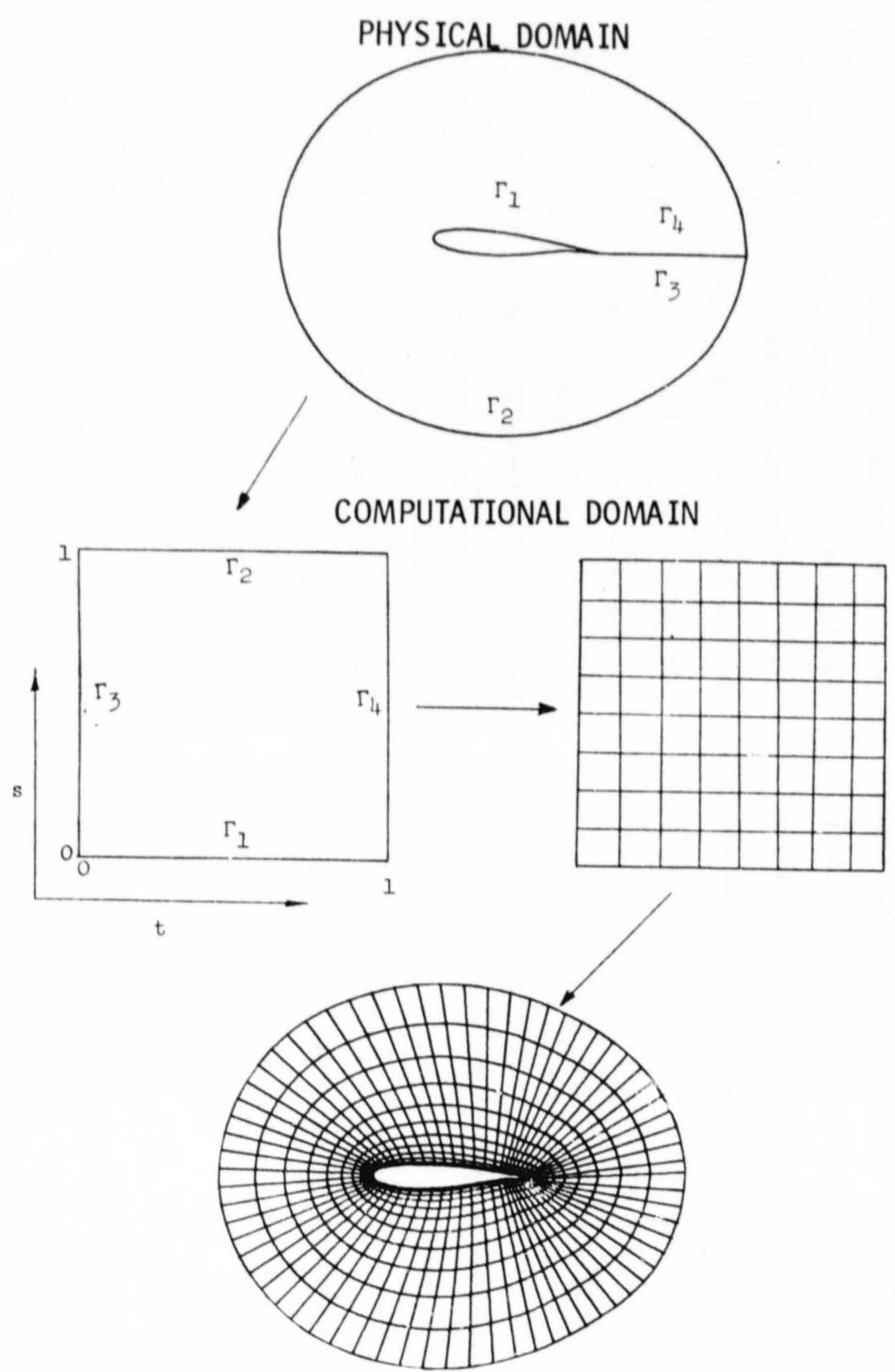


Figure 1 TRANSFORMATION DOMAINS



Figure 2:

There is a set of transformation equations relating the physical domain to the computational domain. For a doubly connected region in two-dimensions the transformation equations and boundary conditions are shown in this figure. The equations are two nonlinear coupled elliptic partial differential equations relating the computational domain to the physical domain. A technique for numerically solving this system of equations is found in reference 1. The approach is to select a set of points on each boundary which are to be connected by grid lines, choose initial guesses of all the grid points in the physical domain corresponding to grid points in the computational domain, and select forcing functions  $F$  and  $G$  that will yield the desired concentration of grid points. This is followed by the application of Successive Over-Relaxation of the discretized partial differential equations until convergence. Initial guesses to the nodes in the computational domain are necessary because of the nonlinearity, and these guesses should be relatively close to the desired converged values.

$$AX_{tt} - 2BX_{ts} + CX_{ss} = F(t, s)$$

$$AY_{tt} - 2BY_{ts} + CY_{ss} = G(t, s)$$

(1)

$$A = X_s^2 + Y_s^2$$

$$B = X_t X_s + Y_t Y_s$$

$$C = X_t^2 + Y_t^2$$

Boundary Conditions

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} f_1(t, s) \\ g_1(t, s) \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} f_2(t, s) \\ g_2(t, s) \end{bmatrix}$$

Figure 2 TRANSFORMATION EQUATIONS  
(2-D Doubly Connected Region)

Figure 3:

The approach presented herein is algebraic and is based on parametric cubic polynomial equations and tension spline approximation to the boundary data. The technique works for singly and doubly connected regions in two-dimensions and, it can be extended to three-dimensions. Since the process is algebraic, it is computationally fast and amenable to interactive computer graphics. This technique is a special case solution to the general transformation equations. The primary functions are shown in this figure. The algebraic transformation equations which relate  $t$  and  $s$  to  $x$  and  $y$  are parametric cubic polynomials in the variable  $s$  and depend on eight parameters which are functions of the variable  $t$ . (see reference 2). The parameters are position and derivatives with respect to  $s$  on the boundaries  $\Gamma_1$  and  $\Gamma_2$ . These parameters are obtained by tension spline fitting to sets of data defining  $\Gamma_1$  and  $\Gamma_2$ . The relationship between derivatives with respect to  $s$  and  $t$  is shown at the bottom of the figure. The variable  $t$  is effectively the percentage of accumulated cord length on the two boundaries.

$$X(t, s) = X(t)_1 f_1(s) + X(t)_2 f_2(s) + \frac{dX(t)}{ds} 1 f_3(s) + \frac{dX(t)}{ds} 2 f_4(s) \tag{2}$$

$$Y(t, s) = Y(t)_1 f_1(s) + Y(t)_2 f_2(s) + \frac{dY(t)}{ds} 1 f_3(s) + \frac{dY(t)}{ds} 2 f_4(s)$$

$$f_1(s) = 2s^3 - 3s + 1$$

$$f_2(s) = -2s^3 + 3s^2 \quad 0 \leq s \leq 1$$

$$f_3(s) = s^3 - 2s^2 + s$$

$$f_4(s) = s^3 - s^2$$

$$\left. \frac{dY}{dX} \right|_{\Gamma} = \frac{\left. \frac{dY}{dt} \right|_{\Gamma}}{\left. \frac{dX}{dt} \right|_{\Gamma}} = - \frac{\left. \frac{dX}{ds} \right|_{\Gamma}}{\left. \frac{dY}{ds} \right|_{\Gamma}} \Rightarrow \frac{dY}{ds} = - \frac{dX}{dt}$$

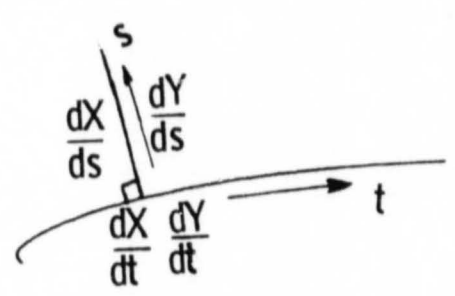


Figure 3 PARAMETRIC CUBIC TRANSFORMATION 2-D

Figure 4:

The tension spline functions are represented symbolically in this figure. The independent variable ( $\bar{t}$  or  $\hat{t}$ ) of the spline fits to the boundaries is accumulated cord length along the boundaries. The variable  $t$  ( $0 < t < 1$ ) is the percent of cord length. The spline functions consist of sets of piecewise continuous hyperbolic functions and the parameters  $\sigma_1$  and  $\sigma_2$  are tension parameters which govern the degree of damping of the fit. Reference 3 describes the tension spline functions.

$$\begin{bmatrix} X(t) \\ Y(t) \end{bmatrix}_{r_1} = \left[ \begin{array}{c} S^X(X_i, \bar{t}_i, \sigma_1) \\ S^Y(Y_i, \bar{t}_i, \sigma_1) \end{array} \right]_{i=1}^N$$

$$\bar{t}_i = \left[ (X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2 \right]^{1/2} + \bar{t}_{i-1}$$

$$t = \frac{\bar{t}}{\bar{t}_N} \quad \bar{t}_1 = 0 \quad 0 \leq t \leq 1$$

$$\begin{bmatrix} X(t) \\ Y(t) \end{bmatrix}_{r_2} = \left[ \begin{array}{c} S^X(X_j, \hat{t}_j, \sigma_2) \\ S^Y(Y_j, \hat{t}_j, \sigma_2) \end{array} \right]_{j=1}^M$$

$$\hat{t}_j = \left[ (X_j - X_{j-1})^2 + (Y_j - Y_{j-1})^2 \right]^{1/2} + \hat{t}_{j-1}$$

$$t = \frac{\hat{t}}{\hat{t}_M} \quad \hat{t}_1 = 0 \quad 0 \leq t \leq 1$$

Figure 4 PARAMETRIC SPLINE APPROXIMATION  
TO BOUNDARY DATA WITH TENSION

Figure 5:

This figure illustrates the reasons behind using tension spline functions. Initially cubic splines were used, but wiggles occurred in some of the fits such as near the leading edge of the airfoil shown in the figure. The tension spline routine that has been used degenerates to a cubic spline when the tension factor is near zero. Increasing the tension factor to a large number in effect increases the damping which forces the fit between data points to be nearly straight lines as illustrated at the bottom of the figure. Note that the tension factors are user chosen.

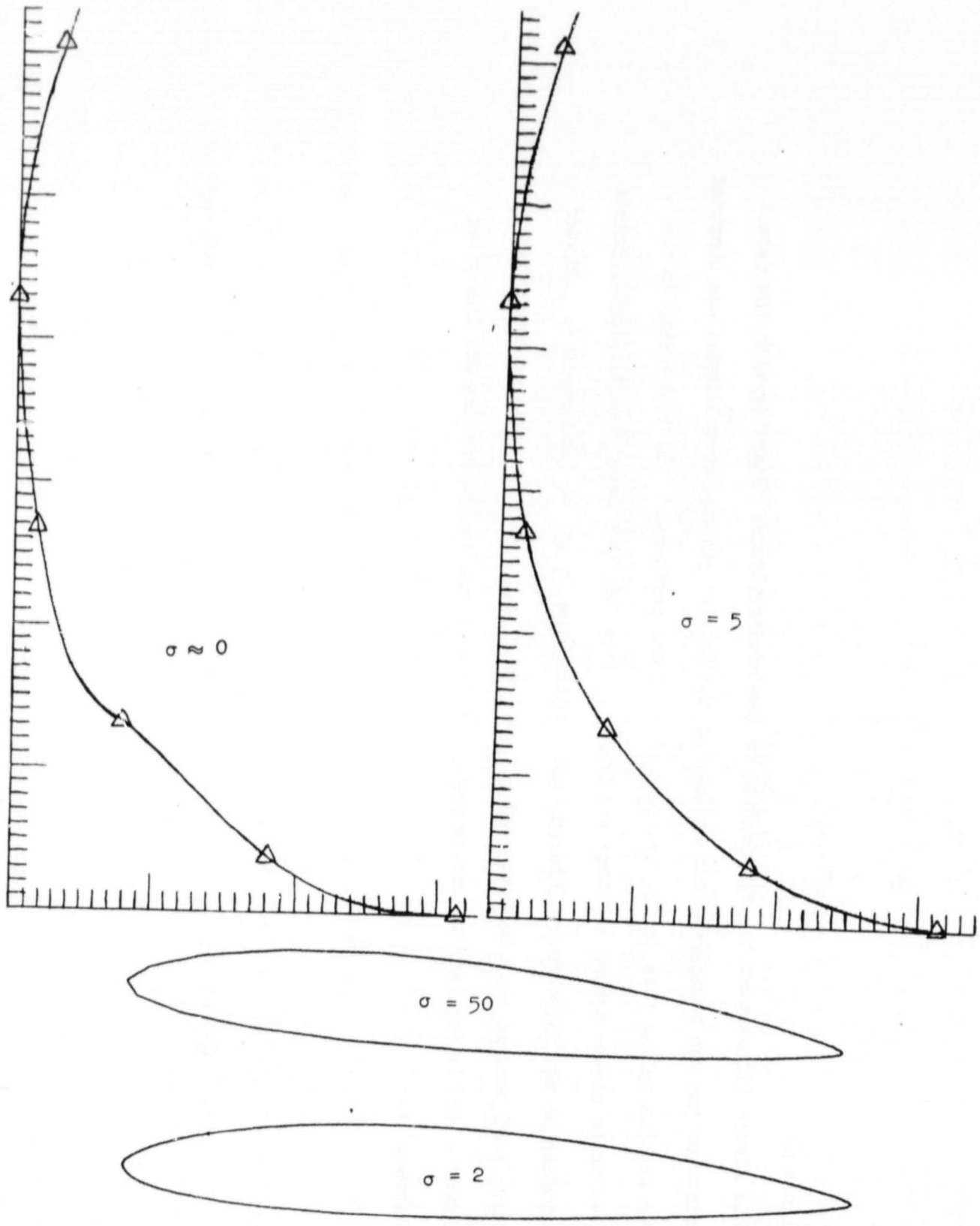


Figure 5 EFFECTS OF TENSION FACTOR

C-5



Figure 6:

This figure illustrates the spline fits to the boundary data. Starting with the data points on the two boundaries and indicating the initial points, cord lengths are computed and tension spline fits to the two sets of data are performed. The boundaries do not need to be closed nor of the same arc length. Once the fits have been performed, points anywhere on the fits can be interpolated. Noting that  $t$  is the percent of accumulated cord, positions on each boundary and derivatives with respect to  $t$  can be evaluated. Equation (2) is applied to compute any point between the two boundaries for the given value of  $t$ .

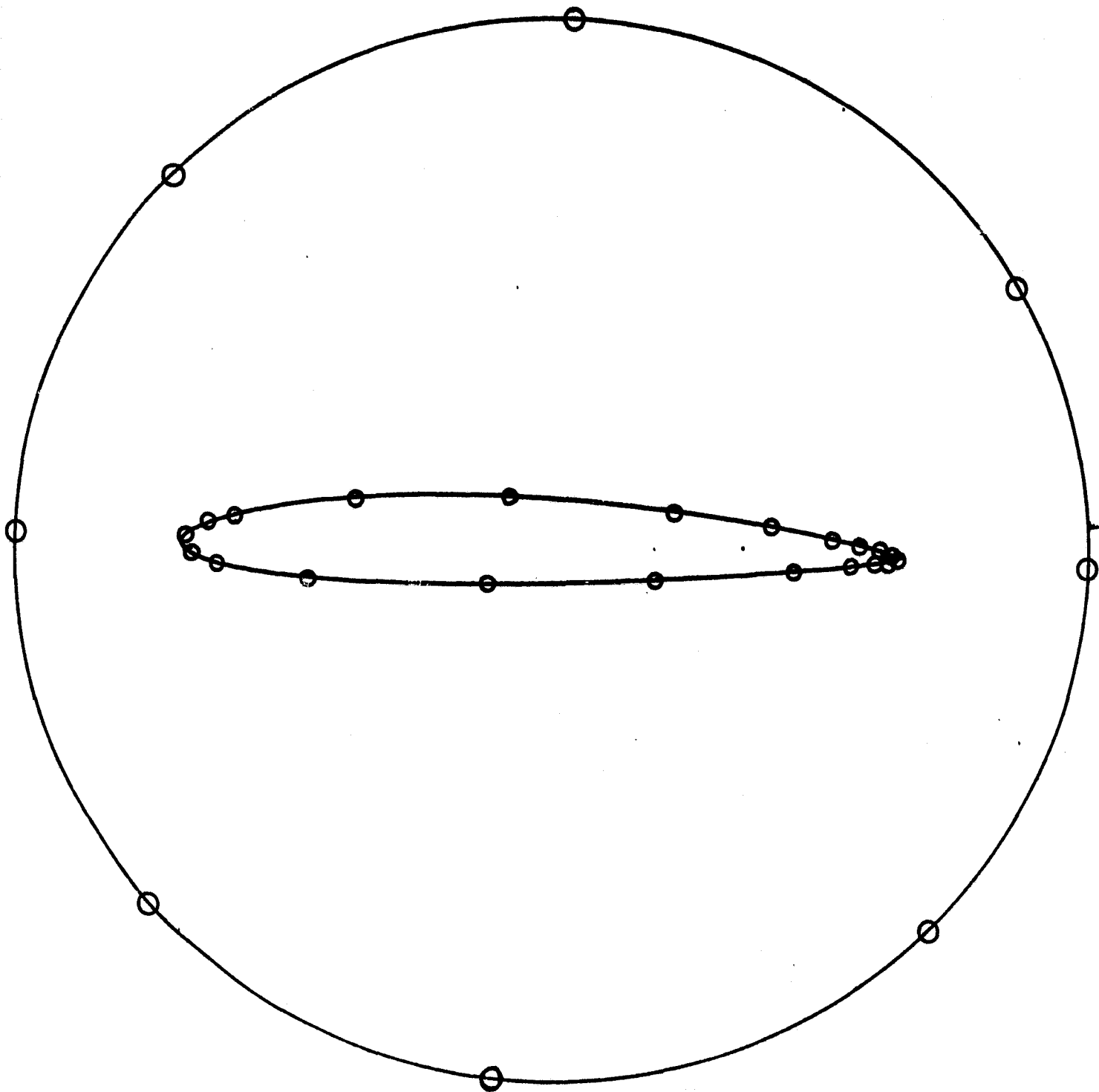


Figure 6 ILLUSTRATION OF SPLINE FIT

6

19

Figure 7:

This figure illustrates the transformation from a uniform rectangular coordinate system to a coordinate system about a Karman Trefftz airfoil. The technique has worked as well for other airfoils including supercritical airfoils. Also, it has worked for singly connected domains in two dimensions. It is noted again that the technique is a special case solution of the general transformation equations, however, it is algebraic and computationally fast yielding dense data. Also, the use of the technique is simple as compared to numerically solving the differential equations.

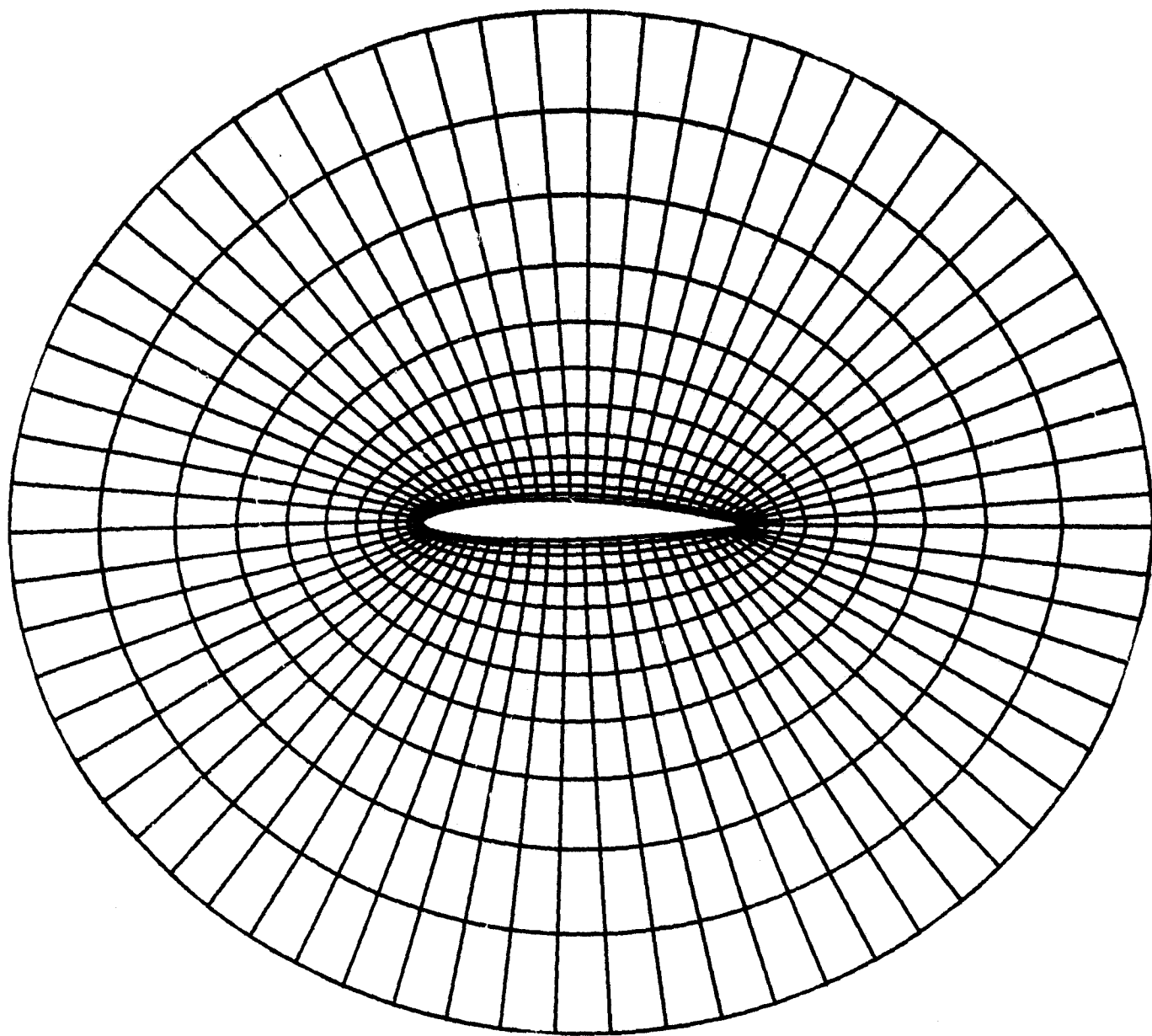


Figure 7 ILLUSTRATION OF GRID GENERATION

Figure 8:

The density of the grid lines near a boundary can be controlled by the transformation shown in this figure. Large negative values of  $k$  concentrate grid lines near  $\Gamma_2$ . Large positive values of  $k$  concentrate grid lines near  $\Gamma_1$ . When solving the differential system (equation 1) this is controlled by the forcing functions.

$$s = \frac{e^{k\bar{s}} - 1}{e^k - 1}$$

$$0 \leq \bar{s} \leq 1$$

Figure 8 CONTRACTION OF THE GRID NEAR A BOUNDARY

Figure 9:

The effects of the parameter  $k$  are shown in this figure. A value of  $k = 5$  is used with the Karman Trefftz airfoil. Four normal grid lines are shown corresponding to  $\bar{s} = .05$ ,  $.1$ ,  $.15$ , and  $.2$ . At the bottom of the figure one grid line is shown for  $\bar{s} = .05$  and  $k = 2$ . There are other ways of controlling the grid line in both the  $t$  and  $s$  directions while  $\Delta t$  and  $\Delta s$  remain constant, however, this illustrates the ease of adding such transformations.

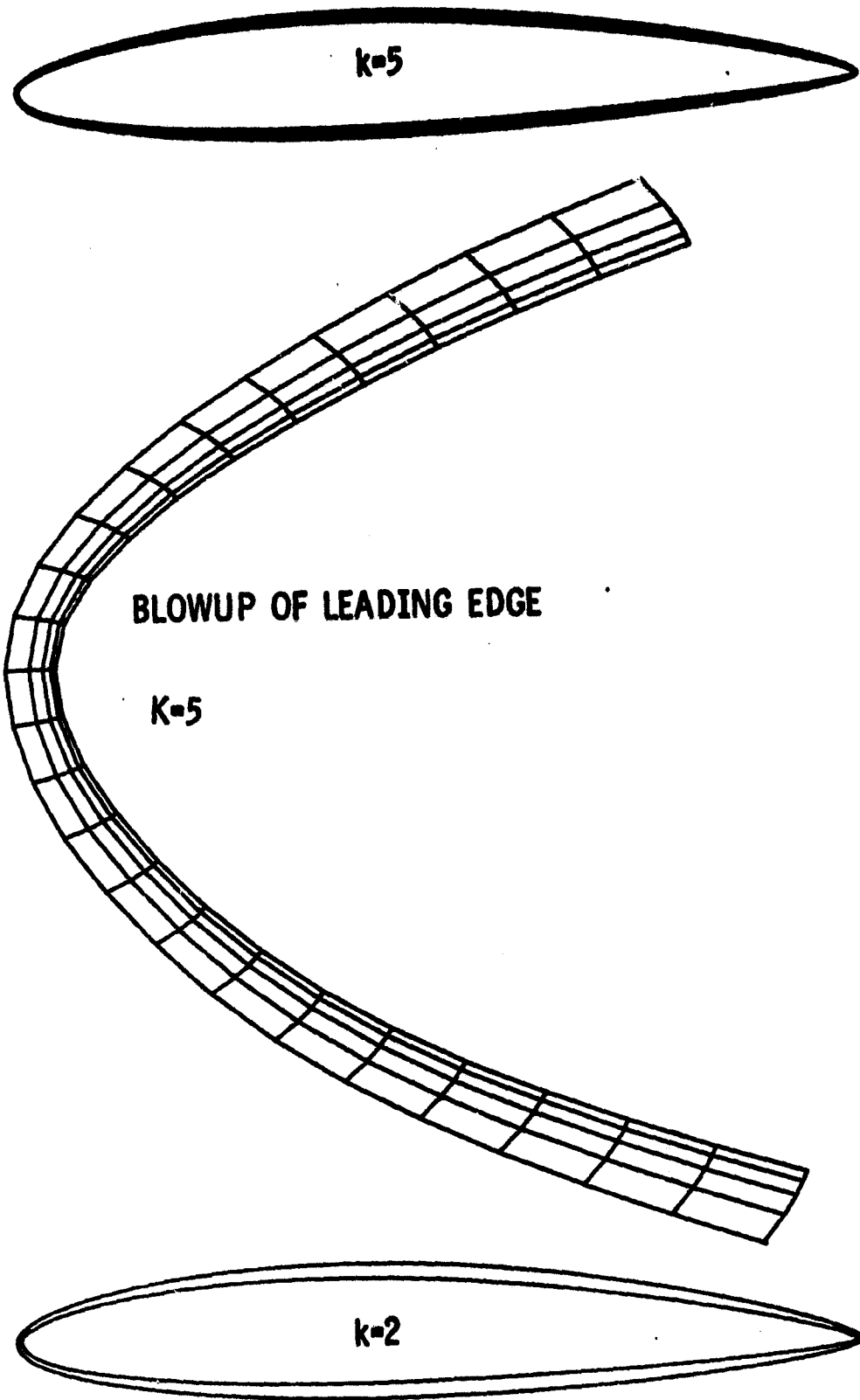


Figure 9 ILLUSTRATION OF GRID CONTRACTION



Figure 10:

This figure illustrates the proposed extension to three-dimensions. The parametric cubic equations are exactly like those on figure 3 except for the addition of one equation for the third coordinate and the replacement of the variable S by W. The position and derivative parameters are now obtained from surface definition of the "inner" and "outer" boundaries. The derivatives with respect to W are obtained from the cross product relation and U and V correspond to percent of cord in the longitude and latitude directions.

$$X(u, v, w) = X(u, v) \underset{1}{f_1(w)} + X(u, v) \underset{2}{f_2(w)} + \frac{dX}{dw}(u, v) \underset{1}{f_3(w)} + \frac{dX}{dw}(u, v) \underset{2}{f_4(w)}$$

$$Y(u, v, w) = Y(u, v) \underset{1}{f_1(w)} + Y(u, v) \underset{2}{f_2(w)} + \frac{dY}{dw}(u, v) \underset{1}{f_3(w)} + \frac{dY}{dw}(u, v) \underset{2}{f_4(w)}$$

$$Z(u, v, w) = Z(u, v) \underset{1}{f_1(w)} + Z(u, v) \underset{2}{f_2(w)} + \frac{dZ}{dw}(u, v) \underset{1}{f_3(w)} + \frac{dZ}{dw}(u, v) \underset{2}{f_4(w)}$$

$$\frac{dX}{dw} \underset{j}{i} + \frac{dY}{dw} \underset{j}{i} + \frac{dZ}{dw} \underset{j}{i} = \begin{vmatrix} \underset{i}{1} & \underset{j}{1} & \underset{k}{1} \\ \frac{dX}{du} & \frac{dY}{du} & \frac{dZ}{du} \\ \frac{dX}{dv} & \frac{dY}{dv} & \frac{dZ}{dv} \end{vmatrix} \underset{r}$$

$$\begin{bmatrix} X(u, v) \\ Y(u, v) \\ Z(u, v) \end{bmatrix} \underset{r} = \begin{bmatrix} S^X(u, v) \\ S^Y(u, v) \\ S^Z(u, v) \end{bmatrix} \underset{r}$$

$$f_1(w) = 2w^3 - 3w + 1$$

$$f_2(w) = -2w^3 + 3w^2$$

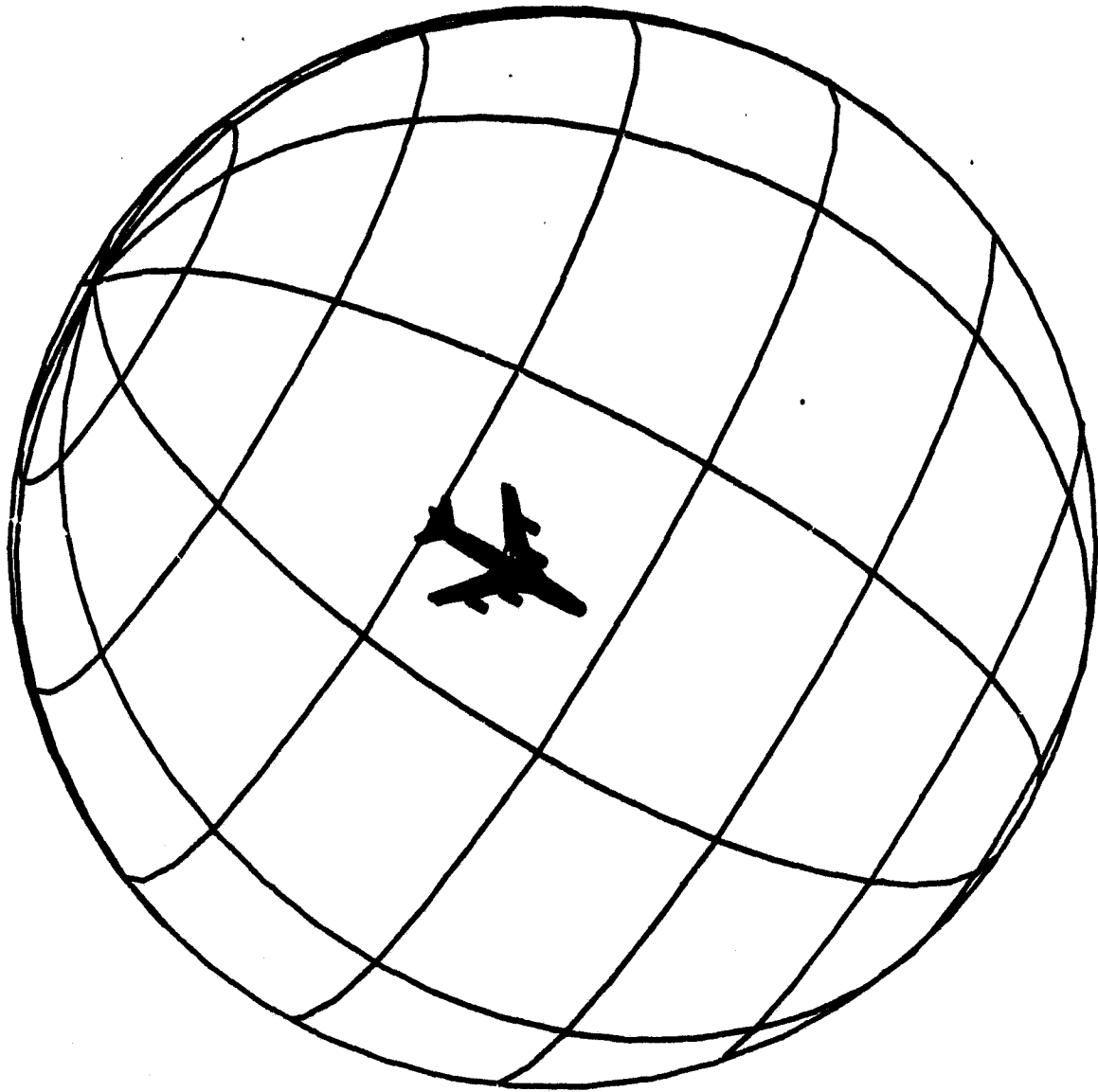
$$f_3(w) = w^3 - 2w^2 + w$$

$$f_4(w) = w^3 - w^2$$

FIGURE 10 EXPANSION TO THREE DIMENSIONS

Figure 11:

This figure illustrates how the inner and outer boundaries might be conceived. Although the complexity of the inner boundary may be over optimistic, each component part such as wing, fuselage, or nacelle could be used to generate a three-dimensional grid. The boundaries presented here were generated with the computer program "A Computer Program for Fitting Smooth Surfaces to an Aircraft Configuration and Other Three-Dimensional Geometries" described in reference 4. Positions and derivatives are available on both boundaries.



**FIGURE 11 ILLUSTRATION OF BOUNDARIES FOR  
EXTENSION TO THREE-DIMENSIONS**

**Conclusions:**

Although it is not anticipated that this technique will supplant the solving of the differential transformation equations, it offers a simple and rapid solution for a transformation in two-dimensions for a large number of cases and is extendable to three-dimensions.

## CONCLUSIONS

1. Curvilinear coordinate systems can be generated algebraically for singly and doubly connected regions in 2-D using parametric cubics and tension spline functions.
2. Density of grid lines near a boundary is easily controlled.
3. The technique should be extendable to three-dimensions.

Relative Tchebycheff  
Approximations  
for  
Aerodynamic Surfaces.

H. Hry. Ames

# Requirements/Objectives

good mathematical representation

aircraft geometry:  
wing sections  
airfoils  
fuselages

aerodynamic flows:  
pressure distributions

HOY 2



**SLIDE 3**

The intent of the approach is to not only provide an algorithm which is intuitively correct but is also systematically correct. Hence, here we attempt to obtain a mathematical representation not only accurate relative to the data, but also correct in its mathematical form.

**H. Hoy**

# Justification for Approach

represents wide class of data

prescribe the accuracy

no assumption of fixed formula  
eg. cubic/quintic splines, etc

no spurious waviness

lowest order representation

not sensitive to adding/deleting data

minimizes the effect of errors in the data

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SLIDE 4

This "goodness of fit" criteria (the Tchebycheff Criteria) allows us to approximate with this error in mind. We attempt to deduce a mathematical representation constrained by minimizing this maximum relative error.

surface:  $f(x, y) = a_{00} + a_{10}x + a_{01}y + a_{11}xy + \dots$

Tchebycheff Criteria: Given  $f_1, x_1, y_1, xy, x^2, \dots$

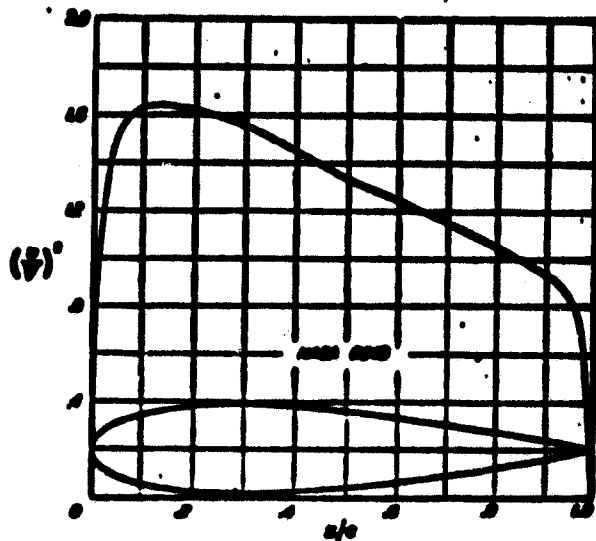
$$\text{with } f(x, y) = \sum_{i=0}^r \sum_{j=0}^r a_{ij} x^i y^j$$

Determine parameters:  $a_{ij}$

such that  $\max_{i,j} \frac{|f(x_i, y_j) - f(x_i, y_j)|}{|f(x_i, y_j)|}$  is minimized

**SLIDE 5**

Shown here is a typical pressure profile for a NACA wing section. Typically, the point to be noted is that the pressure data is recorded to four digits. Hence, we intuitively deduce that this data is accurate to four significant digits. Secondly, we note the rapidly changing pressure gradient from the stagnation point at the leading edge and likewise on the trailing edge. Now, we want to deduce a mathematical representation which is only constrained by such a relative error, i.e., accurate approximately to four significant digits.



$\alpha$ (per cent $c$ )	$\delta$ (per cent $c$ )	$(\delta/V^2)$	$\delta/V$	$\delta_0/V$
0	0	0	0	1.343
0.5	.....	0.465	0.682	1.175
1.25	2.941	0.857	0.926	1.022
2.5	3.923	1.317	1.108	0.891
5.0	5.322	1.807	1.238	0.782
7.5	6.300	1.998	1.264	0.694
10	7.024	1.928	1.278	0.679
15	8.018	1.698	1.278	0.582
20	8.608	1.626	1.278	0.520
25	8.912	1.562	1.262	0.474
30	9.008	1.556	1.247	0.438
40	8.705	1.453	1.205	0.384
50	7.941	1.331	1.184	0.344
60	6.845	1.246	1.116	0.312
70	5.496	1.153	1.074	0.287
80	3.935	1.051	1.026	0.268
90	2.172	0.923	0.966	0.259
95	1.210	0.836	0.914	0.255
100	0.180	0	0	0

L.E. radius: 3.56 per cent  $c$

NACA 0018 Basic Thickness Form

Handwritten signature or initials.

SLIDE 6

Four basic mathematical forms are considered: the polynomial form, the rational form (i.e. ratio of two polynomials), and their piecewise counterparts: piecewise polynomials, piecewise rational and with or without smoothness constraints imposed. Likewise, the four basic mathematical forms in two-dimensional space are the double polynomials/rationals/with or without smoothness constraints, i.e.

$$f(x,y) = \sum_{j=1} \sum_{i=1} a_{ij} x^{i-1} y^{j-1}, \text{ etc.,}$$

for example.

# Admissible Forms of Representation

polynomial: 
$$p(x) = a_0 + a_1x + a_2x^2 + \dots + a_nx^n = \sum_{i=0}^n a_i x^i$$

rational: 
$$\frac{p(x)}{q(x)} = \frac{a_0 + a_1x + \dots + a_r x^r}{b_0 + b_1x + \dots + b_s x^s} = \frac{\sum_{i=0}^r a_i x^i}{\sum_{j=0}^s b_j x^j}$$

piecewise polynomial 
$$p(x) = a_0^i + a_1^i x + a_2^i x^2 + \dots + a_r^i x^r$$

rational 
$$\frac{p^i(x)}{q^i(x)} = \frac{a_0^i + a_1^i x + a_2^i x^2 + \dots + a_r^i x^r}{b_0^i + b_1^i x + b_2^i x^2 + \dots + b_s^i x^s}$$

w/o smoothness constraints

$x \in [x_{i-1}, x_i]$



**SLIDE 7**

**Analogously, these basic forms can be represented in terms of Tchebycheff Polynomials. We perform our computation in terms of such expansions for the purpose of maintaining computational accuracy. This advantage is due to their orthogonality property.**

# Tchebycheff Representation

polynomial: 
$$p(x) = a_0 + a_1 T_1(x) + a_2 T_2(x) + \dots + a_n T_n(x) = \sum_{i=0}^n a_i T_i(x)$$

rational: 
$$\frac{p_r(x)}{q_r(x)} = \frac{a_0 + a_1 T_1(x) + a_2 T_2(x) + \dots + a_r T_r(x)}{b_0 + b_1 T_1(x) + b_2 T_2(x) + \dots + b_s T_s(x)} = \frac{\sum_{i=0}^r a_i T_i(x)}{\sum_{j=0}^s b_j T_j(x)}$$

piecewise polynomial: 
$$p_r^i(x) = a_i^i + a_i^i T_1(x) + a_i^i T_2(x) + \dots + a_i^i T_r(x)$$

or  
rational

$$\frac{p_r^i(x)}{q_r^i(x)} = \frac{a_i^i + a_i^i T_1(x) + a_i^i T_2(x) + \dots + a_i^i T_r(x)}{b_i^i + b_i^i T_1(x) + b_i^i T_2(x) + \dots + b_i^i T_s(x)}$$

w/o

smoothness

constraints

$$x \in [x_{i-1}, x_i]$$

**SLIDE 8**

On this slide is shown the Tchebycheff Polynomials expanded in terms of the ordinary polynomials and vice-versa. The detail to be noted here is the magnitude of the integral coefficients. The Tchebycheff Polynomials are large relative to the Power Series coefficients. This characteristic leads us to a mathematical representation which is more compact (fewer coefficients) and has better behaved coefficients.

# Chebyscheff Polynomials

$$T_0(x) = 1$$

$$T_n(x) = 2x T_{n-1}(x) - T_{n-2}(x)$$

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

$$T_3(x) = 4x^3 - 3x$$

$$T_4(x) = 8x^4 - 8x^2 + 1$$

$$T_5(x) = 16x^5 - 20x^3 + 5x$$

$$T_6(x) = 32x^6 - 48x^4 + 18x^2 - 1$$

$$T_7(x) = 64x^7 - 112x^5 + 56x^3 - 7x$$

$$T_8(x) = 128x^8 - 256x^6 + 160x^4 - 32x^2 + 1$$

# Ordinary Polynomials

$$1 = T_0$$

$$x = T_1$$

$$x^2 = \frac{1}{2}(T_2 + T_0)$$

$$x^3 = \frac{1}{4}(3T_3 + T_1)$$

$$x^4 = \frac{1}{8}(3T_4 + 4T_2 + T_0)$$

$$x^5 = \frac{1}{16}(10T_5 + 5T_3 + T_1)$$

$$x^6 = \frac{1}{32}(10T_6 + 15T_4 + 6T_2 + T_0)$$

$$x^7 = \frac{1}{64}(35T_7 + 21T_5 + 7T_3 + T_1)$$

$$x^8 = \frac{1}{128}(35T_8 + 56T_6 + 28T_4 + 8T_2 + T_0)$$

SLIDE 9

Shown on this slide is the pieewise construction of smoothness at assumed knots  $x$ . If we have a mathematical representation  $y^{(1)}(x)$  for a set of prescribed data over the first subinterval expressed as shown, we can impose the value  $y^{(1)}(x_1)$  for the second approximation at its left-hand end point. Likewise, the value  $y^{(1)}(x)$  is imposed. Inductively, we can do so for any such subinterval. What we get is a over-determined coupled system of linear equations which we eliminated for a  $a_j^{(i)}$  simultaneously. Likewise, the two-dimensional counterparts follow analogously.

# Piecewise Construction of Smooth Polynomial Fits

$$y^{(0)}(x) = \sum_{j=0}^{n_1} a_j^{(0)} x^j$$

$$y^{(k)}(x) = \sum_{j=0}^{n_1} a_j x_k^j + (x - x_k) \sum_{j=0}^{n_1-1} j a_j^{(1)} x_k^{j-1} + (x - x_k)^2 \sum_{j=0}^{n_1-2} a_j^{(2)} x_k^j$$

Continuity for function value, 1<sup>st</sup> derivative, etc.  
at  $x = x_k$ .

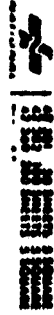
SLIDE 10

The Tchebycheff Problem restated in matrix form is shown. We note we have a set of inconsistent linear equations ( $m > k$ ,  $m$  = number of data points,  $k$  = order of the approximation) which we want to solve for  $a_j$  satisfying the Tchebycheff Criteria.

# Tchebycheff Problem

$$\begin{bmatrix} \rho_{1,1} \\ \rho_{1,2} \\ \vdots \\ \rho_{1,n} \end{bmatrix} \begin{bmatrix} \rho_{2,1} \\ \rho_{2,2} \\ \vdots \\ \rho_{2,n} \end{bmatrix} \dots \begin{bmatrix} \rho_{k,1} \\ \rho_{k,2} \\ \vdots \\ \rho_{k,n} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_k \end{bmatrix} = \begin{bmatrix} f \\ f \\ \vdots \\ f \end{bmatrix}$$

$n > k$





SLIDE 11

Now since in general, we are interested in not only determining one dimensional curves  $f(x)$  but also two dimensional surfaces  $f(x,y)$ , we have arrived at an apparent impasse because the classical Tchebycheff theory does not apply. However, if we reformulate our Tchebycheff problem in terms of the Linear Programming context, we are able to solve our problem. The opposite slide shows this reformulation.

# Primal Linear Programming Problem

Minimize  $w$  subject to

$$\sum_{j=1}^k a_j \frac{b_{ij}}{|b_{ij}|} + w \geq \frac{f_i}{|b_{ij}|}$$

$$\sum_{j=1}^k a_j \frac{b_{ij}}{|b_{ij}|} + w \geq -\frac{f_i}{|b_{ij}|}$$

0, 1, 2, ... n

SLIDE 12

Now computationally, we do not wish to solve the primal linear programming problem, but rather its dual. Computationally, this is desirable because the number of constraints is typically much less in the dual formulation. Also we seek to determine the least order of such an approximation. This is possible since the least order approximation is related to the  $k$ th approximation by the fact that one additional constraint ( $k+1$ th) can be added to the dual simplex tableau and we can resume the ordinary simplex operations.

Linear Programming Problem

Maximize  $\sum_{i=1}^n c_i x_i$  subject to

$$\sum_{i=1}^n a_{ij} x_i \leq b_j, \quad j=1, 2, \dots, k$$

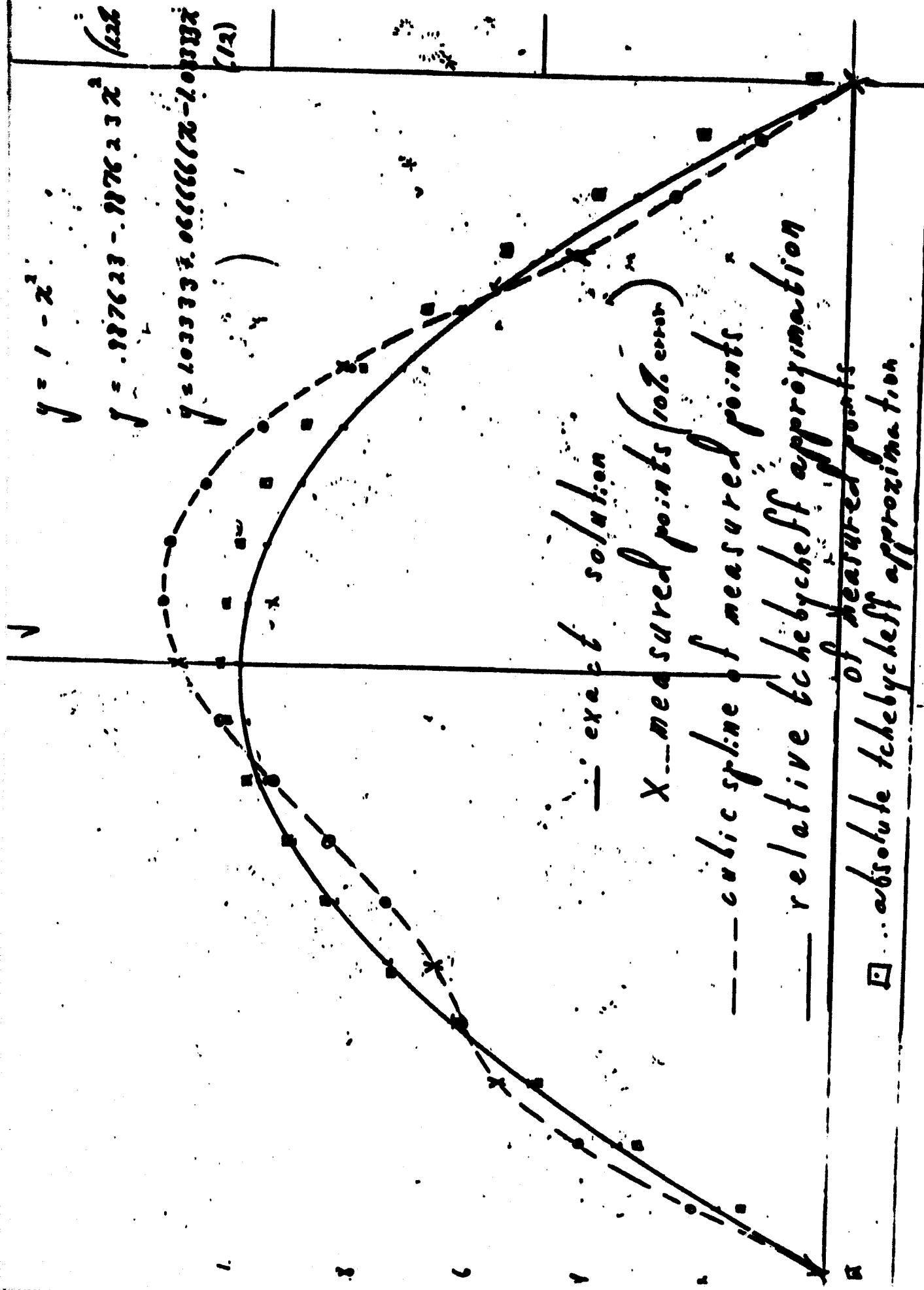
$$\sum_{i=1}^n (x_i) \leq 1$$

$$x_1, x_2, \dots, x_n \geq 0$$

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SLIDE 13

Some numerical results are shown on the opposite slide. The test case is  $y = 1 - x^2$ . Seven data points are inputted with a 10% error. These data points could reflect measured data with some error and are marked on the chart with X's. The exact solution is the solid curve. The dashed curve is a cubic spline fit. The absolute Tchebycheff solution is depicted by  $\square$ . The relative Tchebycheff solution is approximately on top of the exact solution. The results show waviness of the cubic spline solution due in part to interpolation thru the data points. The absolute Tchebycheff approximation failed near the roots of  $y = 1 - x^2$  and was affected by the 10% error resulting in a .12 maximum residue. The relative Tchebycheff approximation not only showed no waviness, but was the most accurate (1.2% maximum relative error). It also was able to identify the curve  $y = 1 - x^2$ . That is, it characterized it by determining it was in fact a parabola by determining its coefficients  $y = .987623 - .987623x^2$ . Finally, the approximation was able to reduce the effect of the error.



## Conclusions

- accurate for surfaces
- induces no waviness
- compact representation
- alternative to interpolation

# IPEGS

**INTERACTIVE PARAMETRIC EQUATION GEOMETRY SYSTEM**

**BY**

**CAPT. JOHN B. ASHBAUGH, USAF**

**NASA SURFACE REPRESENTATION WORKSHOP  
AMES RESEARCH CENTER**

**1-2 MARCH 1978  
MOFFETT FIELD, CALIFORNIA**

*ASHBAUGH /*



A major objective at NASA-Ames Research Center is to develop the ability to integrate aerodynamic theory with experiment. Wind tunnel test results and theoretical predictions of the aerodynamic configurations will be compared on the local minicomputer system. In order to accomplish this objective, it is necessary to develop geometry models that are as detailed and as accurate as the physical wind tunnel model. In order to develop such a mathematical model, the Interactive Parametric Equation Geometry System (IPEGS) was developed.

J. Ashbaugh  
Vugraph #2

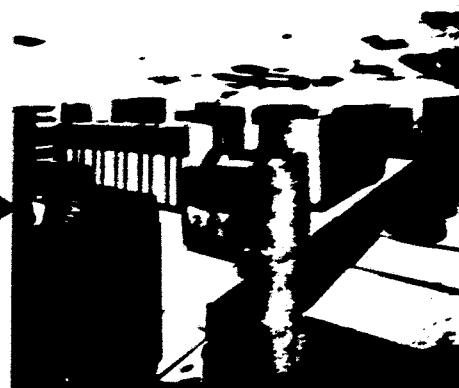
**AERODYNAMIC THEORY & EXPERIMENT INTEGRATION**



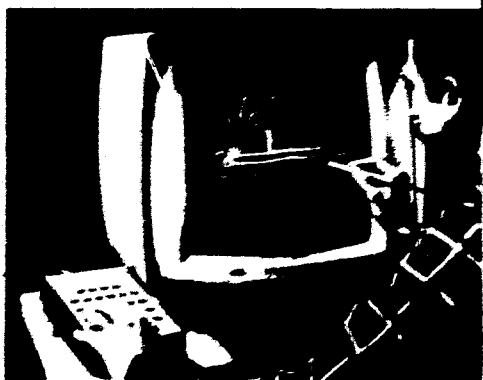
**WIND TUNNEL TEST**



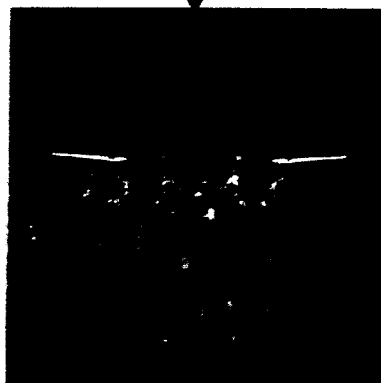
**LOCAL COMPUTER AND DISPLAY**



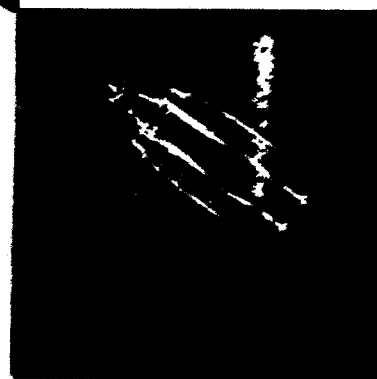
**CENTRAL COMPUTER FLOW CALCULATIONS**



**AERODYNAMIC FLOW CONTOURS**



**MATHEMATICAL SURFACE CROSS SECTION**



**AIRCRAFT MATHEMATICAL SURFACE**

TOP VERTICAL

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*ASHBAUGH 2*

The IPEGS System can be broken down into six major steps:

STEP 1: Digitize Drawings

The cross sections of a particular component of the wind tunnel model, e.g., the tail, nose, or upper fuselage, are digitized using an optical digitizer. The digitized points of the cross section are displayed as they are being digitized on an IMLAC CRT. This display ensures that the operator doesn't digitize a bad point and also that he has sampled the cross section sufficiently to get its representative shape. Some of the components of the model, e.g., the wing, canard, or vertical tail, are not digitized but are input analytically into the IPEGS System.

STEP 2: Create Surfaces

The digitized points are transmitted to the local PDP-11 minicomputer where they are transformed into parametric bicubic surfaces through the use of tension splines.

STEP 3: Review Surfaces

The parametric bicubic surfaces are then examined on the Evens & Sutherland Picture System. The picture system allows the operator to rotate, translate, or scale the object in all 3 dimensions. The operator can also display the object in four views simultaneously, reflect the object about any axis or display cross-sectional views of the object.

STEP 4: Modify Surfaces

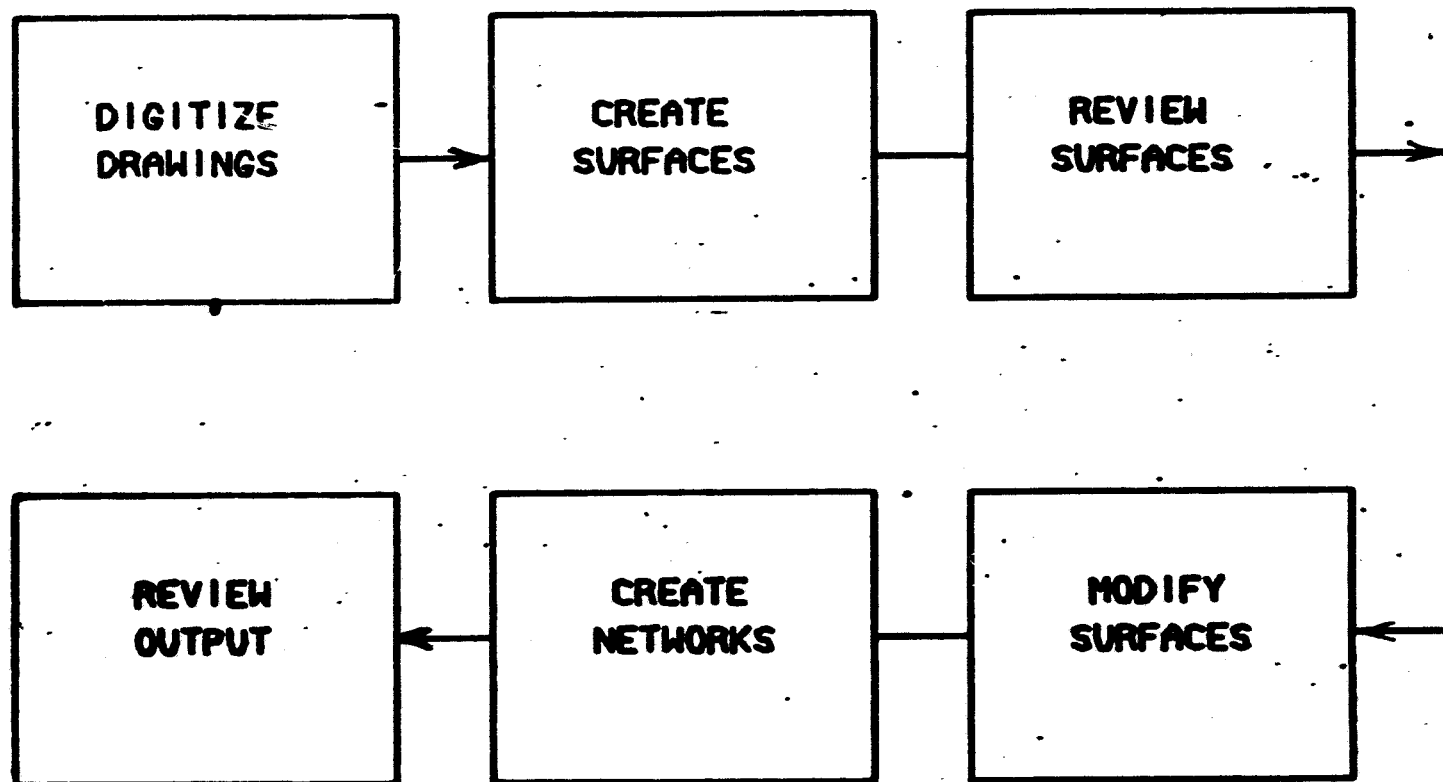
The operator can interactively translate or scale the entire object or any component of the object. In this way he can easily exchange components of the model or modify any component. He can also "pick" any bicubic surface or patch and then operate on that surface. He has the ability to:

- (a) Split a patch into two patches.
- (b) Delete a patch.
- (c) Force two patches to connect together with or without slope continuity.
- (d) Create a fillet patch between two existing patches.
- (e) Create a ruled surface patch between two existing patches.

(cont'd)

J. Ashbaugh  
Vugraph #3

## FLOW OF DATA IN SURFACE MODELLING



**STEP 5: Create Networks**

After the model has been reviewed and modified to the specifications of the aerodynamicist, the paneling information required by a particular aerodynamic program can be extracted. The distribution (sine, cosine, half cosine, even spacing) and the density of the paneling can be changed interactively to emphasize the critical areas of the model.

**STEP 6: Review Output**

The paneling information is sent to the CDC 7600, operated on by the aerodynamics codes and the output plot information is sent back to the PDP-11 and the E&S Picture System. The output plots can be quickly scanned on the Picture System and a hardcopy made of any plot.

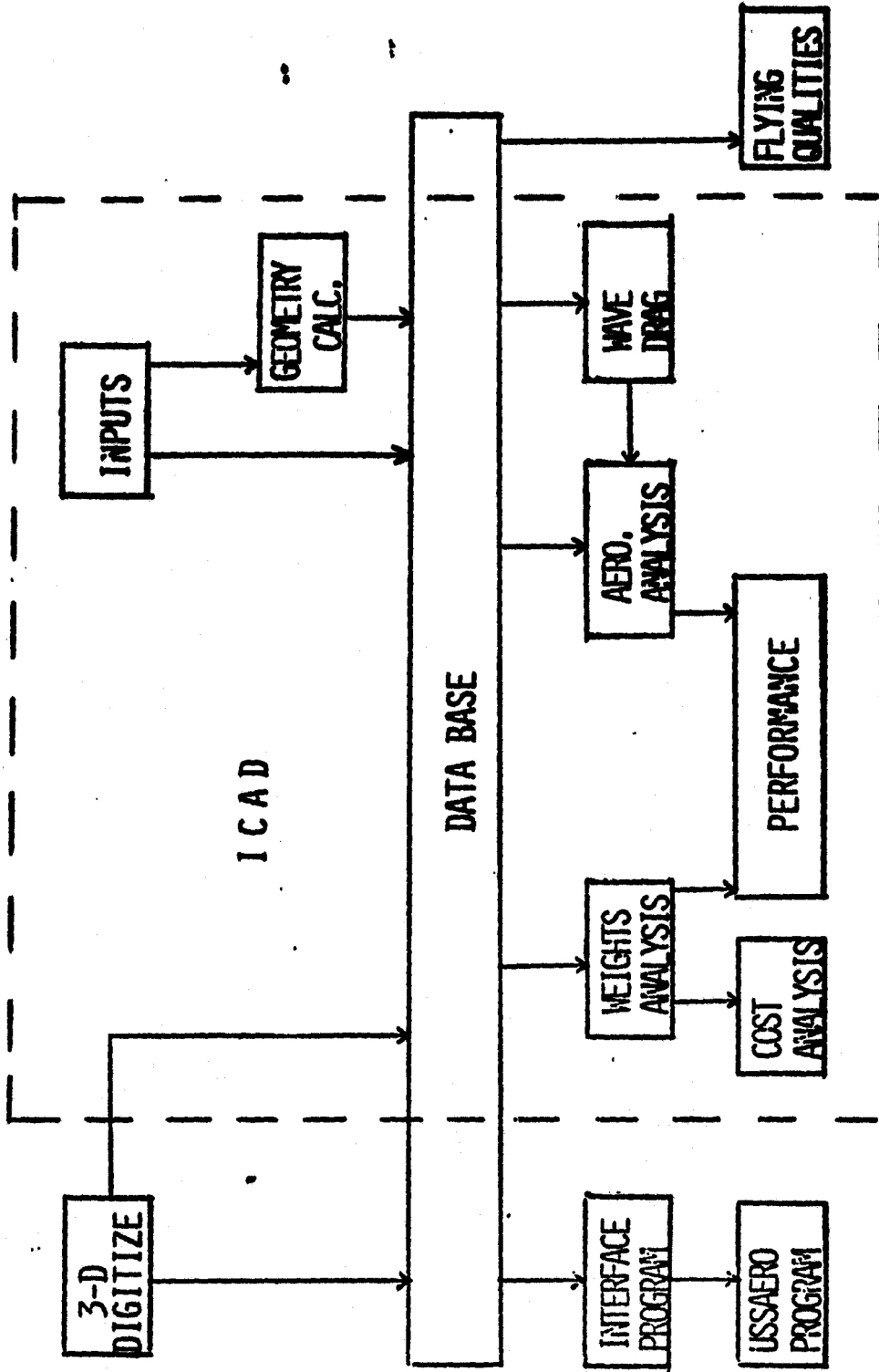
**ICAD**  
**(INTERACTIVE COMPUTER AIDED DESIGN)**

**ED BROWN**

**ASD/XRH**  
**DIRECTORATE OF DESIGN ANALYSIS**  
**AERONAUTICAL SYSTEMS DIVISION**  
**WRIGHT—PATTERSON AFB, OHIO 45433**

*Brown /*

# ICAD OVERVIEW



Draw 2

## GEOMETRY DATA BASE

POINTS IN SPACE; (X, Y, Z) COORDINATES

CREATION METHODS

PRELIMINARY DESIGN INPUT

PARAMETER ARRAY

VECTORS

ARBITRARY BODY

3-D INPUT

INDEPENDENT INTERFACES

AERODYNAMIC ANALYSES

WEIGHTS AND BALANCE

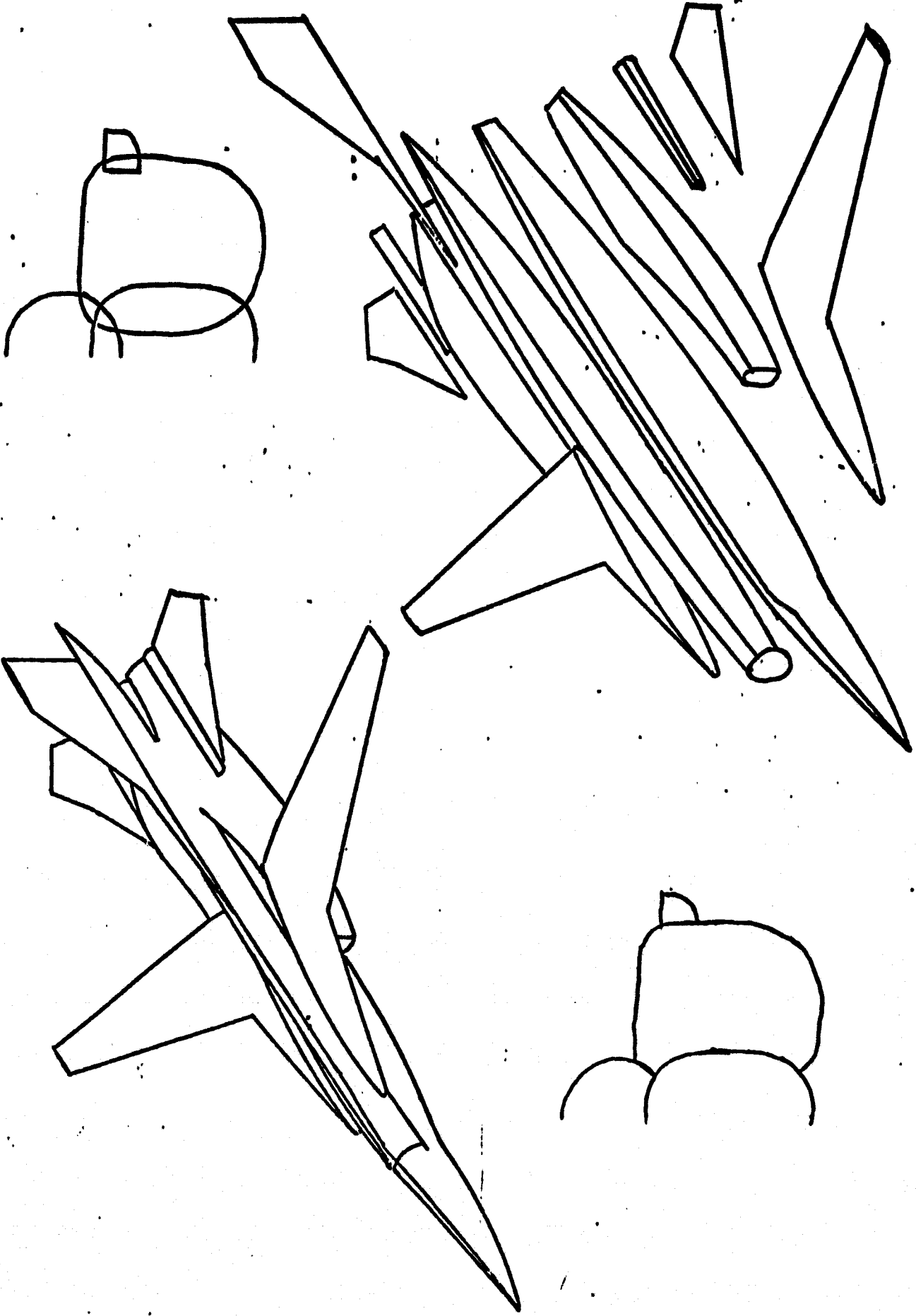
COST PREDICTION

PERFORMANCE

FLYING QUALITIES

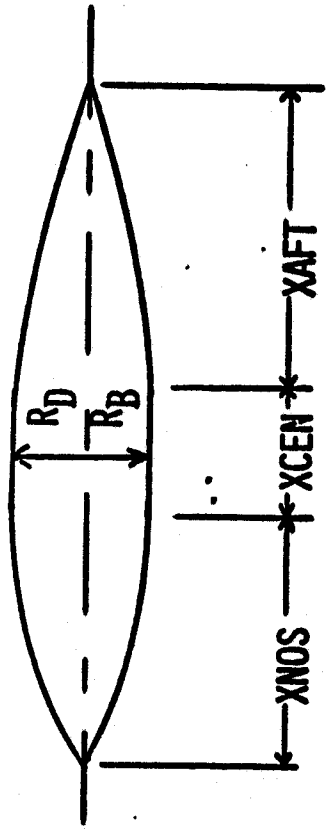


IDENTIFICATION OF COMPONENTS

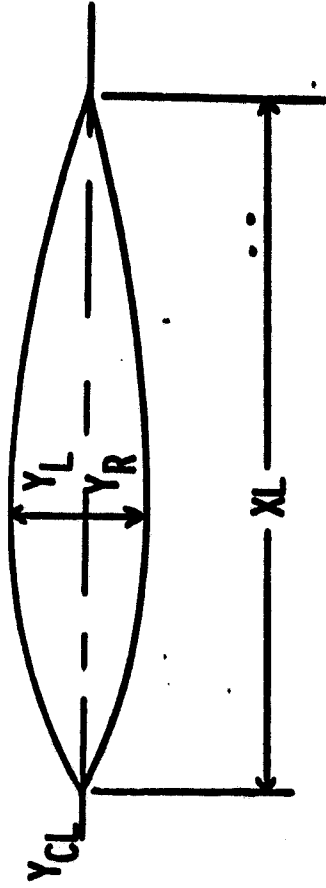


PRELIMINARY DESIGN BODIES

PARAMETRIC:



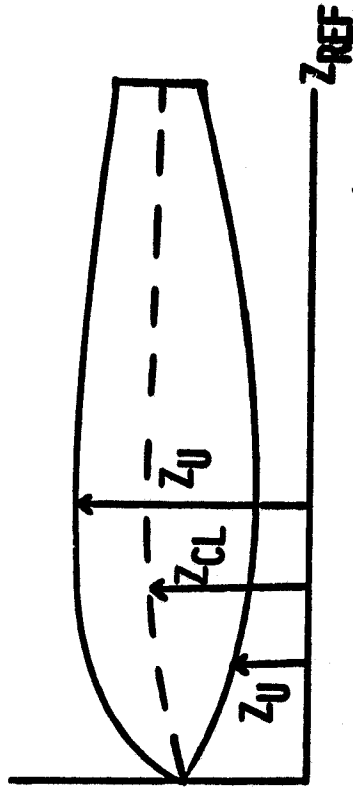
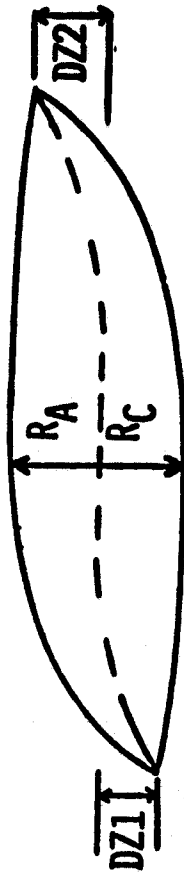
VECTORS:



FITS

SEARS-HAACK

HYPER ELLIPTICAL



FITS

CUBIC SPLINE

# HYPHER-ELLIPTICAL CROSS-SECTIONS

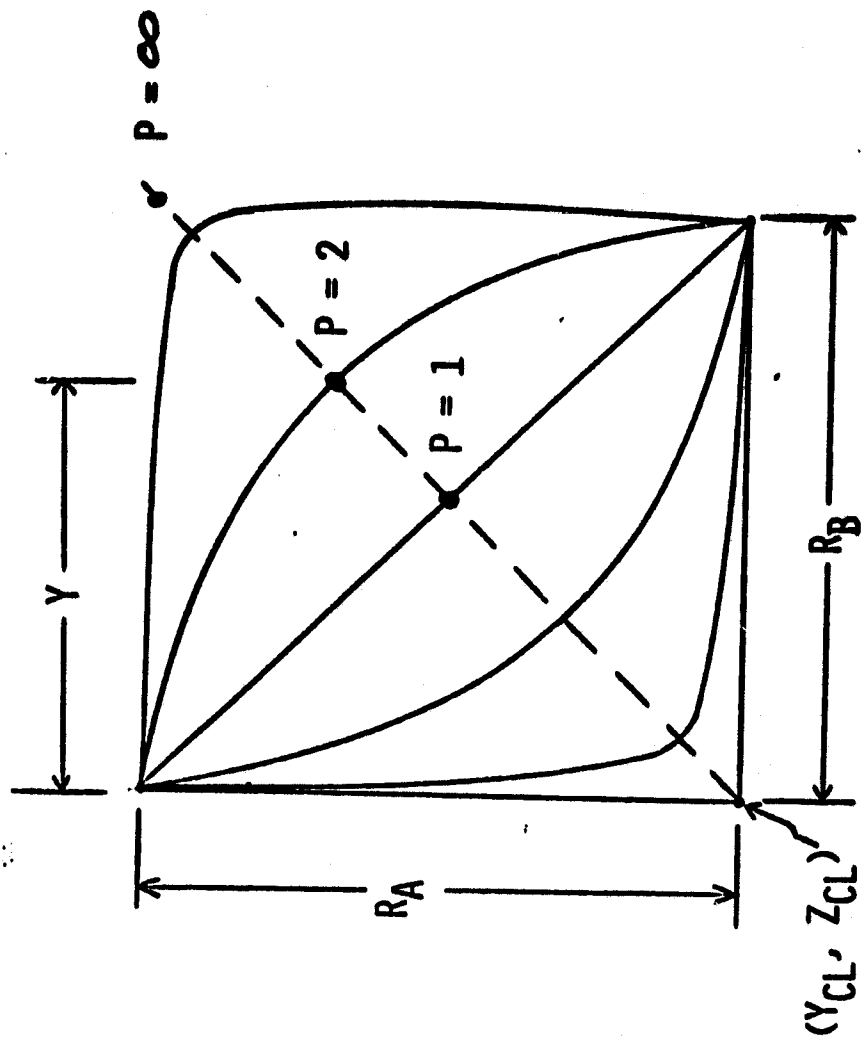
$$\left(\frac{Z}{R_A}\right)^P + \left(\frac{Y}{R_B}\right)^P = 1$$

$$FAC = Y/R_B$$

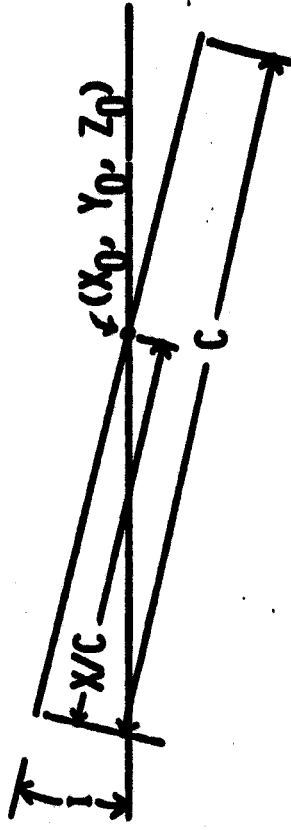
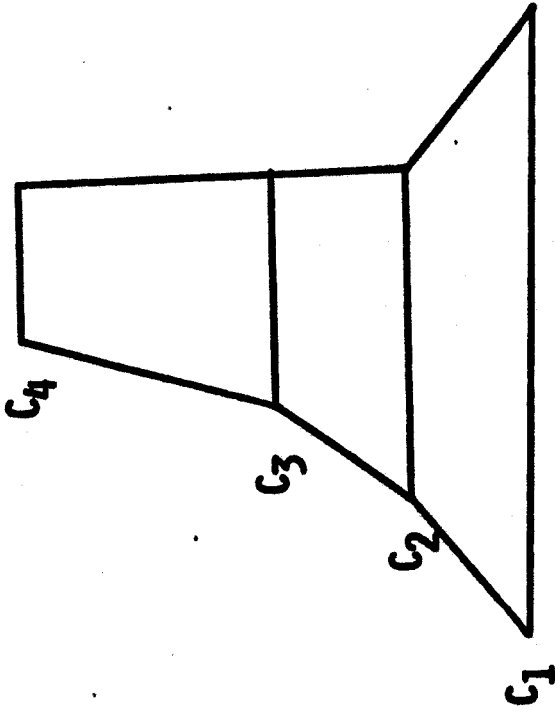
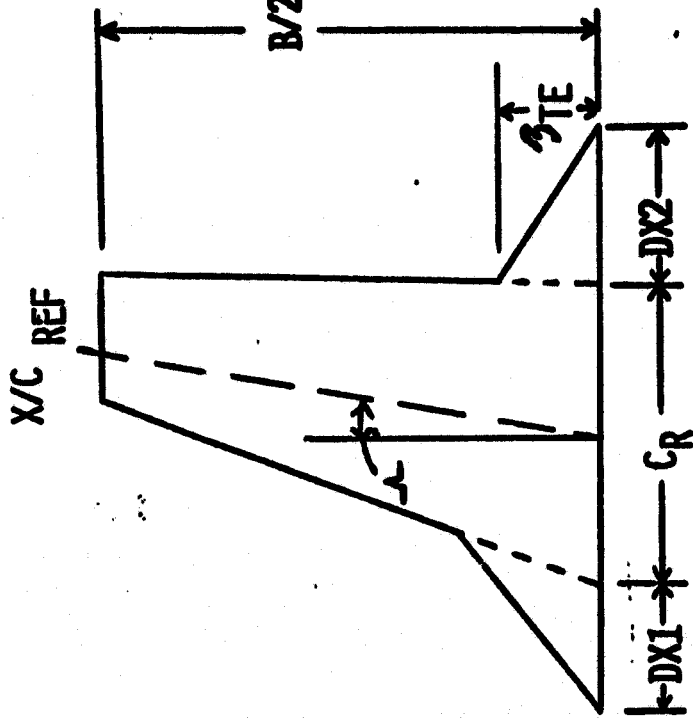
$$P = - \ln 2 / \ln FAC$$

WHERE:

$$0 < FAC < 1$$



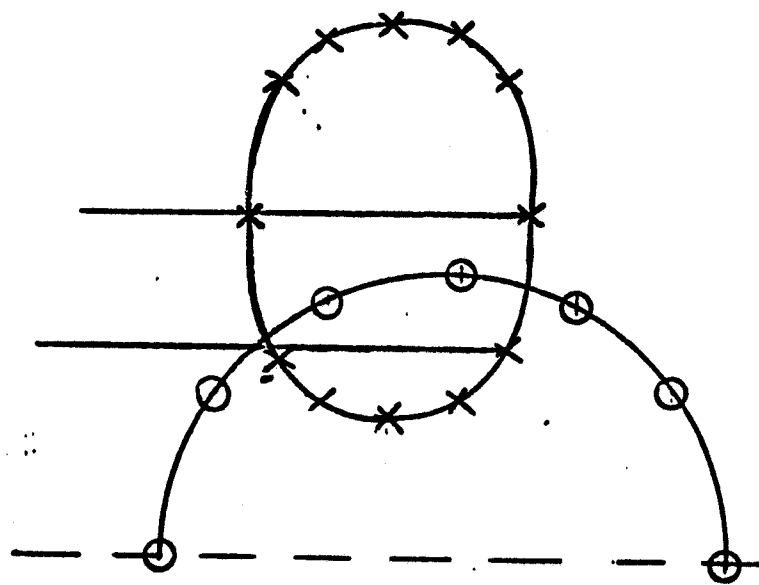
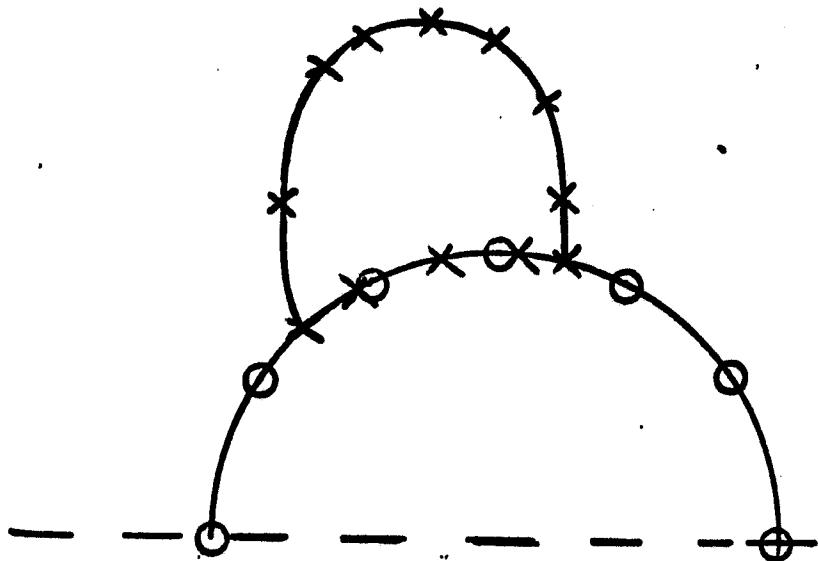
PRELIMINARY DESIGN SURFACES



$X_0, Y_0, Z_0, C, X/C, \lambda$   
AIRFOIL TYPE

$S$   
 $AR$   
 $\lambda$   
 $X/C$   
INCIDENCE  
AIRFOIL TYPE

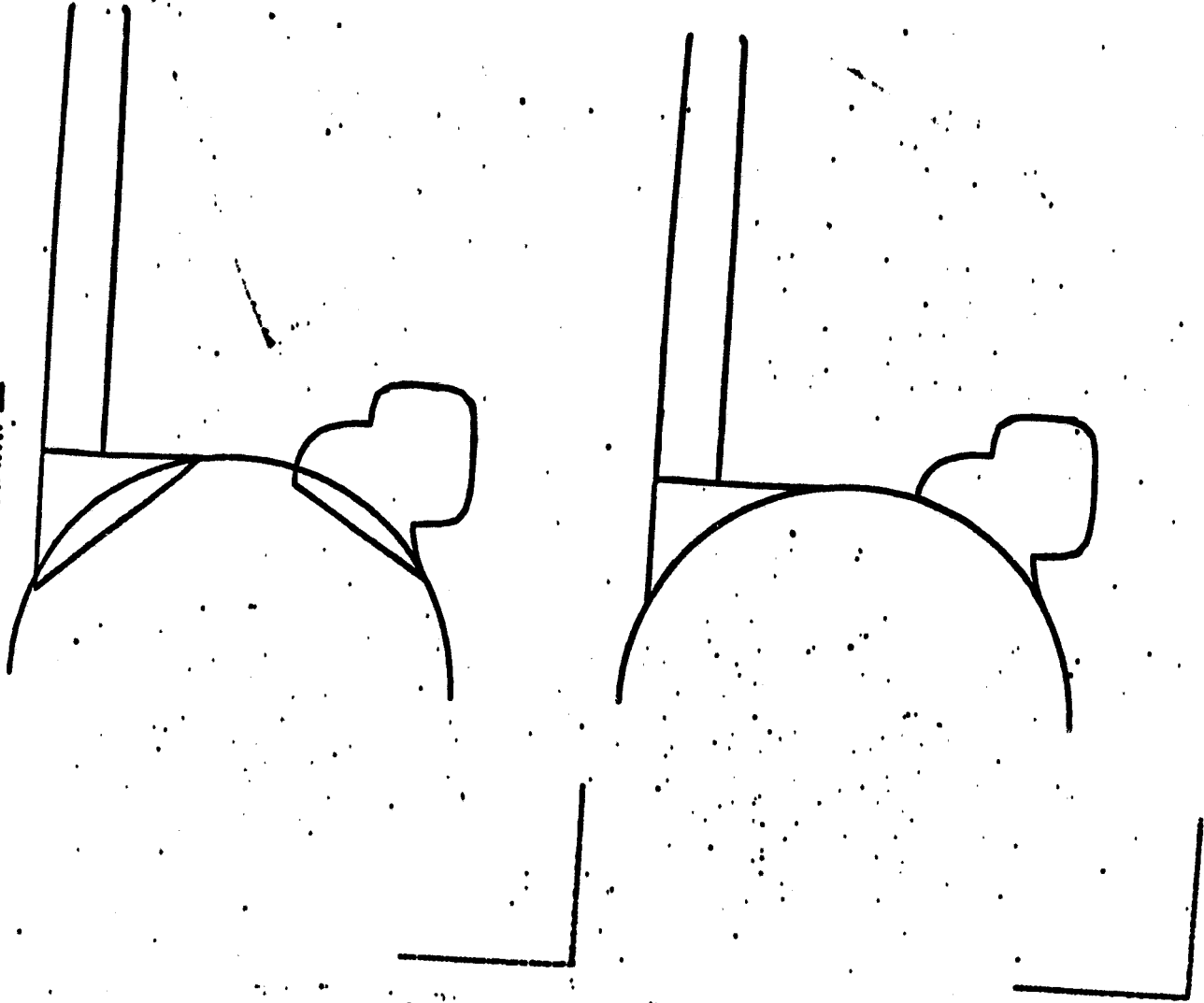
**BODY MERGING**



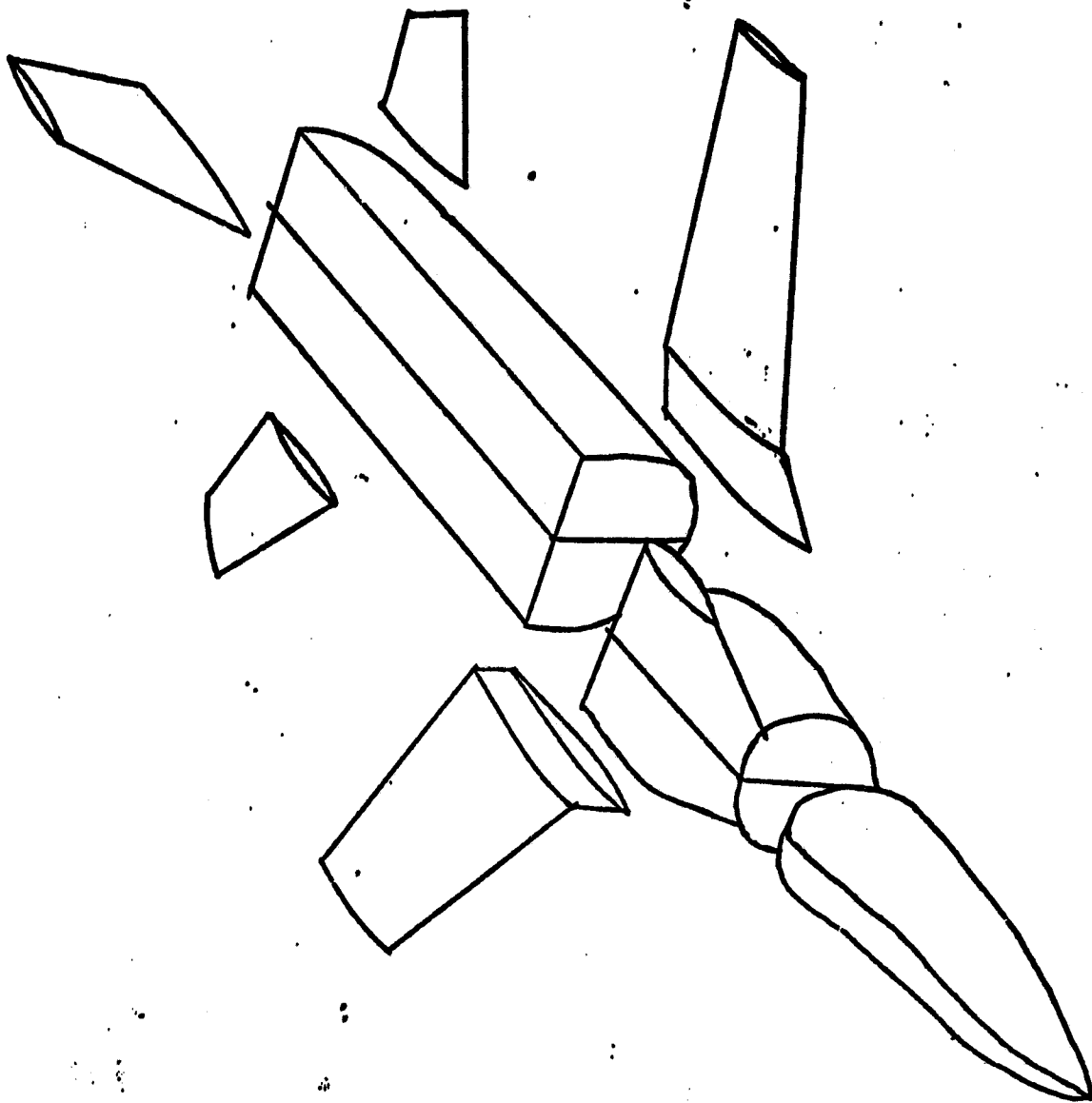
**POINT EXTENSION**

**CROSS ODD NUMBER OF LINES - POINT INSIDE**  
**CROSS EVEN NUMBER OF LINES - POINT OUTSIDE**  
**(INCLUDING ZERO)**

FILET BODY EXAMPLE



**3-D COMPONENT IDENTIFICATION**



# ARBITRARY BODY INPUT

## FEATURES

## OUTPUT

ROTATING CUBIC

FORMATTED

MULTIPLE SEGMENTS

ONE POINT/CARD (X,Y,Z)

SPECIAL SHAPES

: (POINT, CIRCLE, ELLIPSE)

VECSET SURFACES

CONSTRAINTS

MAXIMUM 50 POINTS/HOOP

CORE SIZE

MAXIMUM 20 SEGMENTS

SAME NUMBER POINTS PER HOOP

(FOR CONNECTIVITY)

PERPENDICULAR TO PRINCIPAL AXIS

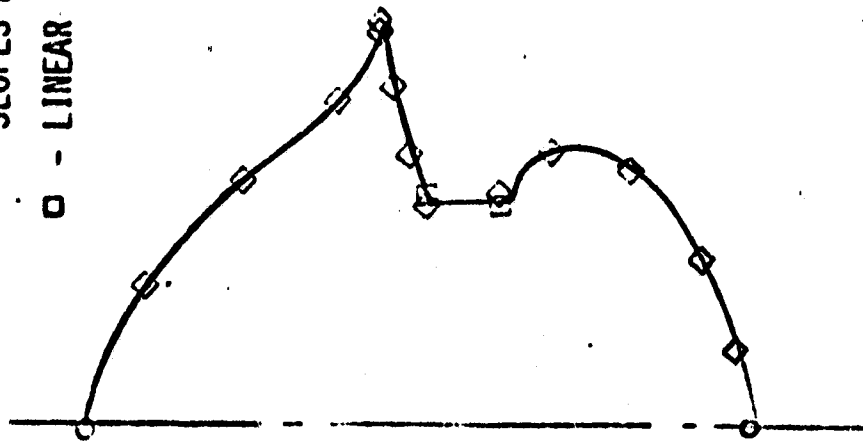
STREAMWISE AIRFOILS

11

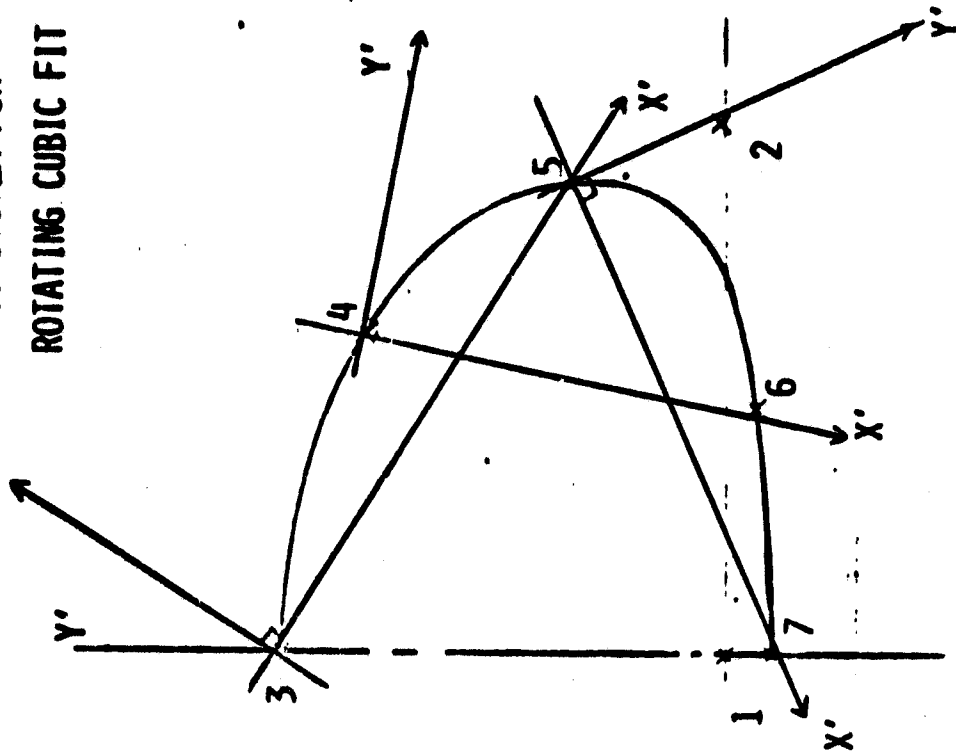


# DIGITIZING WITH SPLINE FITTING

- - ZERO SLOPE
- ◇ - SLOPES MATCHED
- - LINEAR



## AXIS SYSTEM FOR ROTATING CUBIC FIT

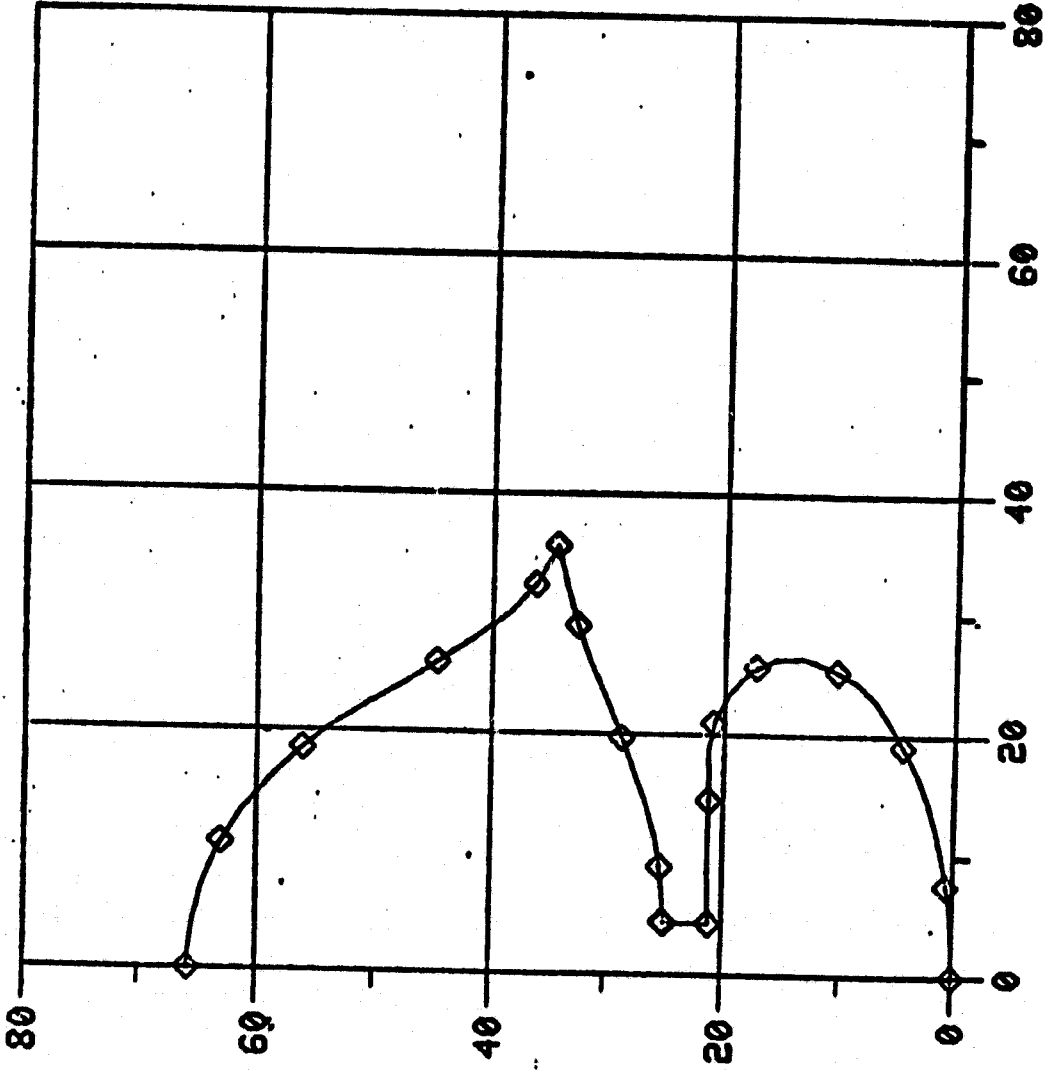


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OF POOR QUALITY

# ACTUAL COMPUTER GRAPHIC DISPLAY

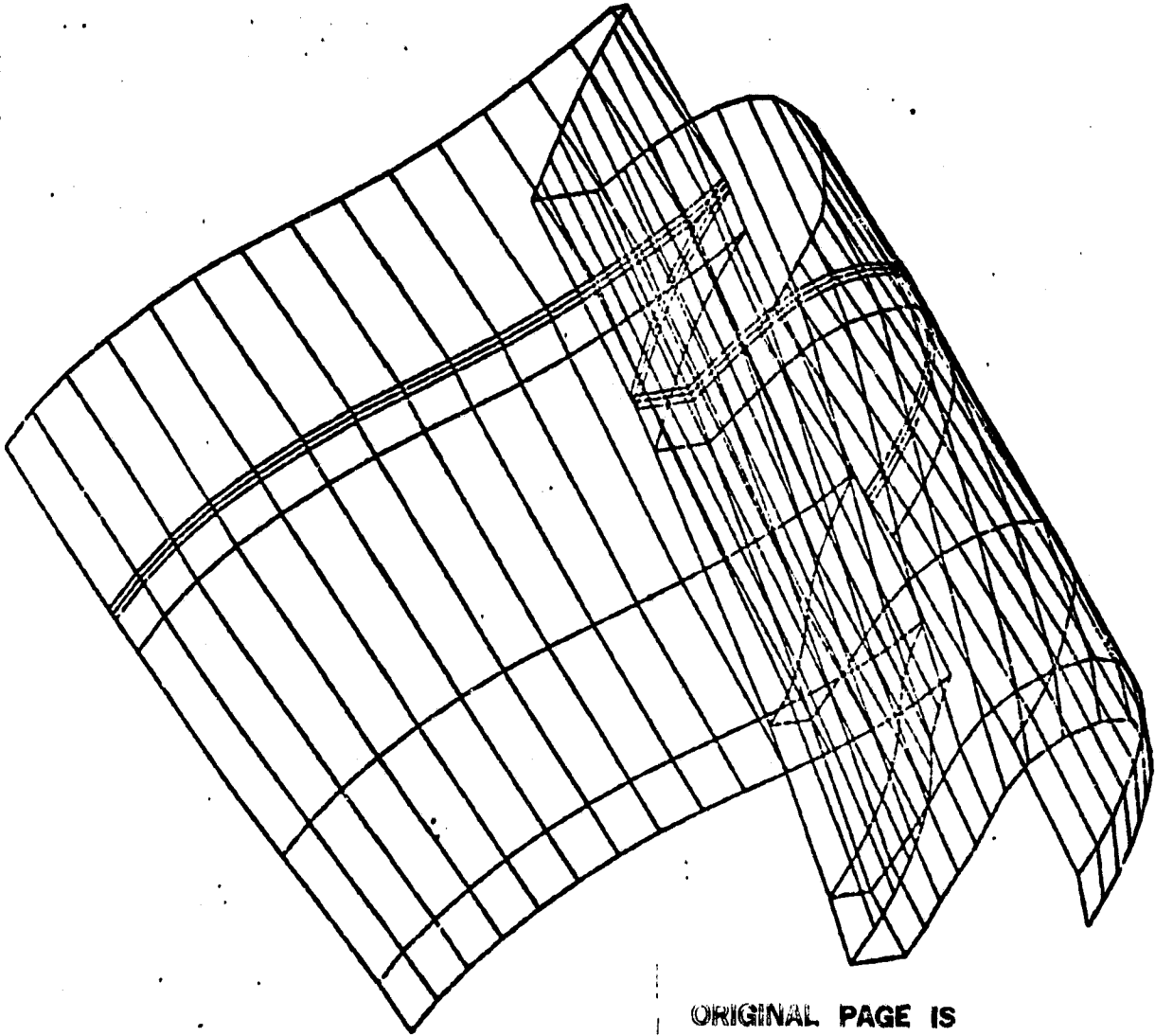
TYPE (V/M) TO ACCEPT THIS SECTION;  
TYPE (M) TO MODIFY SLOPE CONTROLS;

XSTA = 180.000



AREA • 9.5233 SQ. FT. • 1371.36 SQ. IN. PERIMETER • 12.0638 FT. • 144.77 IN.

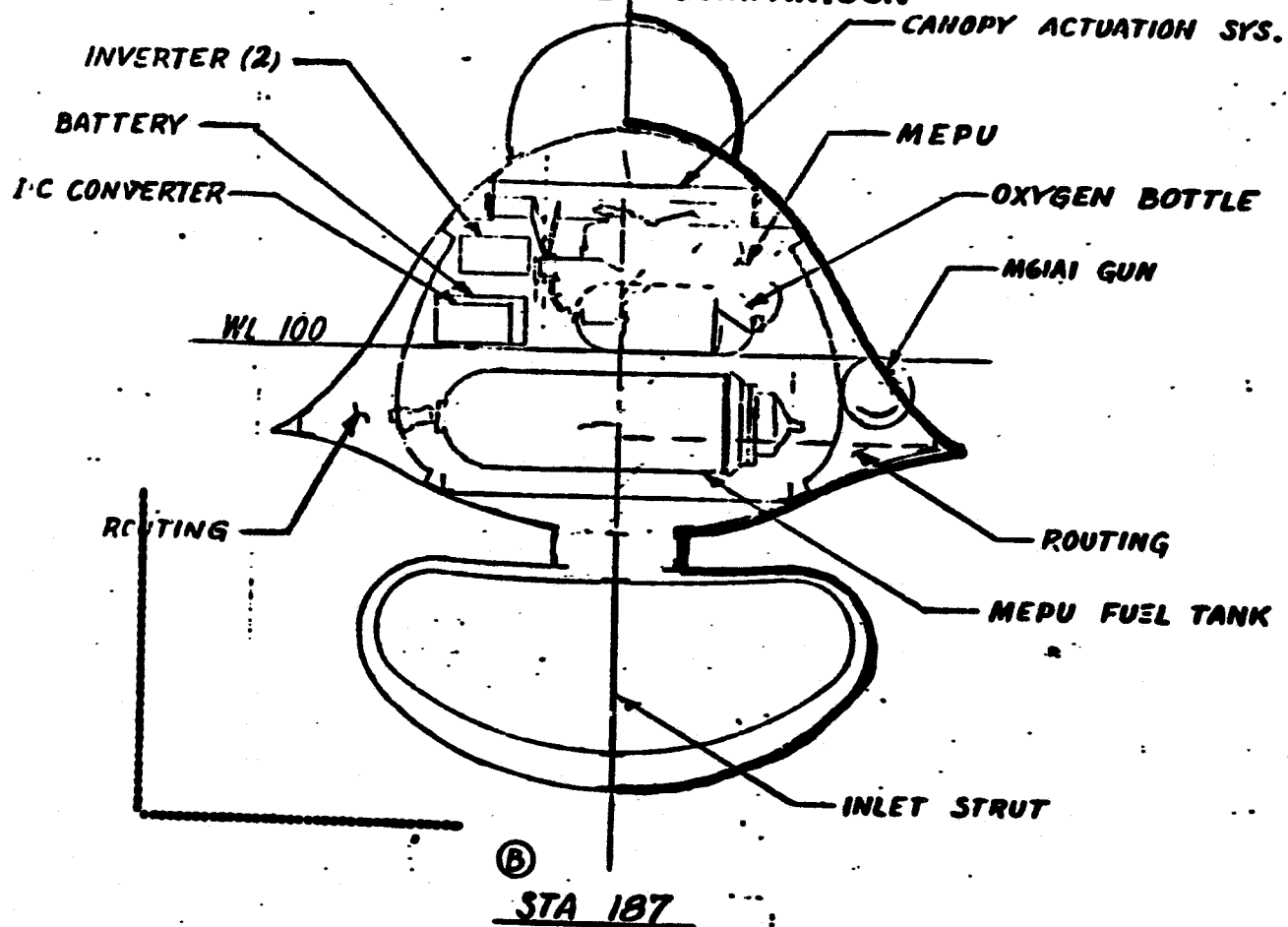
PERSPECTIVE VIEW OF EIGHT CROSS-SECTIONS



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OF POOR QUALITY

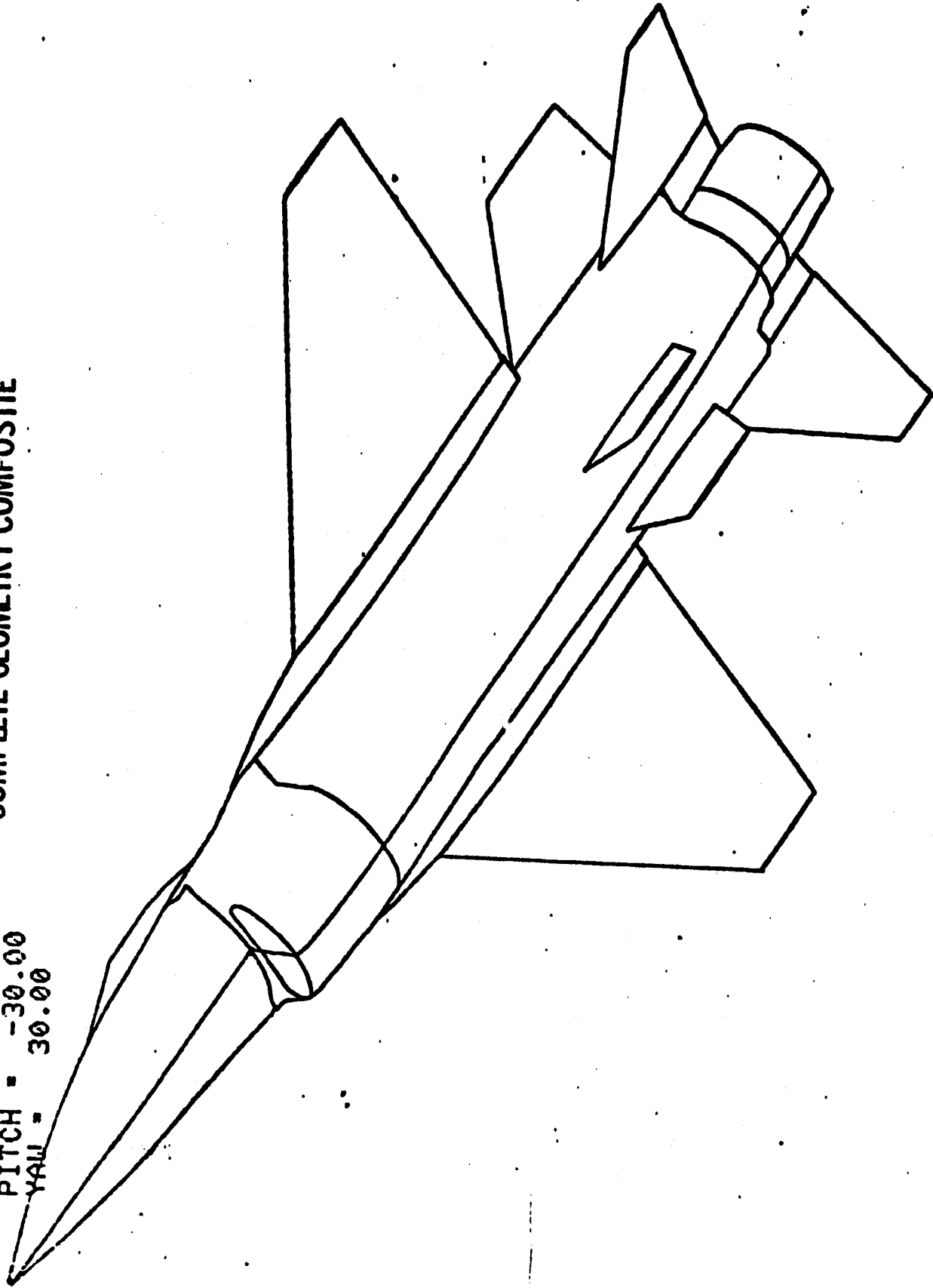
# ORIGINAL CROSS-SECTION

## DIGITIZED COMPARISON

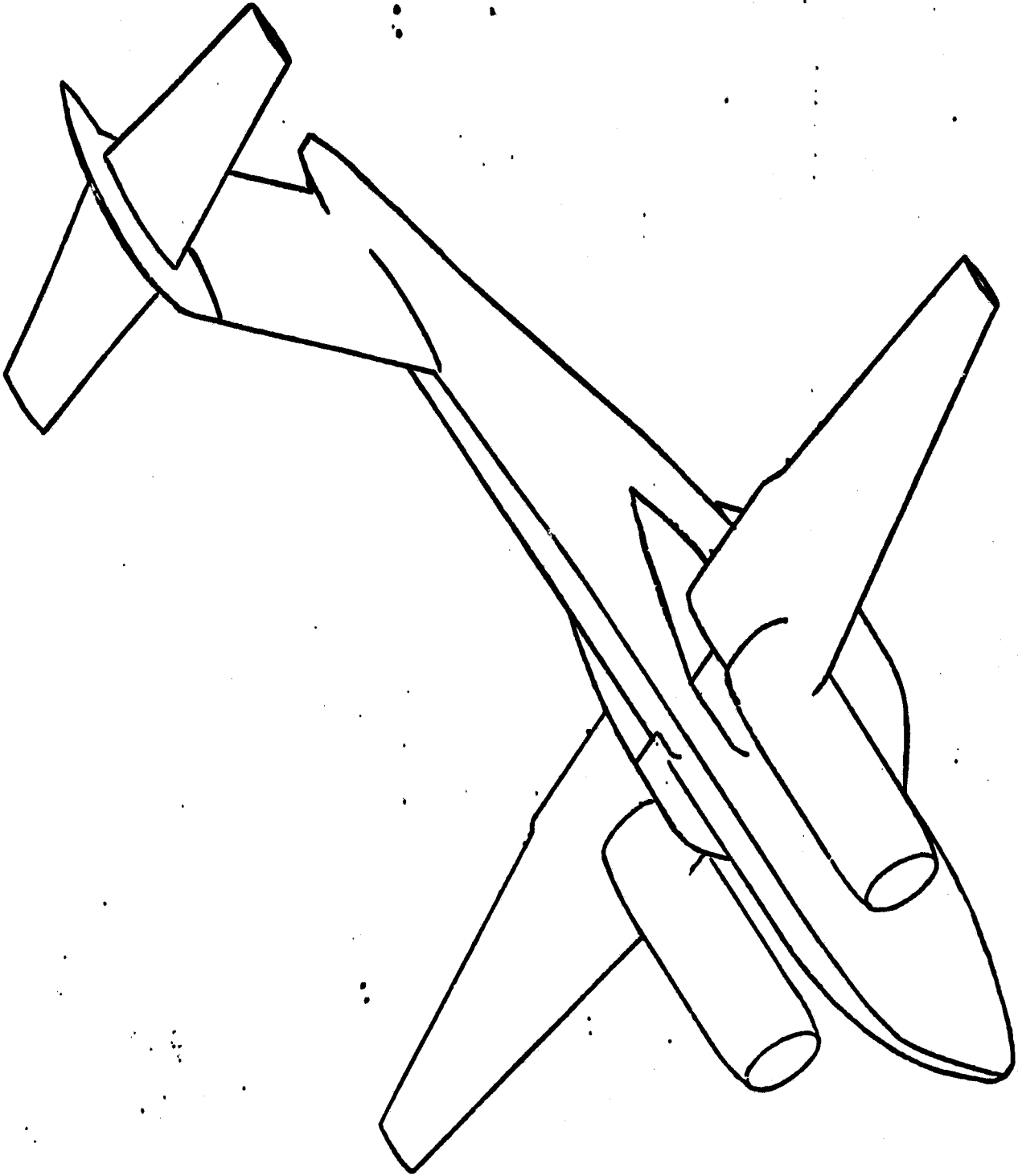


ROLL = -35.00  
PITCH = -30.00  
YAW = 30.00

COMPLETE GEOMETRY COMPOSITE



Brown 17



**SUMMARY**

**CURRENTLY IN USE**

**RAPID AND FLEXIBLE**

**INTERFACE TO USSAERO PROGRAM**

**UPWARD EXPANDABLE**

*Brown/8*

QUICK-GEOMETRY  
REPRESENTATION OF SURFACES

ALFRED F. VACHRIS, JR.  
GRUMMAN AEROSPACE CORPORATION



VACHRIS 1



## OBJECTIVES

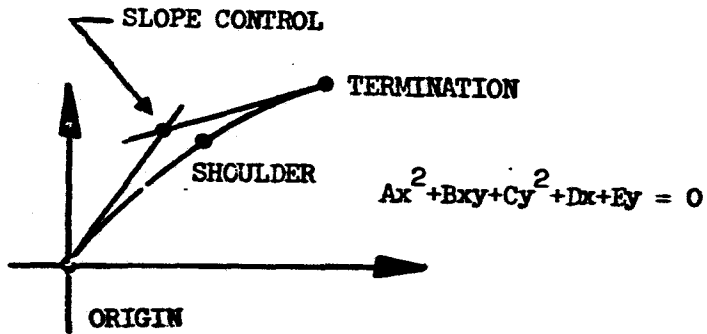
- o ACCURATE MODEL - GEOMETRY DEFINED BY MATHEMATICAL EQUATIONS. SURFACE COORDINATES, SLOPES AND CURVATURES ARE CALCULATED.
- o GENERATE MODELS AT ALL LEVELS OF CONFIGURATION DEFINITION STARTING WITH THE INITIAL "BACK OF THE ENVELOPE" SKETCH THROUGH THE FINAL THREE-VIEW DRAWING.
- o CAPABILITY OF ADDING DETAIL TO THE MODEL AS THE DESIGN IS DEVELOPED.
- o COMMON GEOMETRY - SINGLE SOURCE OF GEOMETRY INPUTS FOR A VARIETY OF PROGRAMS.



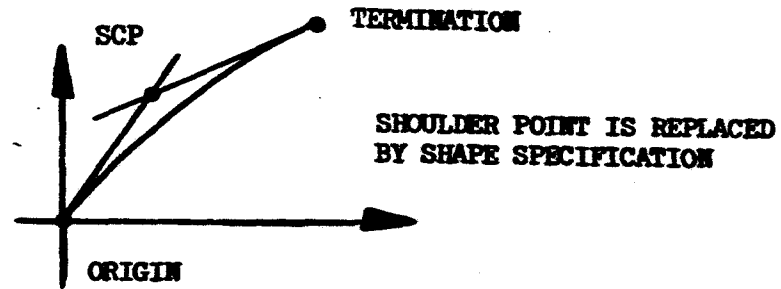
VACHRISZ

# CURVE ELEMENT DEFINITION

## STANDARD LOFTING CONIC



## QUICK CURVE SEGMENT

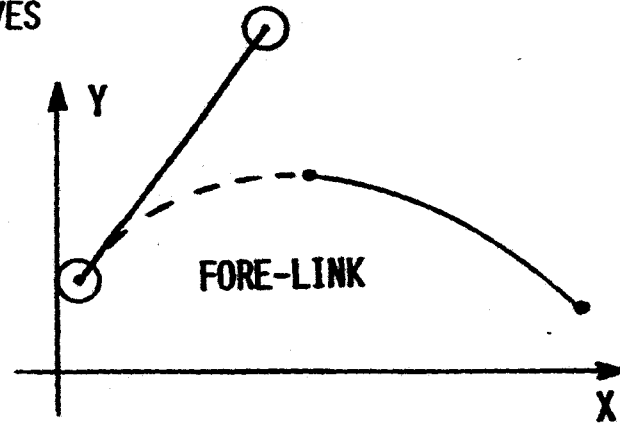
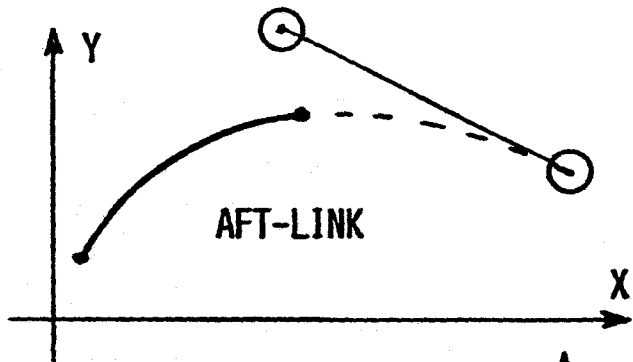


<u>SHAPE</u>	<u>KEYWORD</u>	<u>EQUATION</u>	<u>X-AXIS PARABOLA</u>	<u>ROTATED X-AXIS PARABOLA</u>	<u>X-ELLIPSE</u>
Line	LINE	$Ax + By = 0$			
x-Parabola	XPAR	$Ax + By + y^2 = 0$			
y-Parabola	YPAR	$Ax + By + x^2 = 0$			
Rotated x-Parabola	RXPA	$Ax + By + Cxy + y^2 = 0$			
Rotated y-Parabola	RYPA	$Ax + By + Cxy + x^2 = 0$			
x-Ellipse	ELLX	$Ax + By + Cx^2 + y^2 = 0$			
y-Ellipse	ELLY	$Ax + By + Cy^2 + x^2 = 0$			
Cubic	CUBI(C)	$Ax + By + Cx^2 + x^3 = 0$			

SPURMAN

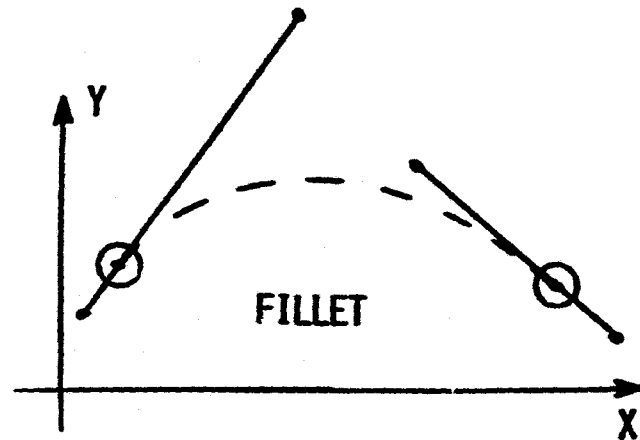
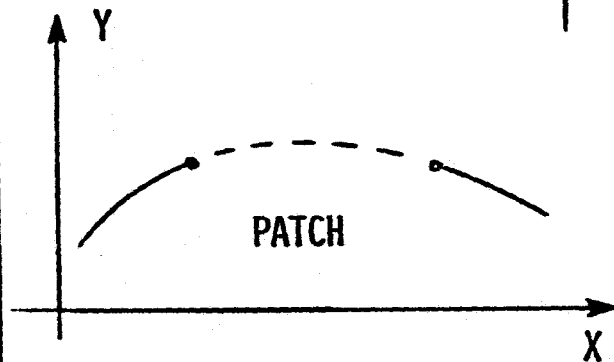
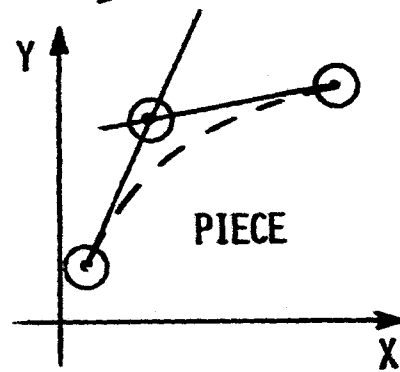
# BLENDING CONTROL FOR CURVE ELEMENTS

CURVE ELEMENTS ARE BLENDED  
TOGETHER TO BUILD UP CURVES



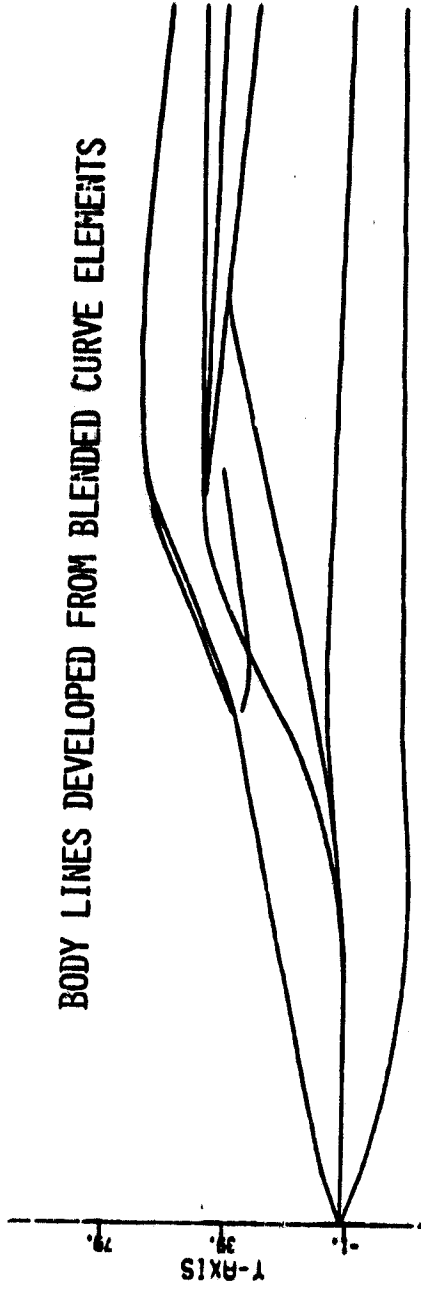
KNOWN POINT •  
INPUT POINT ⊙

KNOWN SEGMENT ———  
INPUT SEGMENT - - - -

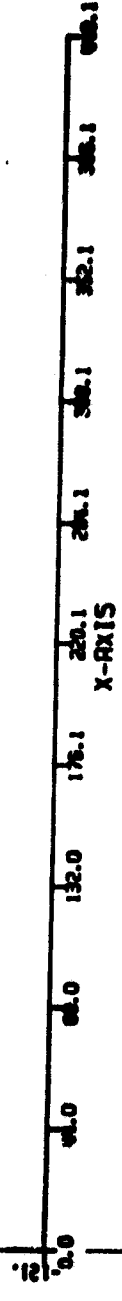


SPILMAN

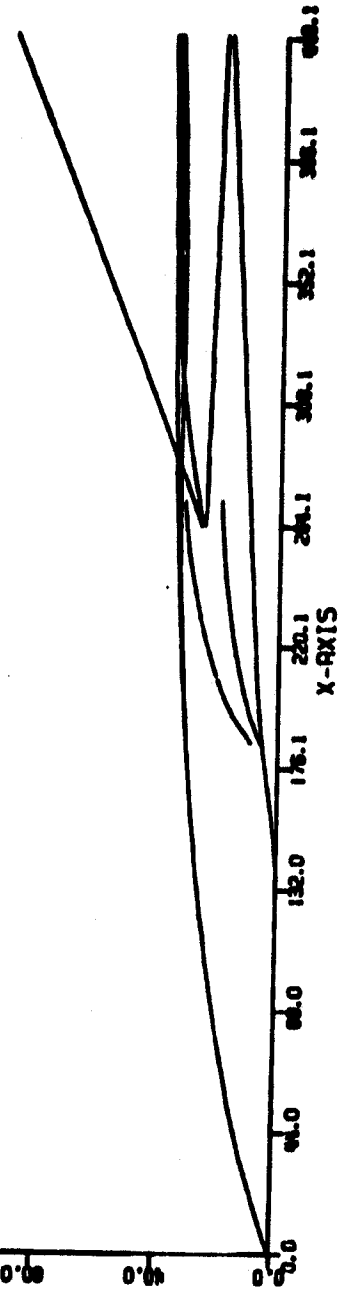
BODY LINES DEVELOPED FROM BLENDED CURVE ELEMENTS



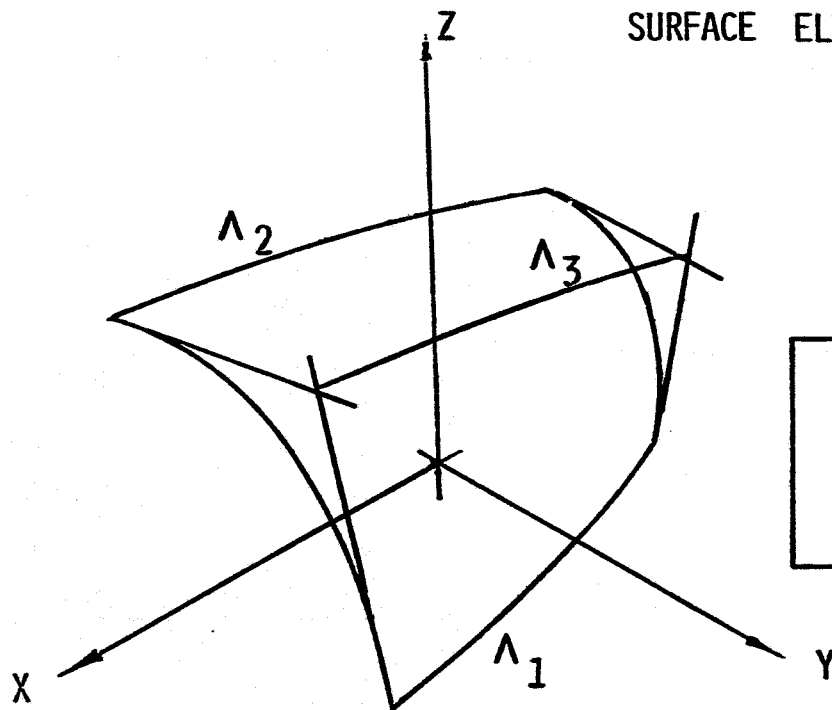
PROFILE-VIEW BODY LINES



PLAN-VIEW BODY LINES



SURFACE ELEMENT



- $\Lambda_1$  - ORIGIN CURVE
- $\Lambda_2$  - TERMINATION CURVE
- $\Lambda_3$  - SLOPE CONTROL CURVE

TYPICAL SHAPE  $\rightarrow$  GROWING ELLIPSE

$$\frac{[Y(X) - Y_0(X)]^2}{A^2(X)} + \frac{[Z(X) - Z_0(X)]^2}{B^2(X)} = 1$$

NOTE THAT QUICK USES BOTH  
CARTESIAN AND POLAR COORDINATES

POLAR FORM  $Q(R, R_0, \theta, \theta_0, A^2, B^2) = 0$

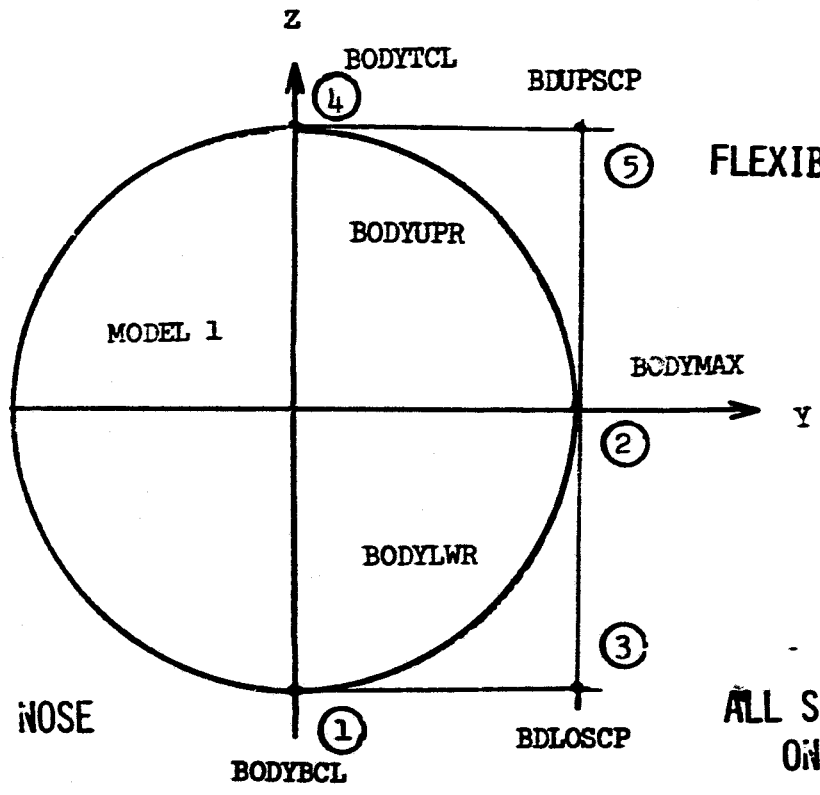
$$B^2 (R \cos \theta - R_0 \cos \theta_0)^2 + A^2 (R \sin \theta - R_0 \sin \theta_0)^2 - A^2 B^2 = 0$$

WHERE  $R_0 = R_0(X)$ ;  $\theta_0 = \theta_0(X)$ ;  $A^2 = A^2(X)$ ;  $B^2 = B^2(X)$

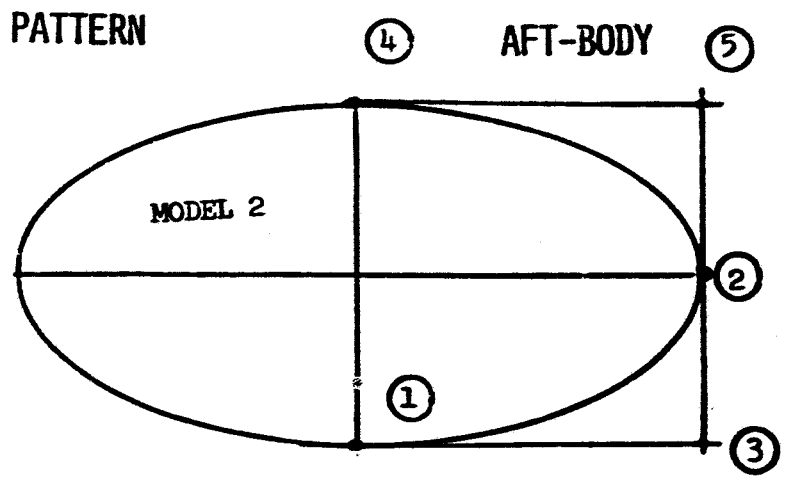
Q IS DIFFERENTIABLE PRODUCING

$$\frac{DR}{DX}, \frac{DR}{D\theta}, \frac{D^2R}{DX^2}, \frac{D^2R}{DXD\theta}, \frac{D^2R}{D\theta^2}$$

BRUNNAN

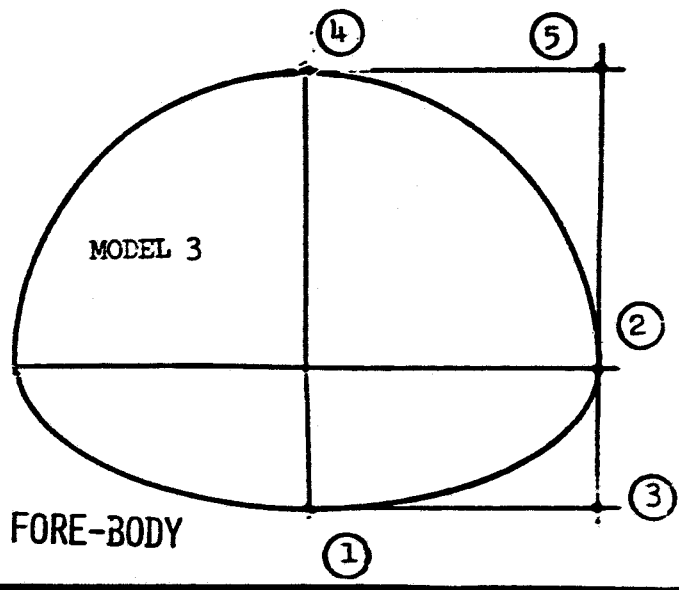


FLEXIBLE PATTERN

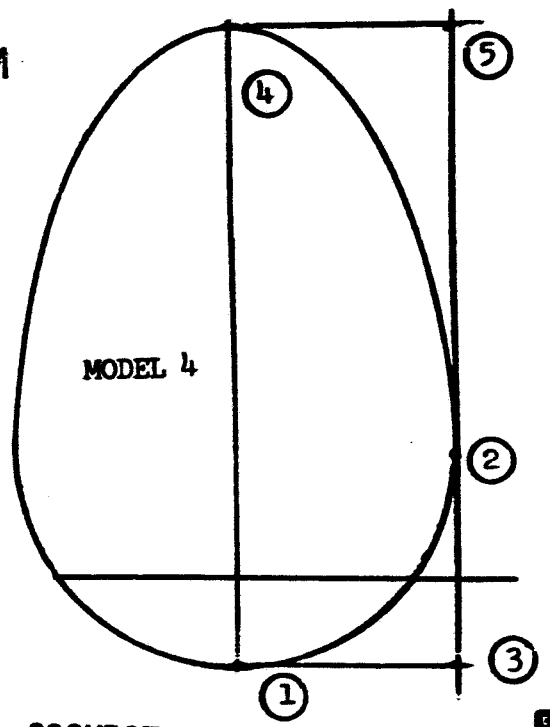


AFT-BODY

ALL SHAPES FROM ONE PATTERN



FORE-BODY

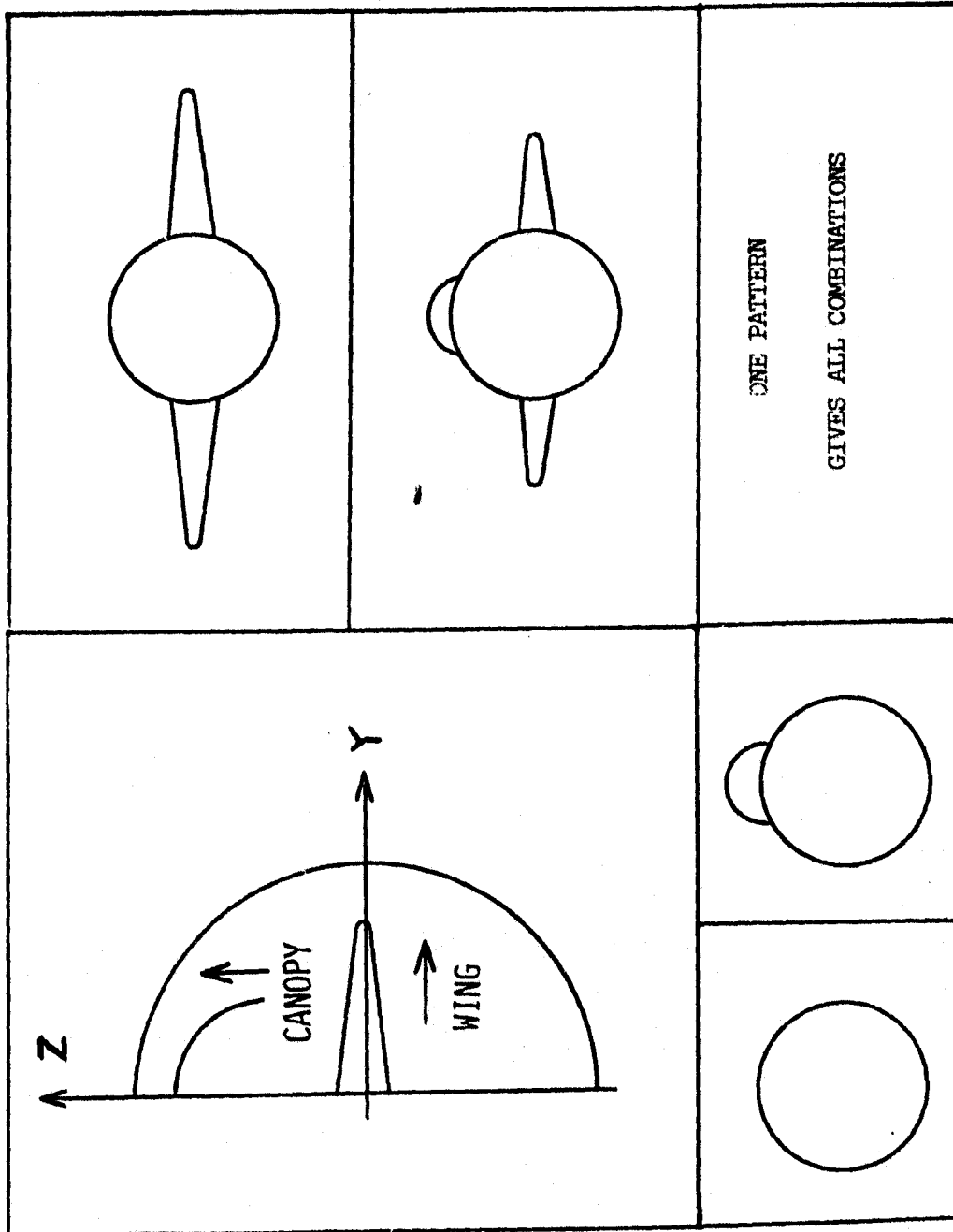


COCKPIT

GRUMMAN

INTERSECTING ARCS  
CONTROL CROSS-SECTION GEOMETRY

ADAPTING PATTERN



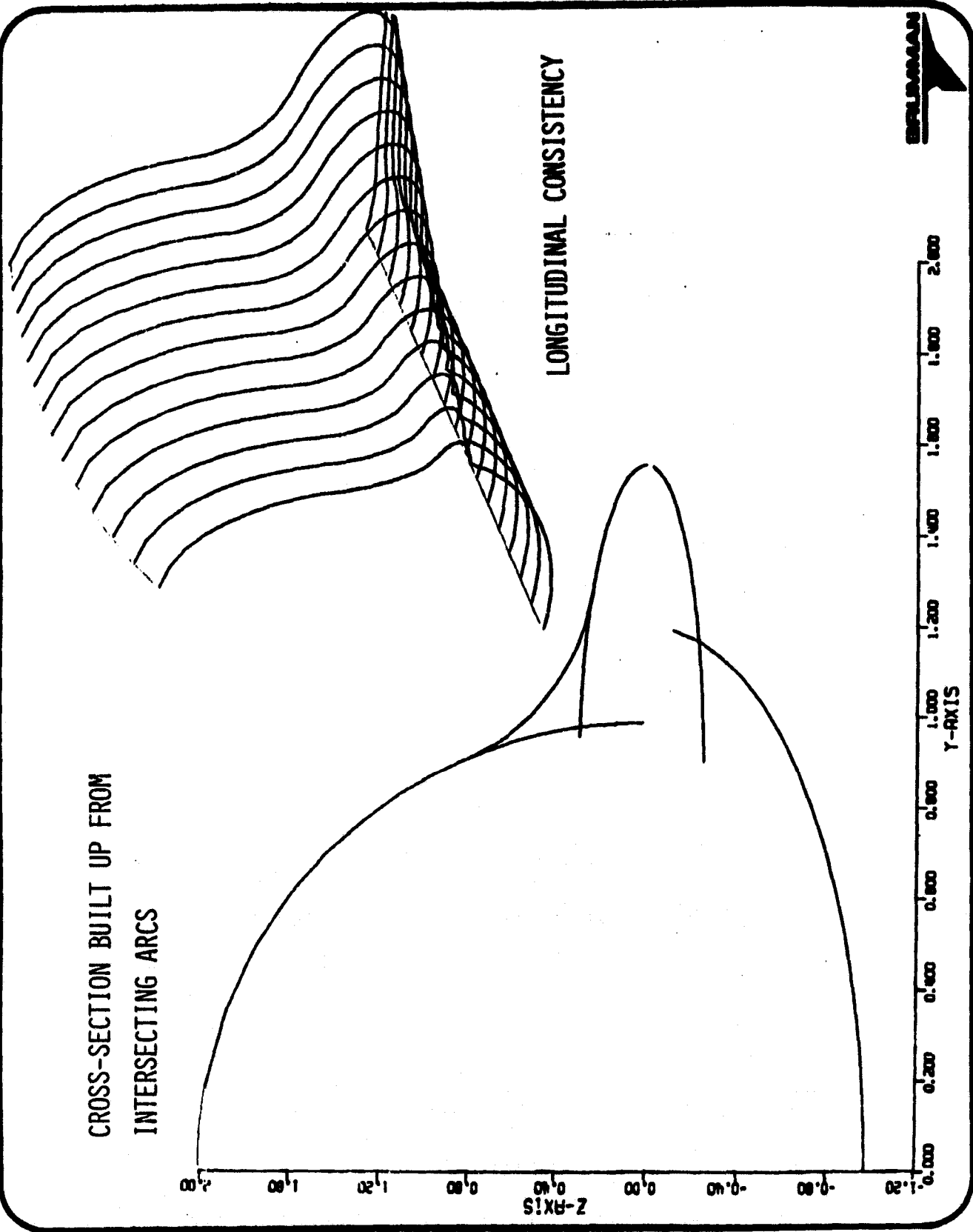
CROSS-SECTION BUILT UP FROM  
INTERSECTING ARCS

Z-AXIS  
-1.20  
-0.80  
-0.40  
0.00  
0.40  
0.80  
1.20  
1.60  
2.00

LONGITUDINAL CONSISTENCY

SPURRMAN

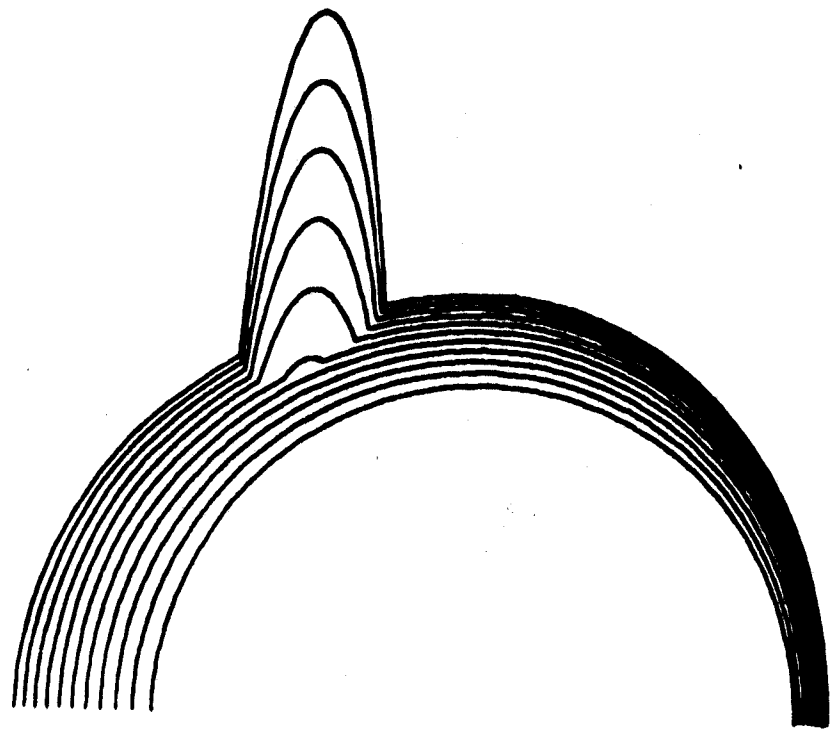
Y-AXIS  
0.000  
0.200  
0.400  
0.600  
0.800  
1.000  
1.200  
1.400  
1.600  
1.800  
2.000



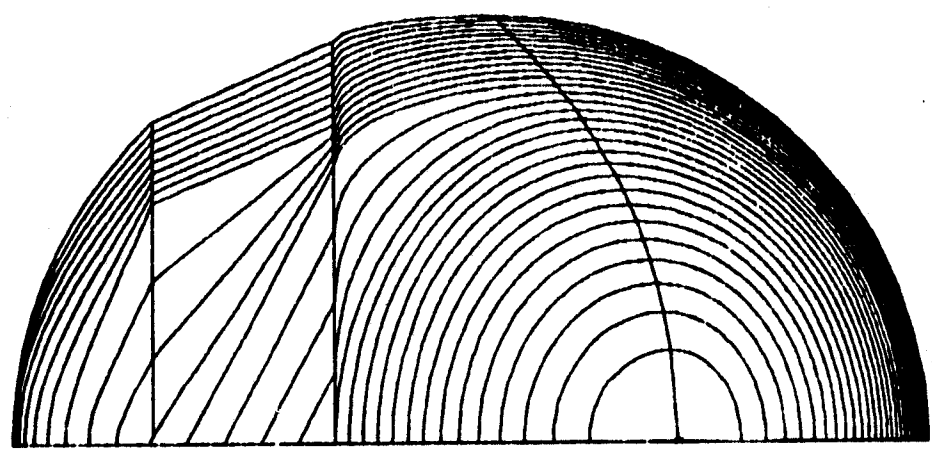




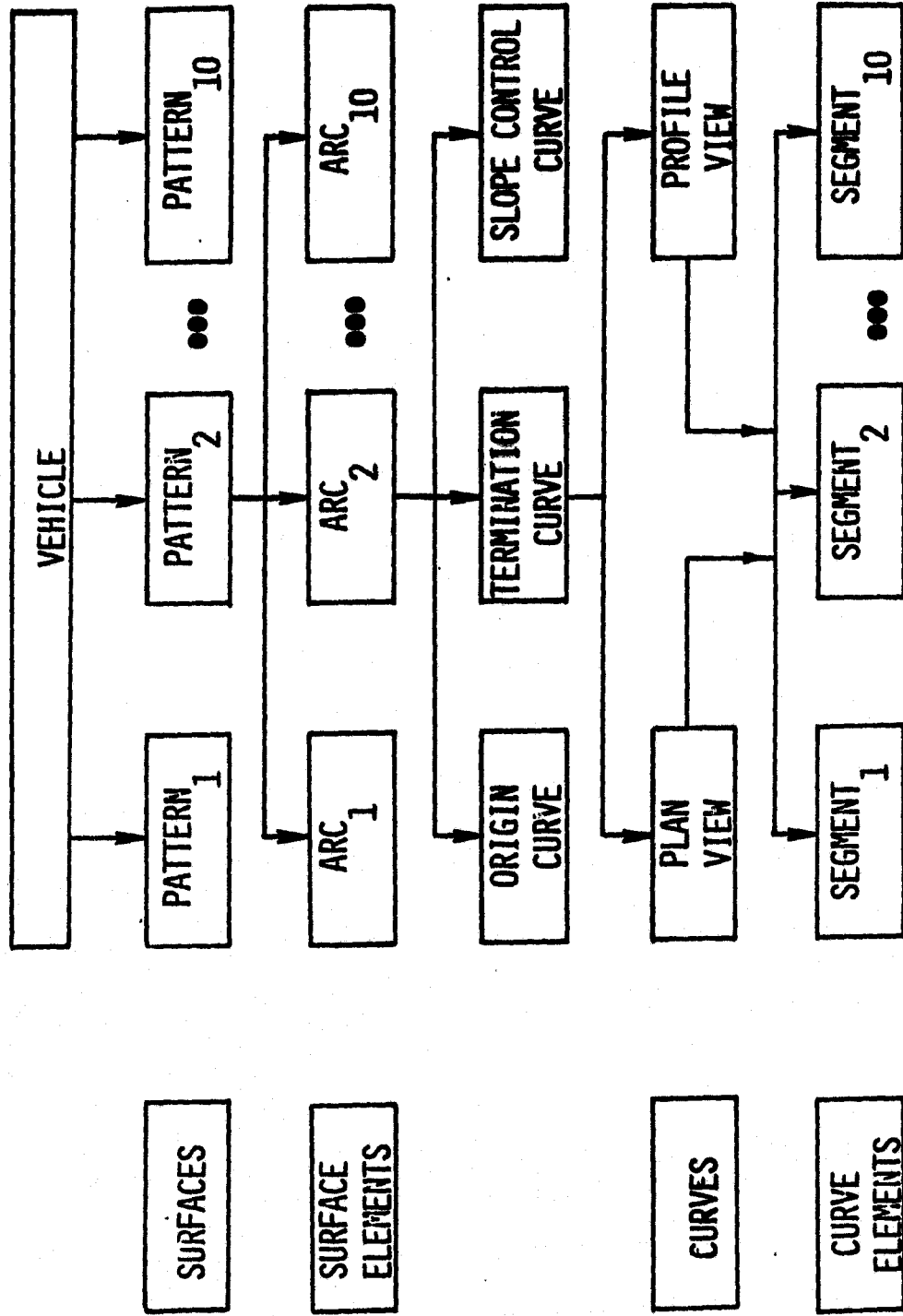
DETAILED CROSS-SECTION GEOMETRY



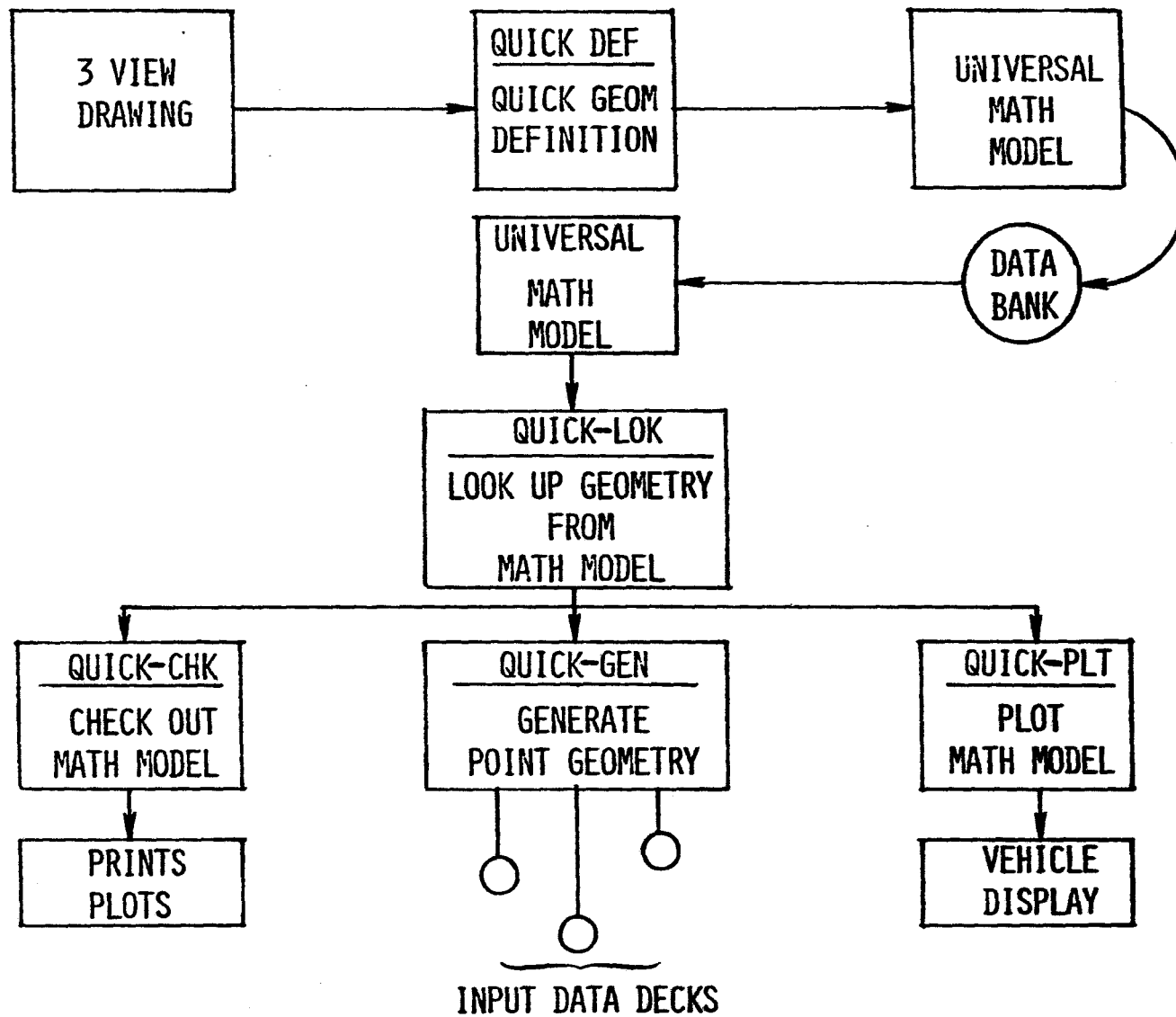
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OF POOR QUALITY



# DATA STRUCTURE



OVERVIEW OF THE QUICK-GEOMETRY SYSTEM



## QUICK-GEOMETRY INTERFACE

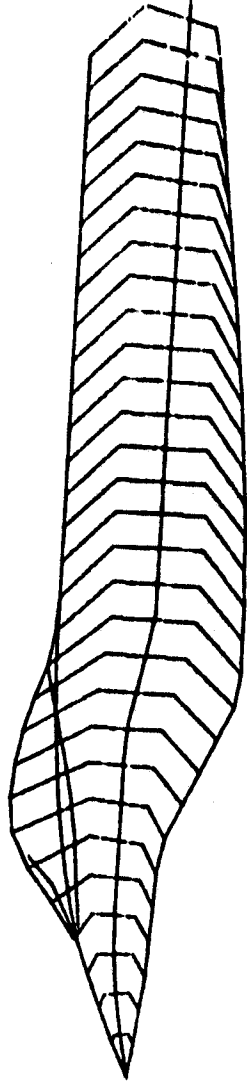
1

7

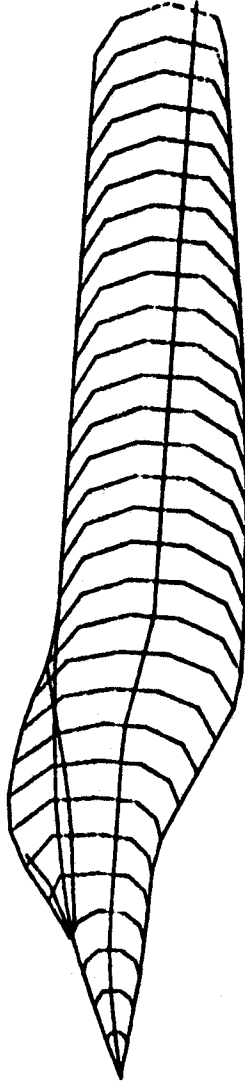
C	PROGRAM: YOUR CODE
C	COMMON BLOCKS FOR COMMUNICATION WITH QUICK COMMON/QUICK/...
C	READ IN QUICK-GEOMETRY MATH MODEL CALL GEOMIN (IREAD, IRITE) : : :
C	GET SURFACE POINT AND LOCAL DERIVATIVES CALL CSGEOM (X,H,R,RX,RH,RXX,RXH,RHH) : : : END



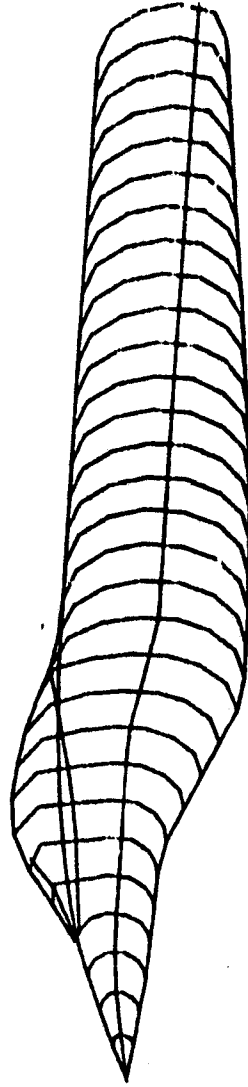
FUSELAGE MODELS FOR PANEL AERODYNAMICS



3 PANELS  
PER SIDE

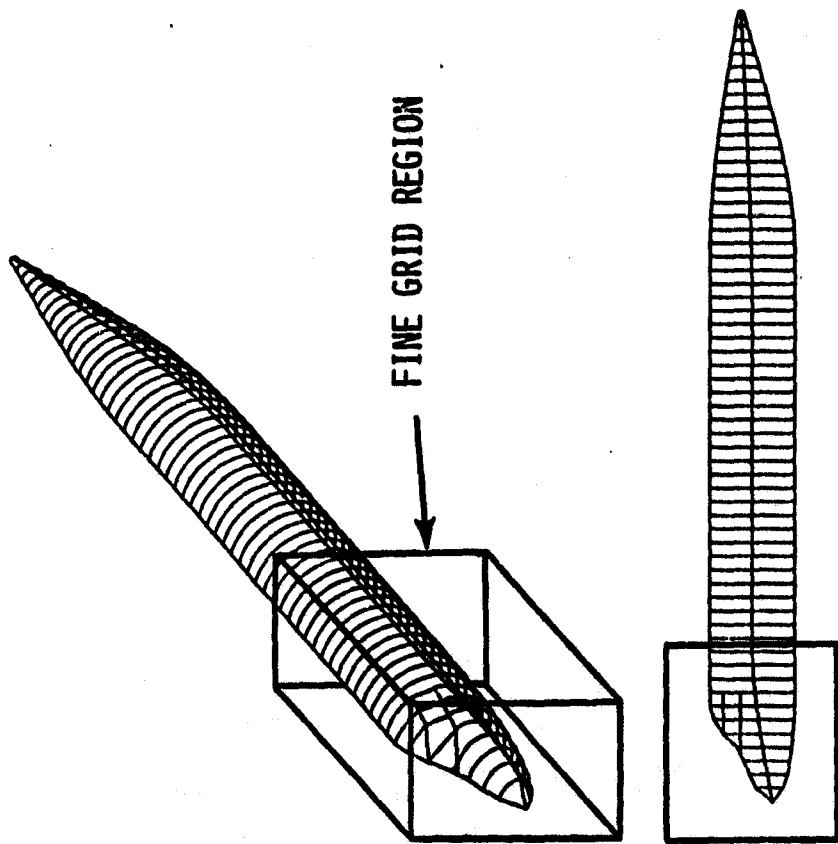


5 PANELS  
PER SIDE

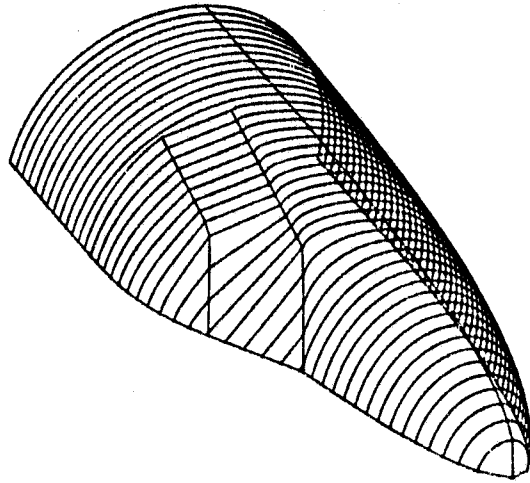
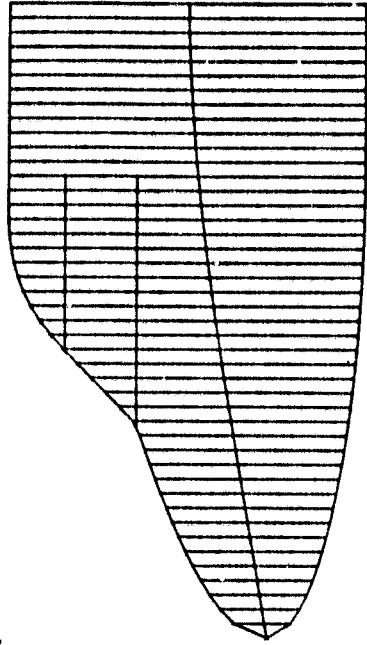


10 PANELS  
PER SIDE

**BODY GEOMETRY FOR TRANSONIC FLOW CALCULATIONS**  
**COARSE GRID**



DETAILS OF BODY GEOMETRY FOR  
FINE GRID REGION



**CURRENT LIMITATIONS**

- o **SINGLE SURFACE GEOMETRY - NO INTERNAL SURFACES**
- o **VEHICLE COMPONENTS ARE INPUT AS PART OF A COMPOSITE MODEL**
- o **WING GEOMETRY MODELED ONLY IN WING-BODY JUNCTION AREA**
- o **CROSS-SECTIONS SHAPES: LINE, CIRCLE, ELLIPSE/HYPERBOLA**



VACHRS 17



## IMMEDIATE PLANS

- o ARC LENGTH LOOKUP FOR MULTIPLE SURFACES
- o WING GEOMETRY DEFINED BY BUTTLINES
- o INTERFACE WITH A SURFACE PATCH TECHNIQUE
- o MODEL SYNTHESIS FOR PRELIMINARY DESIGN

GRUMMAN

VACHRIS18

### Interactive Input For The QUICK Geometry System

In order to compute the flow around any body in detail, the body surface description must be sufficiently smooth to avoid generating disturbances that would not occur on the prototype. Also, many of the methods for flow computation require points on the surface to be defined without restrictions imposed by the geometry method. These requirements can be met by defining the surface analytically. An added benefit of analytic geometry definition is that it allows derivatives of the surface contour to be determined analytically and therefore exactly.

The QUICK geometry system<sup>1</sup> fills that need for an analytic surface definition method for a wide range of moderately complex aircraft geometries. It has been applied to such codes as a supersonic shock-fitting finite difference method<sup>2</sup> and a transonic wing-body flow code<sup>3</sup>. A system for generating the inputs to QUICK interactively, using a graphics terminal connected to a time-sharing computer system, will be described. When fully developed, this system will make QUICK much easier to use and therefore more readily accessible to anyone requiring its capabilities.

1. Vachris, A. F., Jr.; and Yaeger, L. S.: QUICK-Geometry - A Rapid Response Method for Mathematically Modelling Configuration Geometry. NASA SP-390, 1975, pp. 49-61.
2. Marconi, F.; and Yaeger, L. S.: Development of a Computer Code for Calculating the Steady Super/Hypersonic Inviscid Flow Around Real Configurations. NASA CR-2676, 1976.
3. Boppe, C. W.: A Computational Method for Transonic Wing-Body Flows. AIAA Paper 78-104, January 1978.

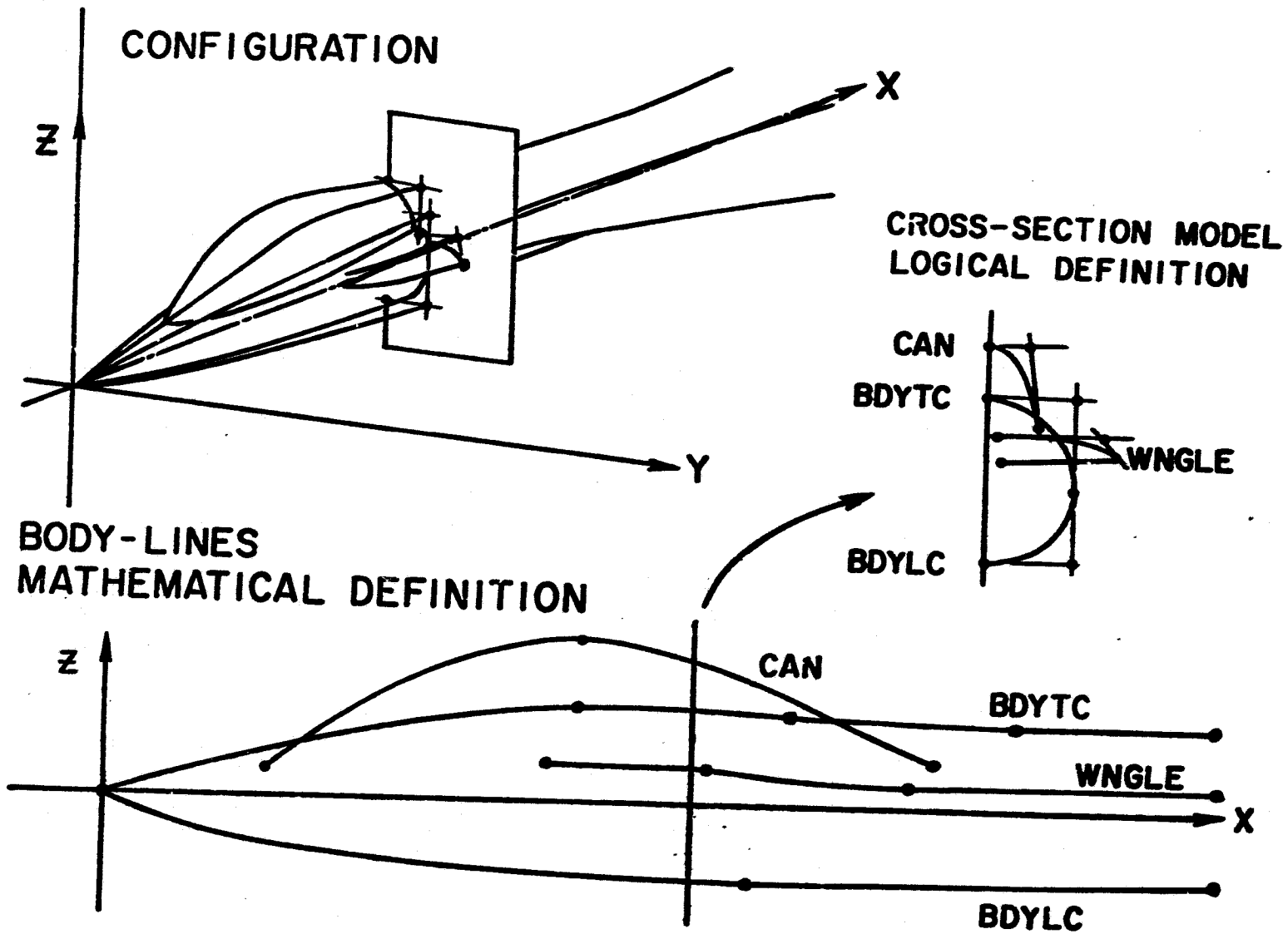
# QUIKII

## INTERACTIVE INPUT FOR THE 'QUICK' GEOMETRY SYSTEM

- ANALYTIC GEOMETRY DEFINITION NEEDED
  - SMOOTH SURFACE
  - UNRESTRICTED SURFACE MESH POINTS
  - ANALYTIC DERIVATIVES
- 'QUICK' FILLS THIS NEED
  - SHOCK-FITTING FINITE DIFFERENCE (MARCONI)
  - TRANSONIC WING-BODY COMPUTATION (BOPPE)
- INTERACTIVE INPUT USING GRAPHICS
  - MAKES 'QUICK' MUCH EASIER TO USE

In the QUICK geometry system concept the aircraft surface is enveloped by a series of body lines. Each of these lines is a mathematically defined curve in space, consisting of a sequence of linked curve segments (generally conics). The intersection of these body lines with any desired cross-section plane defines a set of control points in that plane. Elliptical arcs fitted to these control points according to a logically defined cross-section model determine the surface shape at that axial location.

# CONCEPT OF QUICK METHOD



TOWNSEND 2

A principle barrier to the use of QUICK has been the difficulty in understanding the concept and relating it to the required program inputs. Especially, having to begin the inputs with logical definitions of cross section models has turned some people away without giving the program a fair trial. Once the concept has been mastered, further difficulties arise in trying to accurately match any even moderately complex configuration. Some of these difficulties are related to the geometric limitations of QUICK itself, particularly the requirement that the surface be single-valued in polar coordinates. But, aside from these, there is often difficulty in finding the appropriate locations of body lines controlling surface slopes or in choosing which of the many possible shapes for a body line segment gives the best surface fit with the desired configuration. Making these choices often comes down to an iterative situation for which batch mode operation is too cumbersome to allow a sufficient number of trials to completely determine the optimum model.

What is needed is a new mode of operation which will immediately display the results of a choice graphically to allow its evaluation, which will allow new choices to be made interactively with the computer as required, and which will lead the user through the process of making choices until the whole configuration has been designed. This mode of operation would also do much to avoid the barrier to conceptual understanding of QUICK.

## DIFFICULTIES IN USING 'QUICK'

- CONCEPTUAL
- MATCHING A GIVEN CONFIGURATION
- LIMITATIONS ON GEOMETRY ALLOWED
- BATCH MODE TOO CUMBERSOME

## NEED

- GRAPHICS
- INTERACTION
- 'LEADING THROUGH'

The concept being developed stems from the need to work interactively with the computer using a graphics terminal for display and user input. It will generate an input file (or card deck) in the formats required for the inputs to QUICK. It will operate within the geometric limitations of QUICK (using the same equations and sub-routines where possible) so that the resulting configuration should be acceptable by the QUICK system.

In this concept the control point locations in the cross sections are defined (numerically) as the cross section models are being defined (logically). These control point locations from the cross sections are then "strung together," using the QUICK curve segments interactively, to define the body lines. A data base system (SPAR<sup>4</sup>) is used for mass storage.

4. Giles, Gary; and Haftka, Raphael: SPAR Data Handling Utilities. Proposed NASA TP.



## CONCEPT OF 'QUICK' INTERACTIVE INPUT

- WORK INTERACTIVELY USING GRAPHICS TERMINAL
- GENERATE A 'QUICK' INPUT FILE
- OPERATE WITHIN 'QUICK' LIMITATIONS
- DEFINE CROSS SECTION POINTS FIRST
- DEFINE BODY LINES FROM CROSS SECTION POINTS
- USE DATA BASE (SPAR) FOR MASS STORAGE

These next few slides were made directly from the screen of the graphics terminal. They show some features of the interactive input concept as it has been implemented so far.

Slide 5 shows the first displays on the screen. The circles indicate user responses. "Restart" provides for the option to continue working on a configuration previously started but not completed. The list of cross sections below the response "3" refers to input cross sections to be matched. These are sets of (y,z) surface points obtained by digitizing from drawings or by taking cross section cuts through some other surface description (e.g. Harris inputs). They are previously stored on the data base. There might be a hundred of these, but only the four used for the check case are shown.

QUICK requires as input for the cross-section logical definitions Hollerith control point names, which later become Hollerith body-line names in the body line definition phase of input. The 24 control point names shown were pre-selected so that the user can refer to them by number, rather than by typing names into the key board. The model names help the user keep track of which cross-section logical definitions have been made. The arc shapes and types are also Hollerith inputs required by QUICK and referred to by number.

LIST OF MODEL NAMES, CONTROL POINT NAMES, ARC SHAPES AND ARC TYPES  
PRE-SELECTED FOR 'QUICK' (AS DISPLAYED ON SCREEN)

?

DATA SPACE= 12542 32-BIT WORDS  
 HIT 1 FOR RESTART

②

HIT 1 FOR A LIST OF CROSS SECTIONS  
 HIT 2 FOR MODEL AND CP NAMES, ARC SHAPES AND TYPES  
 HIT 3 FOR BOTH  
 HIT 4 FOR NO MENU

③

I	X	I	X	I	X	I	X	I	X
20	18.000	21	22.000	22	26.000	23	30.000	5	0.000

MODEL NAMES	CP NAMES		ARC		
			SHAPE	TYPE	
	0	NONE			
SHRP	1	B BC	13 W LE	LINE	PIEC
2ELL	2	BBTN	14 WBOS	CIRC	FLIN
3ELL	3	B BS	15 W TM	ELLI	ALIN
4ELL	4	BBSC	16 WTOS	ELLO	PATC
FR0T	5	BSTN	17 W TI		FILE
FSID	6	BSSC	18 WTTS		NULL
FTOP	7	BTTN	19 P BC		
FT/B	8	B TC	20 P BI		
3FLT	9	BTSC	21 PBSC		
LMPY	10	W BI	22 P TI		
	11	W BM	23 P TC		
	12	WBIS	24 PTSC		
	99	STOP			

INPUT CROSS SECTION  
 INPUT 0 TO END PROG

Slides 6A, 6B, and 6C show three stages in the logical definition of a cross section model. The cross section to be matched was obtained from Harris inputs for a supersonic fighter proposal. The cursor is used to locate the map axis (center for polar representation of cross section by QUICK) and each control point as it is called for. A list of control points used is displayed at the upper right. After the user has located the two or three control points needed to define an arc, he enters three numbers corresponding to the arc type, the arc before and the arc after (0 if none). The arc so defined is immediately displayed on the screen to be accepted or rejected. Since the arcs are drawn using the same equations as QUICK uses, any satisfactory arc will be satisfactory when done by QUICK; conversely, if an arc is unsatisfactory it would not be done correctly by QUICK and must be done again with changes in control point location or type. When all of the arcs have been defined, the arc numbers are input in order, thus completing the logical description of the cross section model. The completed cross section is shown as slide 6C. Note that several arc types were used in its definition.

The above process has not only logically defined the model but has also located the control points at one x-station. These locations will later be used to define the body lines.

# EARLY STAGE OF CROSS SECTION MODEL DEFINITION

X- 26.0000

CONTROL POINTS,  
ARC TYPE AND SHAPE  
LISTED AS DEFINED

1 B BC  
2 BBTN  
3 B BS  
5 BSTN

FBOT

PIEC LINE

MAP AXIS

CROSS SECTION TO BE MATCHED

CURSOR POSITIONED TO DEFINE  
SECOND CONTROL POINT (5 BSTN)  
FOR ANOTHER LINE

FIRST ARC DEFINED  
AS STRAIGHT LINE SEGMENT

CUES

INPUT ID FOR MODELS  
MAP AXIS  
CP NAME  
ARC TYPE, ARCS BEFORE AND AFTER

OK (CR)

J C TOWNSEND NASA LANGLEY 2/78 GA

# COMPLETED CROSS SECTION MODEL DEFINITION

X= 26.0000

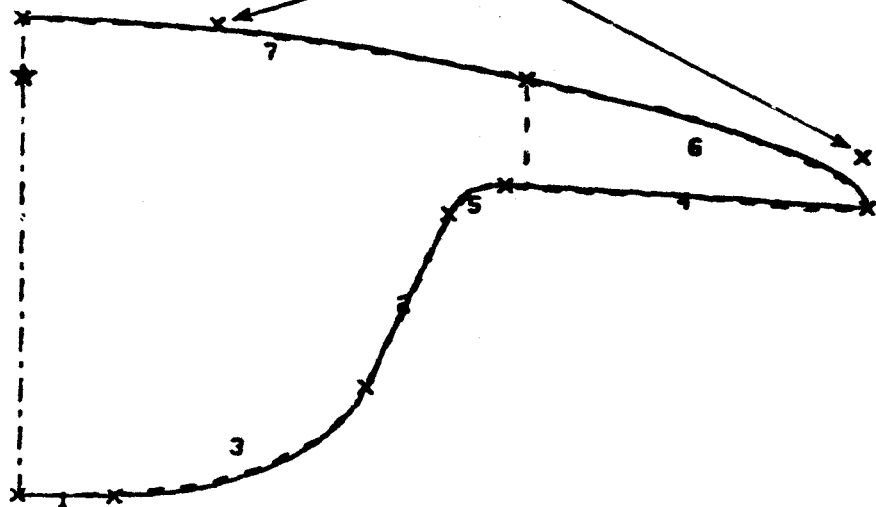
INPUT CROSS

FBOT

COMPLETE LIST OF  
CONTROL POINT NAMES,  
ARC TYPES AND SHAPES  
TO DEFINE THIS MODEL

1	B BC		
2	BBTN	PIEC	LINE
3	B BS		
5	BSTN	PIEC	LINE
2	BBTN		
3	B BS	PATC	ELLI
10	U BI		
13	U LE	PIEC	LINE
5	BSTN		
10	U BI	PATC	ELLO
13	U LE		
15	U TR		
16	UTOS	PIEC	ELLI
15	U TR		
8	B TC		
9	BTSC	ALIN	ELLI

SLOPE CONTROL POINTS  
USED FOR ARCS 6 AND 7



CUES

INPUT ID FOR MODELS

MAP AXIS

CP NAME

ARC TYPE, ARCS BEFORE AND AFTER

PATCH CP

OK (CR)

INPUT ARC NO IN ORDER 325467

Slides 7A and 7B show stages in the process of locating the control points at another x-station using the same cross section logical definition. As soon as the user has indicated that this cross section will use a previously defined cross section model, the complete list of control points and arcs pertaining to that model is displayed and the triangular symbols appear where they occurred on the previous cross section (7A). All that is necessary is to locate the points using the cursor, going down the list. As shown in 7B, a "Q" next to a control point name and a square symbol over the corresponding triangle indicates it is the next to be located. As the arcs are defined they are immediately drawn so they can be checked against the cross section to be matched.

BEGIN NEW CROSS SECTION WITH SAME MODEL

X = 30.0000

COMPLETE LIST OF  
CONTROL POINTS  
AND ARCS  
(ARC NAMES SHOW  
PHYSICAL ORDER)

FBOT

B BC			
BSTN	PIEC	ARC0	LINE
B BS			
BSTN	PIEC	ARC2	LINE
BSTN			
B BS	PATC	ARC1	ELLI
U BI			
U LE	PIEC	ARC4	LINE
BSTN			
U BI	PATC	ARC3	ELLO
U LE			
U TH			
UTOS	PIEC	ARC5	ELLI
U TH			
B TC			
BTSC	ALIN	ARC6	ELLI

CURSOR TO DEFINE MAP AXIS

TRIANGLES SHOW LOCATIONS OF CONTROL POINTS  
FOR PREVIOUS CROSS SECTION

CROSS SECTION TO BE MATCHED

CUES → INPUT ID FOR MODEL ⑤  
MAP AXIS



LATER STAGE FOR NEW CROSS SECTION (SAME MODEL)

X= 30.0000

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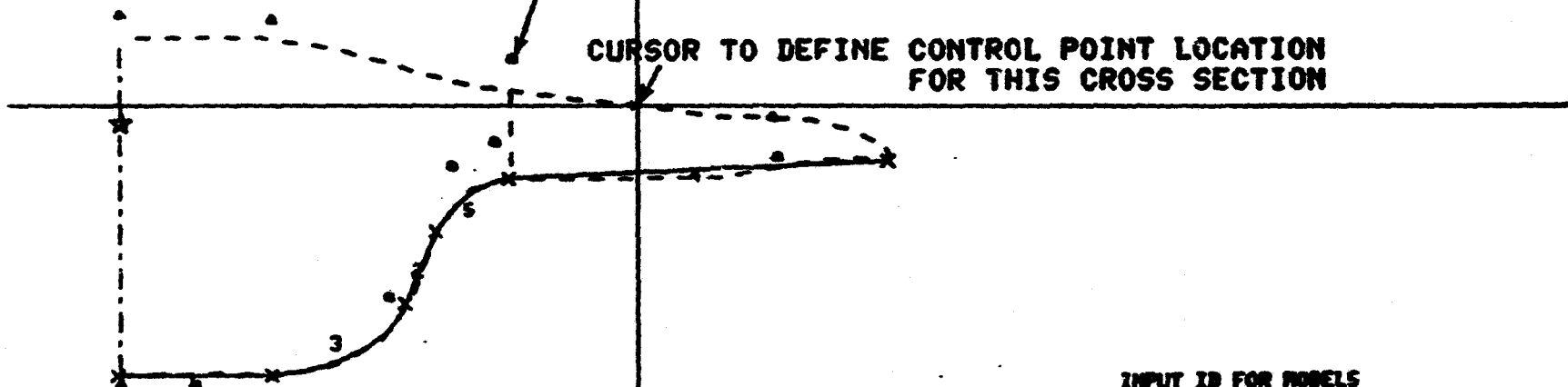
\*Q\* SHOWS CONTROL  
POINT LOCATION TO  
BE DEFINED NEXT

SQUARE SHOWS PREVIOUS  
LOCATION OF NEXT CONTROL POINT

CURSOR TO DEFINE CONTROL POINT LOCATION  
FOR THIS CROSS SECTION

FBOT

OB DC			
OBSTH	PIEC	ARC0	LINE
OB DS			
OBSTH	PIEC	ARC2	LINE
OBSTH			
OB DS	PATC	ARC1	ELLI
OU BI			
OU LE	PIEC	ARC4	LINE
OBSTH			
OU BI	PATC	ARC3	ELLO
OU LE			
OU TH			
UTOS	PIEC	ARC5	ELLI
U TH			
B TC			
BTSC	ALIN	ARC6	ELLI



INPUT ID FOR MODELS  
MAP AXIS

OK (OR)

J C TOWNSEND MASA LANGLEY 2/78 7B

Slide 8 shows the same cross section as on the previous slide. Because of the reverse curvature it was impossible to match the top of this cross section using the same cross section model logical definition. Therefore a new logical definition was made with two additional arcs. Note that arc 7 was not done correctly the first time and had to be done over. On a graphics terminal having a refresh capability the erroneous arc would be deleted so as not to clutter the screen. Note also that the last two arcs could have been done over by moving the control points slightly so as to represent the desired surface more closely.

# COMPLETED SECOND CROSS SECTION MODEL

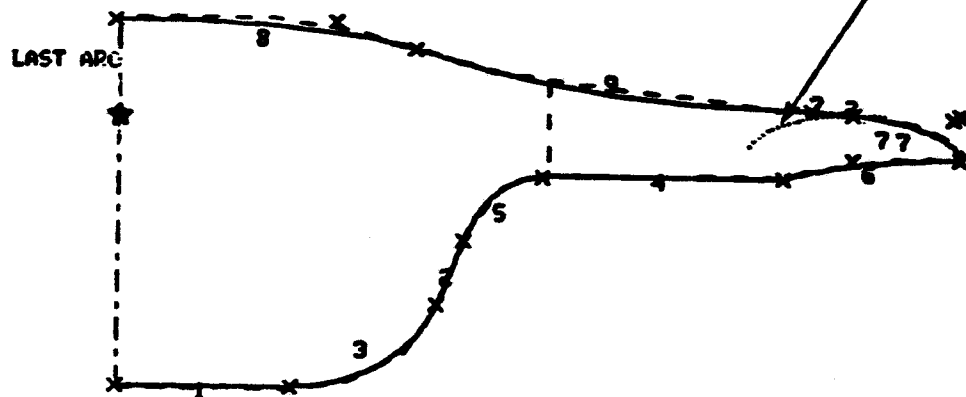
X = 30.0000

INPUT CROSS SECTION  
 INPUT 0 TO END PROC DC  
 CUE FOR  
 NEW INPUT

FTOP

2 BBTN	PIEC	LINE
3 B BS		
5 BSTN	PIEC	LINE
2 BBTN		
3 B BS	PATC	ELLI
10 U BI		
11 U BN	PIEC	LINE
5 BSTN		
10 U BI	PATC	ELLO
11 U BN		
13 U LE		
14 UBOS	PIEC	ELLO
13 U LE		
15 U TH		
16 UTOS	PIEC	ELLO
13 U LE		
15 U TH		
16 UTOS	PIEC	ELLI
7 BBTN		
8 B TC		
9 BTSC	PIEC	ELLI
15 U TH		
7 BBTN	PATC	ELLO

MODELING ERROR  
 (DONE OVER)



INPUT ID FOR MODEL? 7

MAP AXIS

CP NAME 7

ARC TYPE, ARCS BEFORE AND AFTER 7

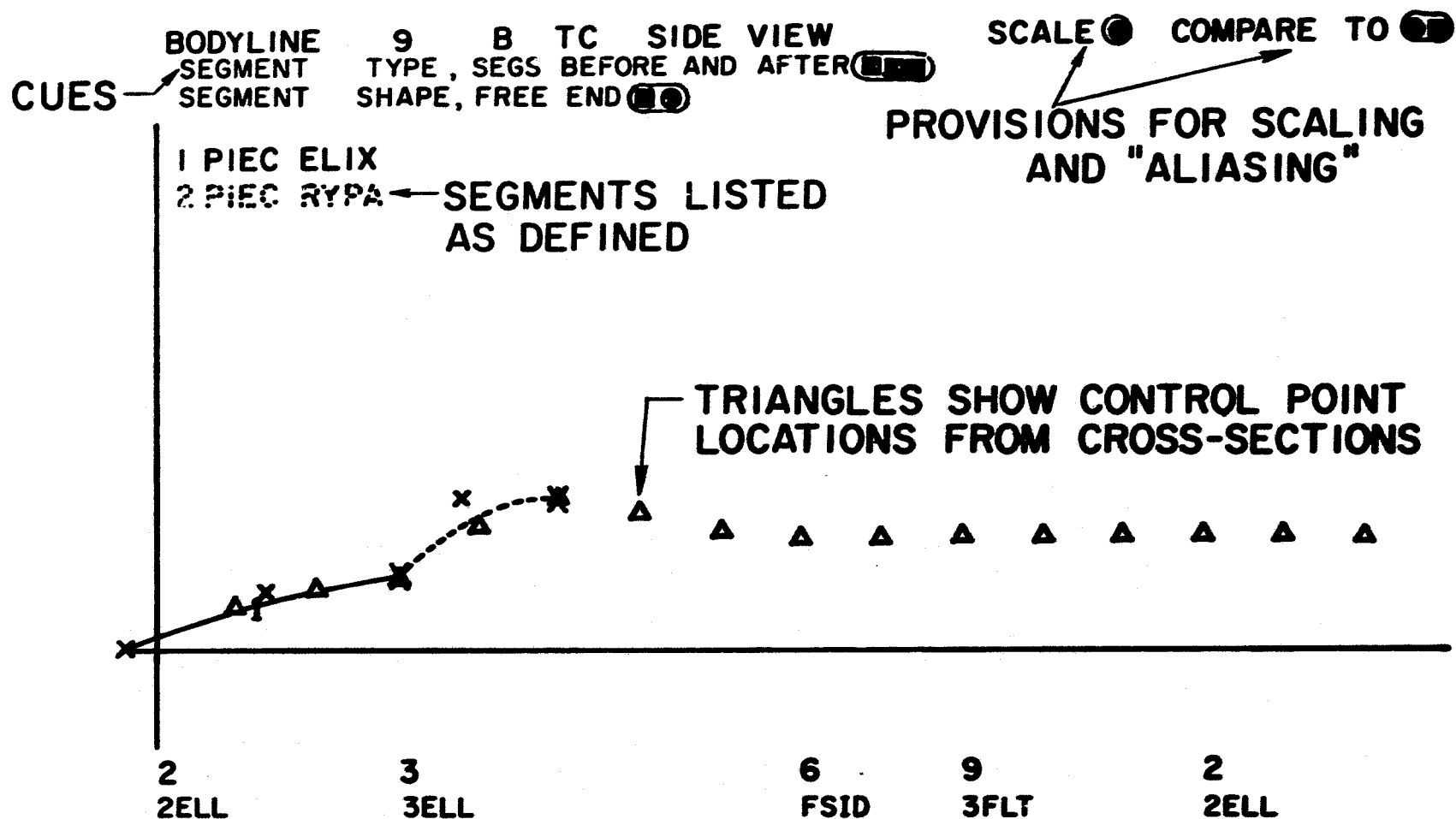
PATCH CP

OK (CR)

INPUT ARC NO IN ORDER 3254678

Slide 9 shows the proposed method of defining body lines to complete the geometric definition of the configuration. As was noted previously the control point locations defined in doing the cross sections are "strung together" using the QUICK curve segments. The side view (xz plane) and top view (xy plane) of each body line is defined separately. "Aliasing" refers to the QUICK provision for defining a body line as exactly matching a previously-defined body line when this occurs rather than re-doing it. "Scaling" is a provision for changing the vertical scale of the plot on the screen to accommodate the variety of body lines which may occur for some configurations.

# EARLY STAGE OF BODY LINE DEFINITION



After all body lines have been defined, all the information collected will be output in the formats required for input to QUICK.

Experience so far has indicated that the system being developed will be easy to learn to use, even by those who have never used QUICK. The results shown indicate that with care good matches can be made with moderately complicated cross sections.

The program is being written using ANSI standard FORTRAN, and is being made machine-independent as much as possible in order to enhance its portability. (The hardware being used are a PRIME 400 computer and a TEKTRONIX 4014 graphics terminal with interactive buffer.) The bodyline part of the program is still being written, and the whole program will continue to be developed as experience is gained with it.

## FINAL REMARKS

- APPEARS EASY TO LEARN
- GIVES GOOD RESULTS (WITHIN LIMITATIONS)
- USES ANSI STANDARD FORTRAN
- DEVELOPMENT CONTINUES
- COMMENTS AND SUGGESTIONS ARE WELCOME

J C TOWNSEND NASA LANGLEY 2/78 10.

Haverly 1

AIRCRAFT SURFACE REPRESENTATION  
FOR AERODYNAMIC CALCULATION

LEON HAVERLY  
LOCKHEED-GEORGIA COMPANY

MARCH, 1978



THE FLOW OF INFORMATION IS BEGUN  
FROM VARIOUS ORGANIZATIONS FOR  
VARIOUS REASONS. DEFINING DATA  
IS FOUND AT VARIOUS PLACES.

HAVERLY 2

## AERODYNAMIC LOADS REQUESTS

### ORIGIN

- CONTRACT
- R & D
- PROPOSAL

### REQUESTING ORGANIZATION

- P.D./PROJECT STRUCTURES
- STABILITY & CONTROL
- PERFORMANCE

### DATA SOURCE

- LOFT
- PRELIMINARY DESIGN
- REPORTS
- ESTIMATES

AERO LOADS CALCULATIONS

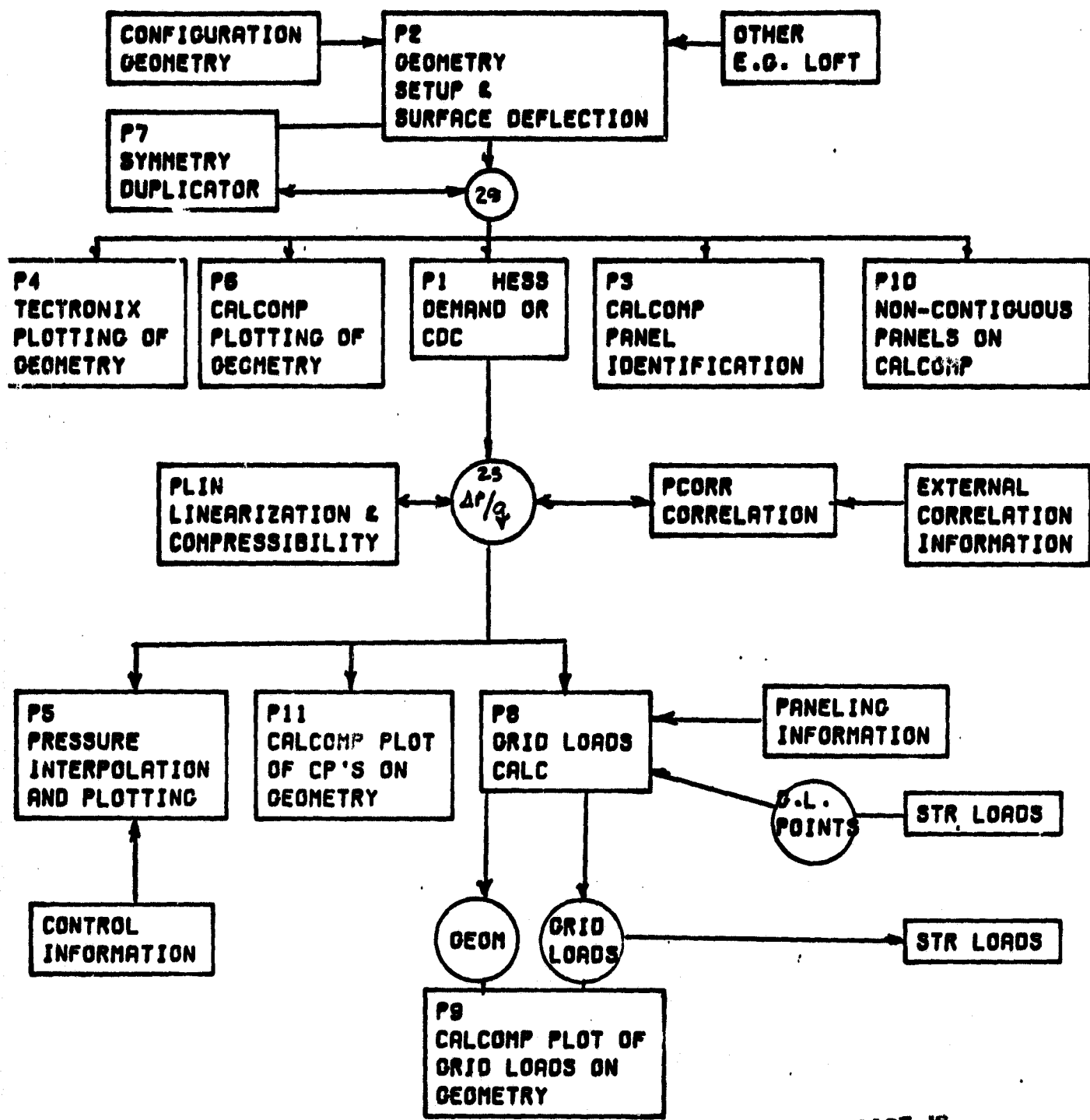
A DECISION MUST BE MADE ON A  
METHOD TO OBTAIN PRESSURE INFORMATION.  
THIS REPORT WILL FOLLOW THE LAST  
METHOD BASED ON THE DOUGLAS PROGRAM,  
WHICH I WILL CALL THE HOSS ROUTINE.

# AERO LOADS ANALYSIS

METHOD	VORTEX ELEMENTS	WIND TUNNEL	HESS ROUTINE
INPUT	LIFTING CAMBER SURFACE FLAT OR CRUCIFORM BODIES	MODELS	SURFACE GEOMETRY
OUTPUT	NET PRESSURES SIX-COMPONENT DISTRIBUTIONS	PRESSURES	PRESSURES

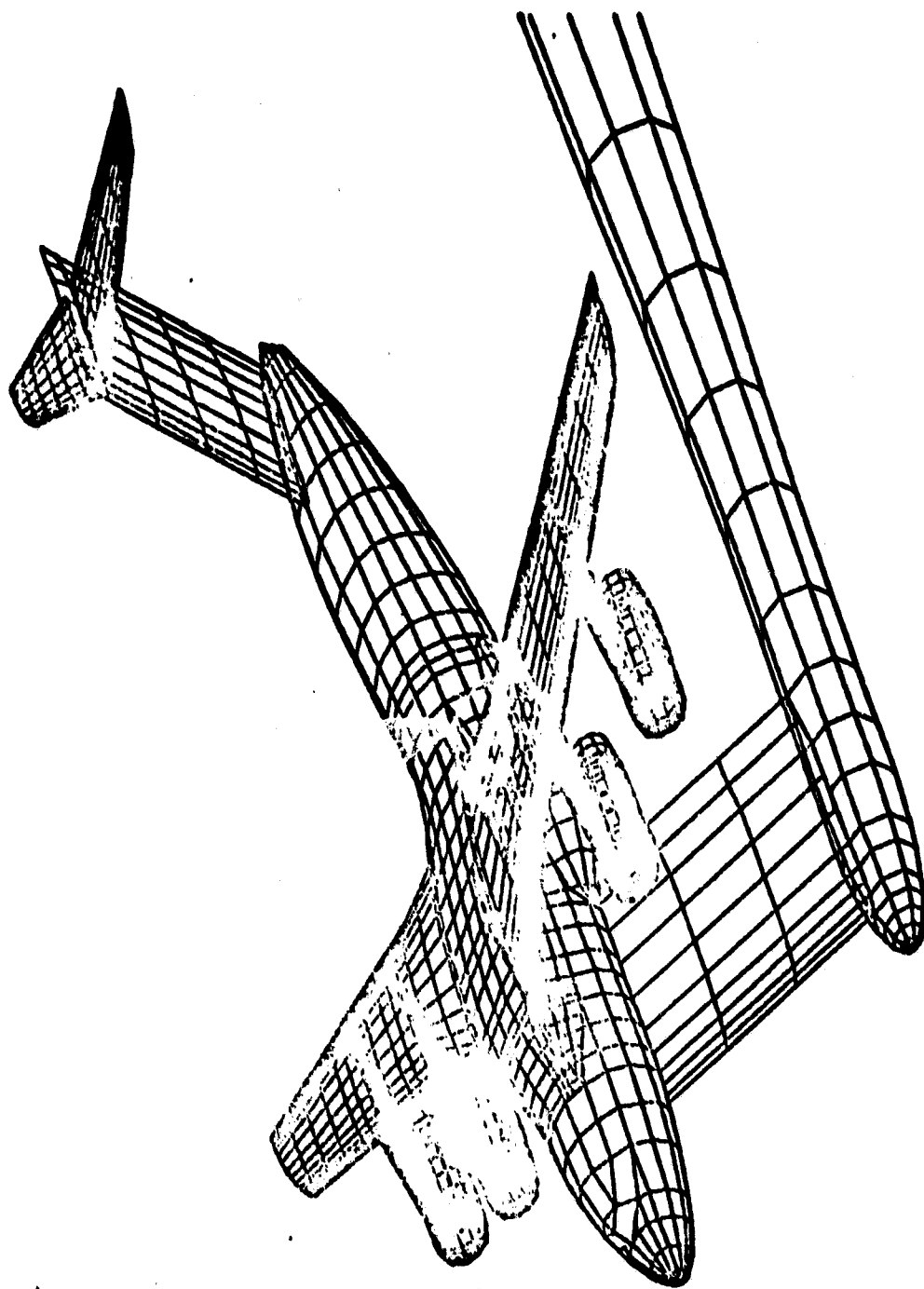
THIS IS THE DATA FLOW FOR THE AERODYNAMIC  
PORTION OF A NEW GRID LOADS DESIGN  
ANALYSIS SYSTEM CURRENTLY BEING  
DEVELOPED.

# ERODYNAMIC ANALYSIS FOR GRID LOADS



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THIS IS OUR C-SA PARBELO MODEL USING  
2338 EFFECTIVE PANELS.



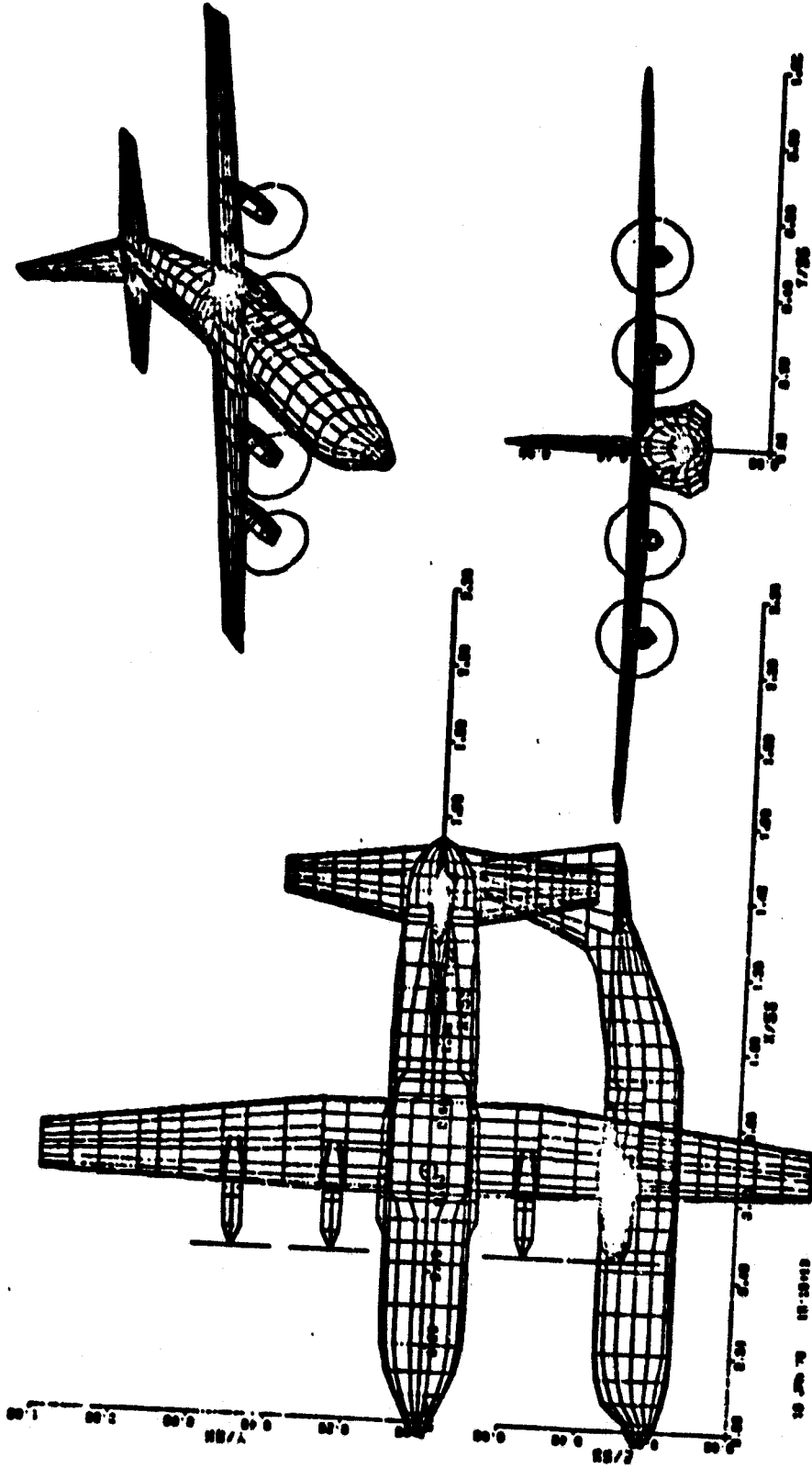
ORIGINAL PAGE IS  
OF POOR QUALITY



THE OBJECT OF OUR FIRST GRID LOADS  
EFFORT IS THE C-130 NS, A STRENGTHENED  
C-130.

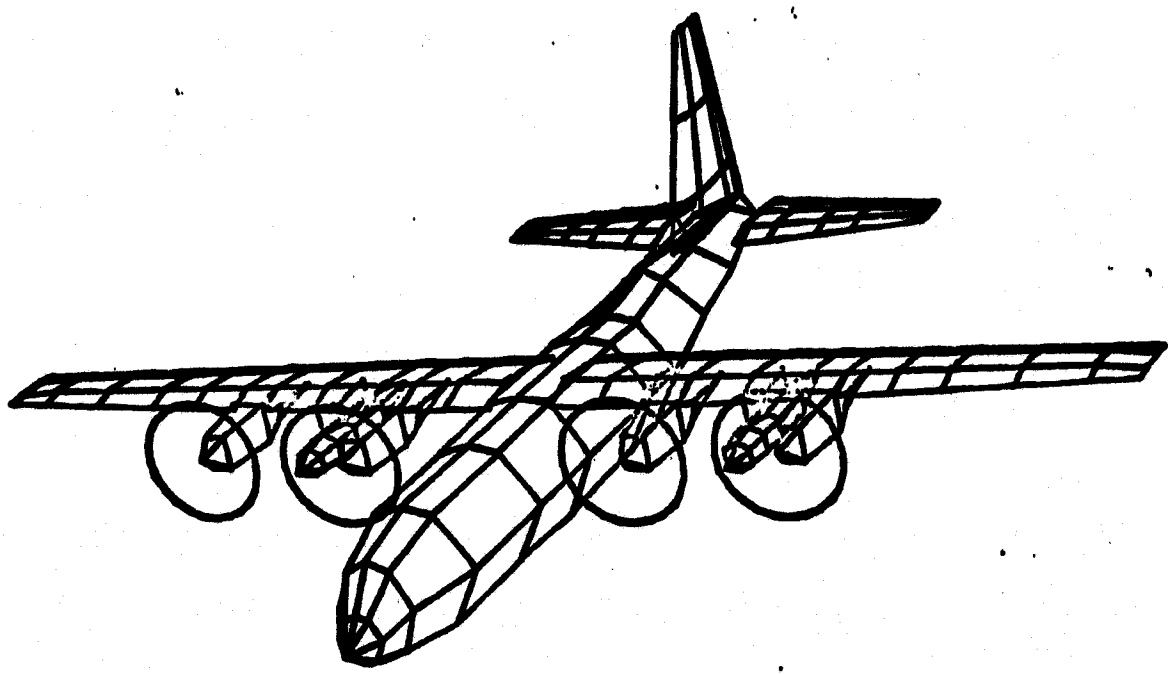
BOULDER 000000 PPOF 000000 FPLUF 000000 EMBD 000000  
TASK UNITS 47 PCH SIZE 18432

C-130-H56 COMPLETE AIRPLANE - WITH CORRECT EMPENNAGE  
1484 EFFECTIVE PANELS  
1038 TOTAL PANELS



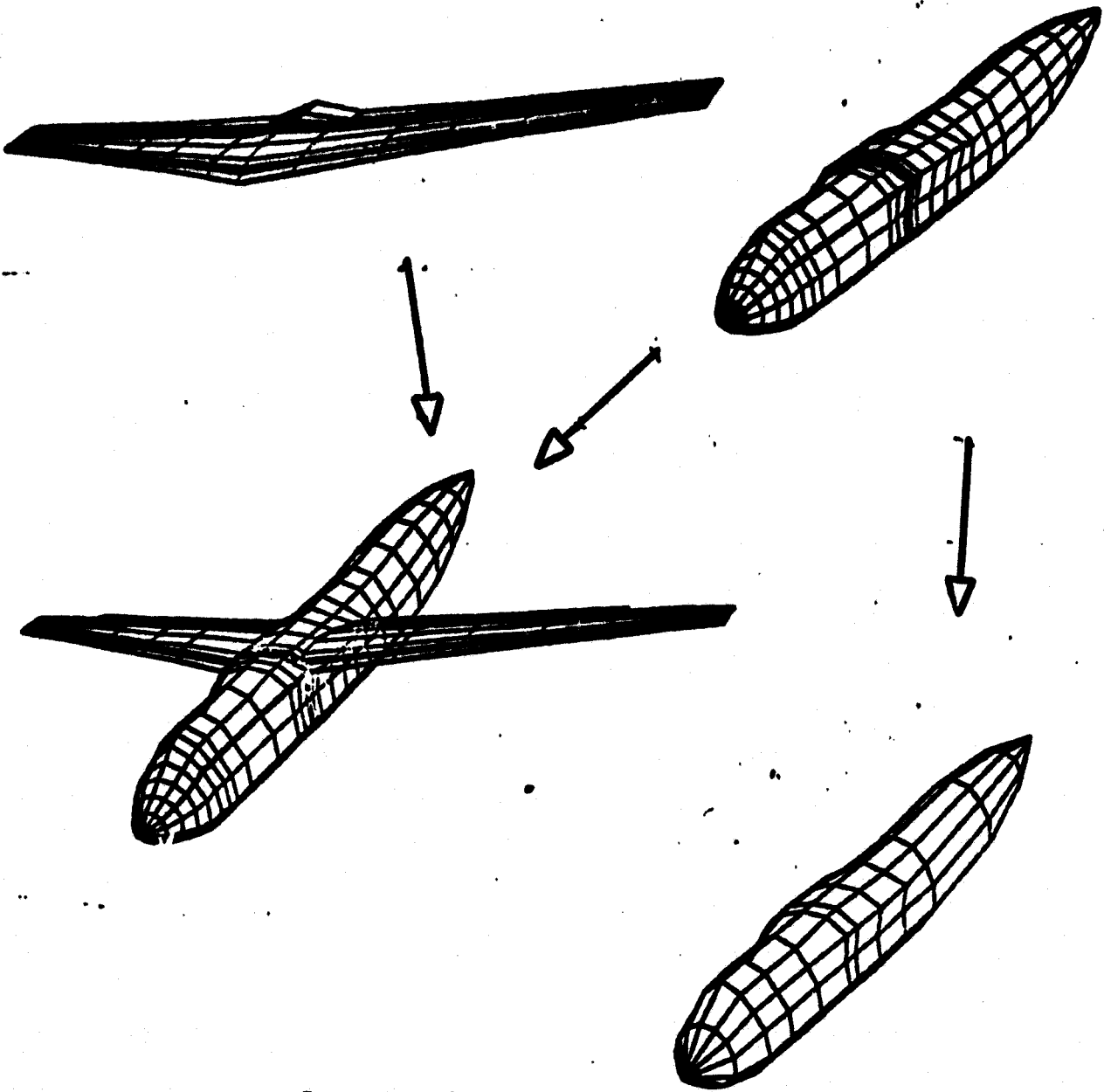
OF MAJOR INTEREST TO US IS THE  
MINIMUM PANELING REQUIRED TO OBTAIN  
SATISFACTORY RESULTS. THIS 420 PANEL  
MODEL GIVES GOOD AGREEMENT WITH  
EXPERIMENT.

8



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OF POOR QUALITY

MOST OF THESE AIRPLANES HAVE BEEN PRODUCED FROM LOFT INFORMATION ACCUMULATED OVER THE YEARS, BUT MAJOR COMPONENTS MAY BE MERGED BY COMPUTER ALSO, SEE THE WING FUSELAGE. ONCE A DEFINING BASE FOR A COMPONENT IS OBTAINED, INTERPOLATION FOR PANELS MAY BE DONE. THE LOWER RIGHT FUSELAGE WAS REQUESTED WITH FEWER LENGTHWISE SECTIONS.



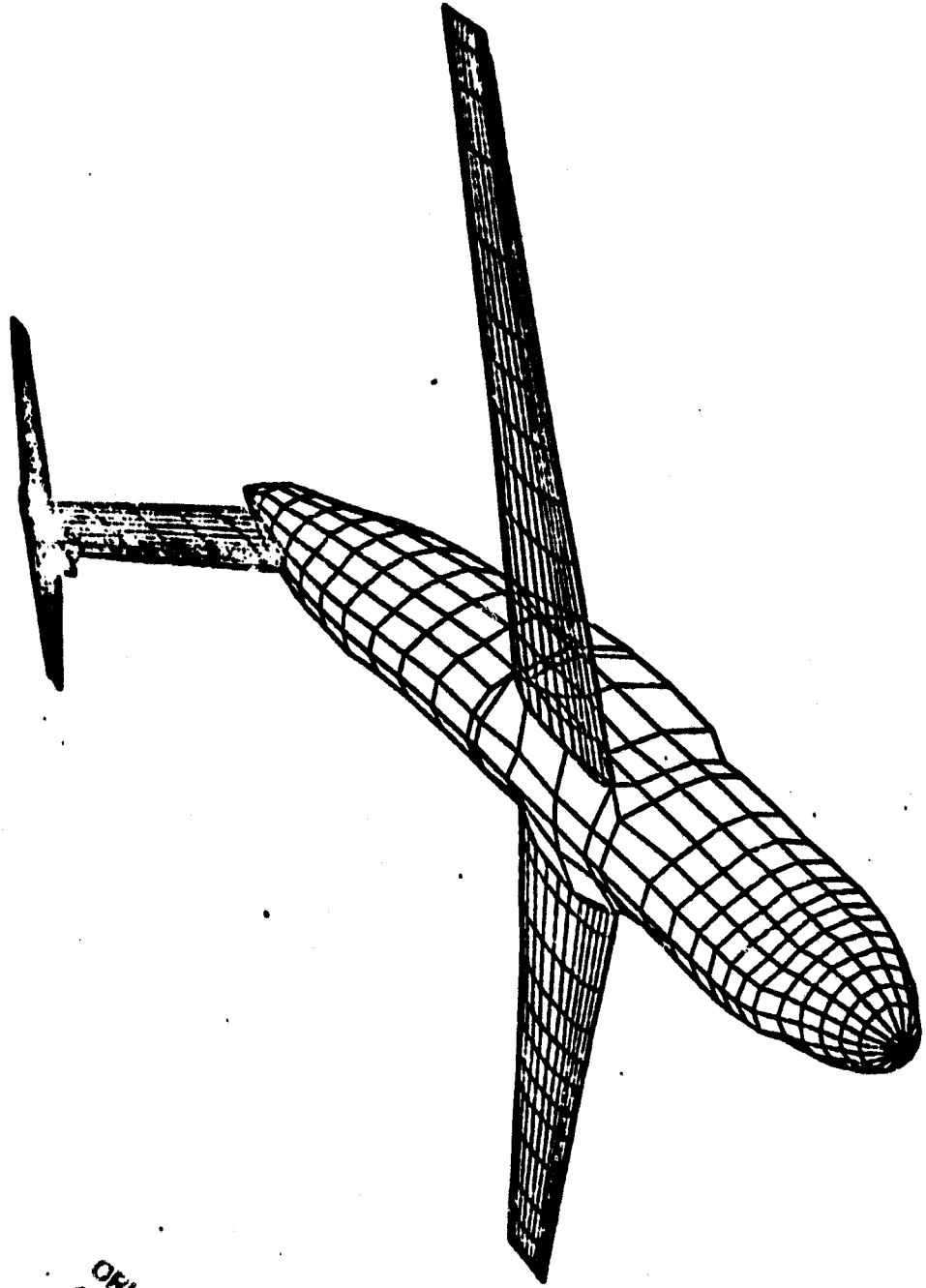
ORIGINAL PAGE IS  
OF POOR QUALITY

THIS IS THE HARDWARE WE ARE USING IN  
THIS DEVELOPMENT

DISCRETE LOAD PROGRAM IMPLEMENTATION

A.I.P. PANELS

(C-5A, 1971 PANELS)

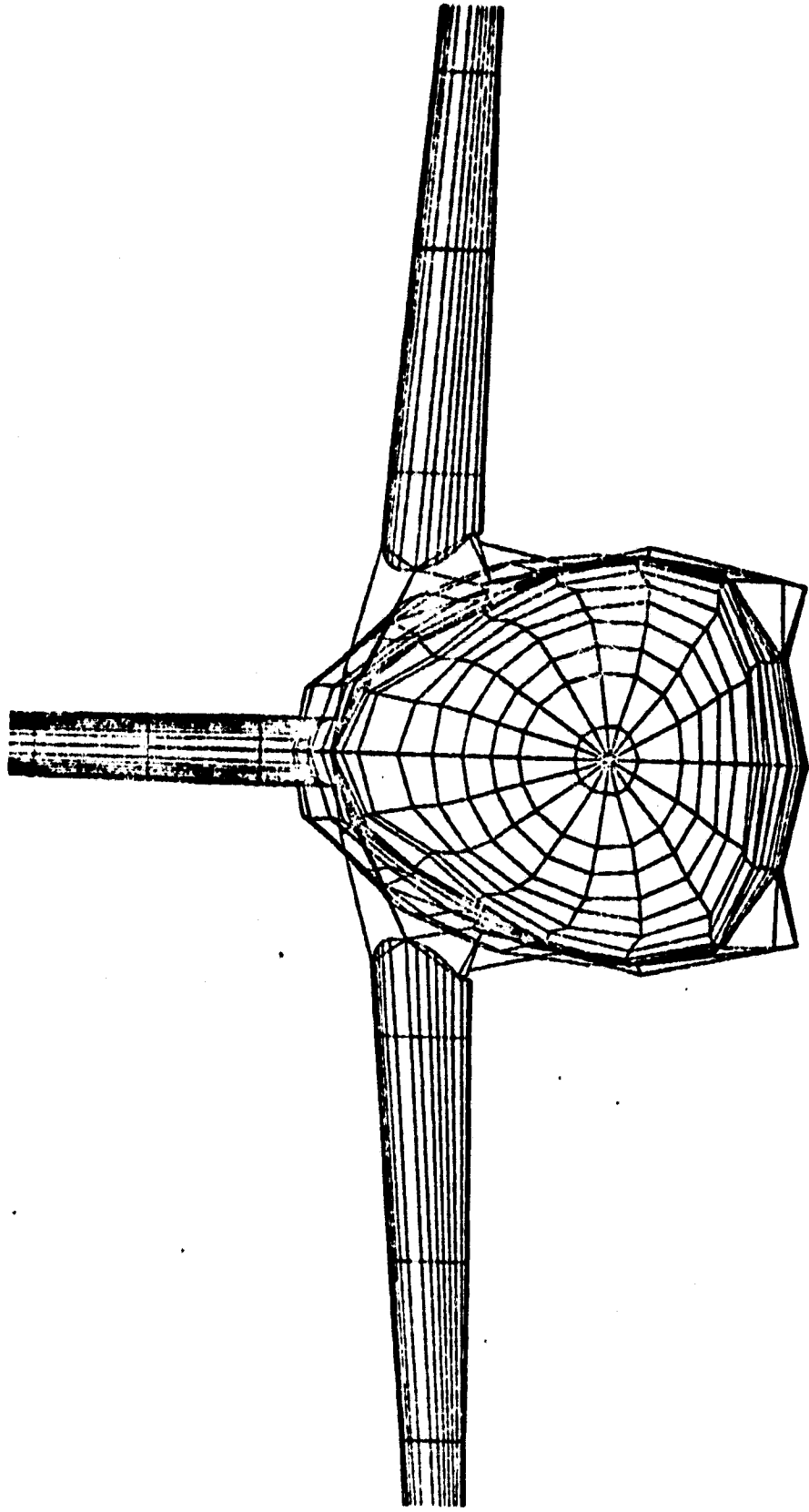


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DISCRETE LOAD PROGRAM IMPLEMENTATION

A.I.P. PANELS  
(ZOOM VIEW)

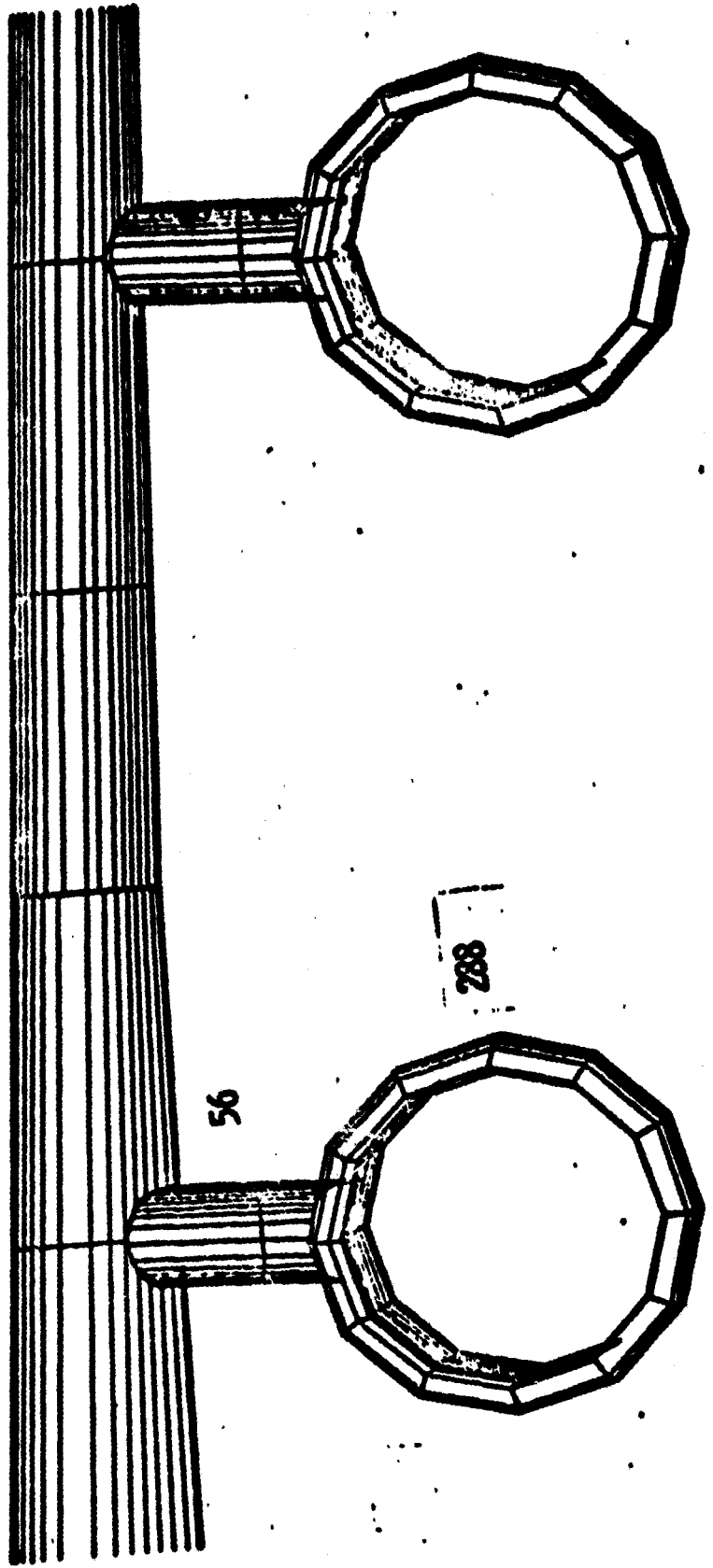


DISCRETE LOAD PROGRAM IMPLEMENTATION

A.I.P. PANELS

TSUOLDE

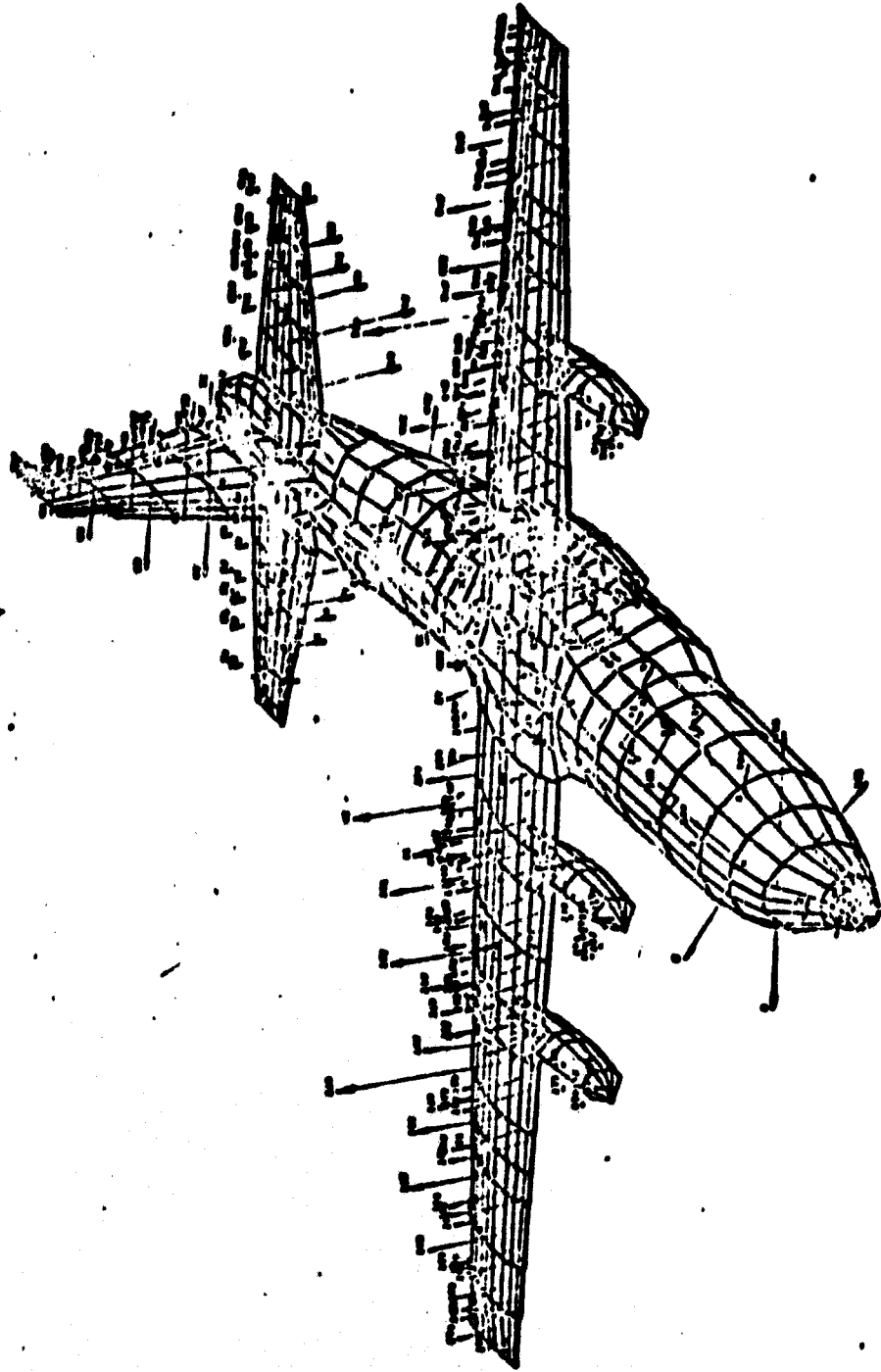
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**DISCRETE LOAD PROGRAM IMPLEMENTATION  
LOAD VECTORS**



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# HARDWARE

## CDC 7600

FOR HESS RUNS OF OVER  
ABOUT 300 PANELS

## UNIVAC 1106

- ALL GEOMETRY SETUP
- GEOMETRY PLOTTING
- PUNCH DECK FOR CDC
- SMALL HESS RUNS
- PRESSURE DATA ANALYSIS
- AERO GRID LOADS ANALYSIS

## TEKTRONIX

INTERACTIVE CRT/QUICK COPY PLOTS OF  
GEOMETRY, PRESSURES, DISTRIBUTIONS  
AND GRID LOADS

## CALCOMP

LARGER, BETTER QUALITY REPRODUCTION

## GERBER

UP TO 4 X 16 FOOT GEOMETRY PLOTTING

AGAIN, MOST OF THESE CONFIGURATIONS  
WERE SETUP FROM LOFT, BUT AIRPLANES MAY  
BE CONFIGURED ~~FROM~~ WITH DATA FROM ANY  
SOURCE.

HAVERY 15

## SETUP TECHNIQUE

LOFT

OTHER

AIRPLANE CO-ORDINATE SYSTEM  
(F.S., B.L., W.L.)  
DATA AVAILABLE BY COMPONENT  
AT SPECIFIED SECTIONS  
SURFACE INTERSECTIONS DEFINED

AIRPLANE OR LOCAL  
CO-OR SYSTEM  
SECTION INFORMATION

DATA INTERPOLATED LINEARLY FOR  
PANEL ARRANGEMENT ON EACH COMPONENT

SURFACE INTERSECTIONS CALCULATED  
IF NEEDED  
HAND MODELING

HESS INPUT

IN GENERAL THESE DATA ARE REQUIRED FOR  
TYPE OF COMPONENT.

Haverly/6

## SETUP DATA REQUIRED

### LIFTING

- AIRFOIL SECTION ORDINATES AT
- SPANWISE POINTS
- WING SWEEPS & DIHEDRAL
- WING ROOT
- GEOMETRIC TWIST
- LOCATION IN AIRPLANE REF SYSTEM

### NONLIFTING

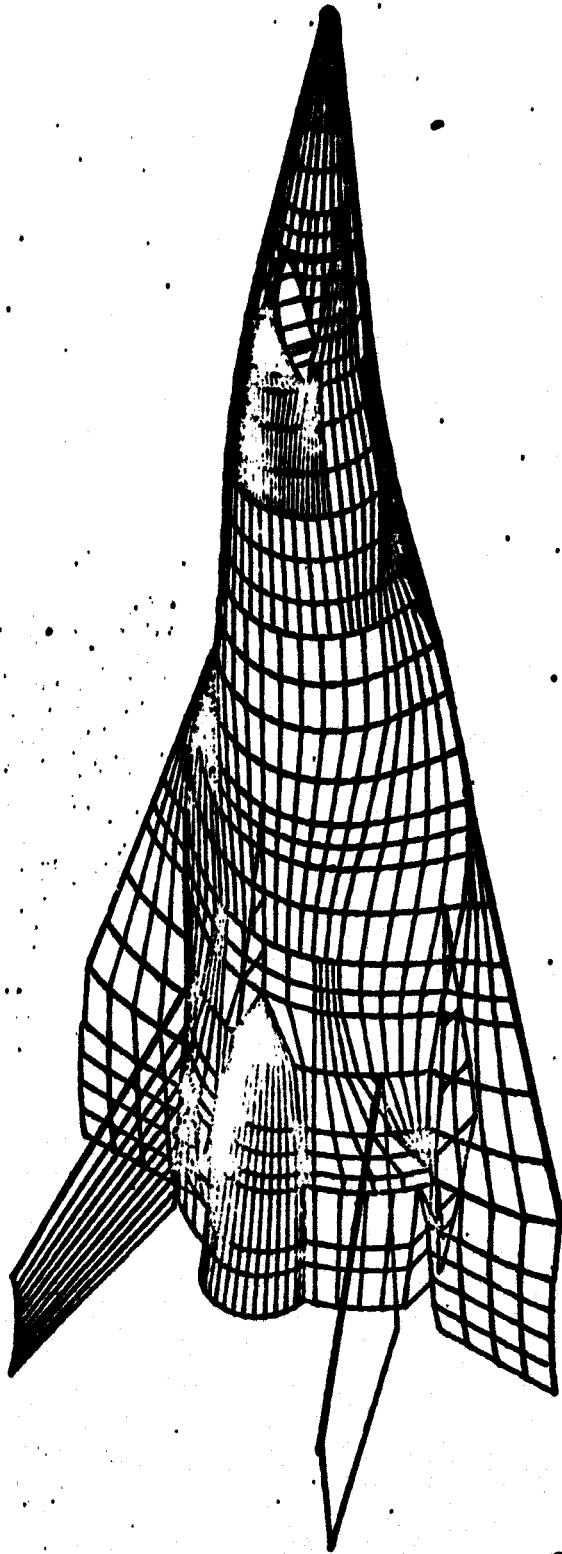
- SET OF FUSELAGE SECTION
- CO-ORDINATES AT SELECTED
- LENGTHWISE STATIONS
- LOCATION IN REF SYSTEM

### ANNULAR WING

- DISTRIBUTED SET OF INSIDE AND
- OUTSIDE RADII
- ANGULAR ORIENTATION
- LOCATION IN REF



LOCKHEED - CALIFORNIA - CO.



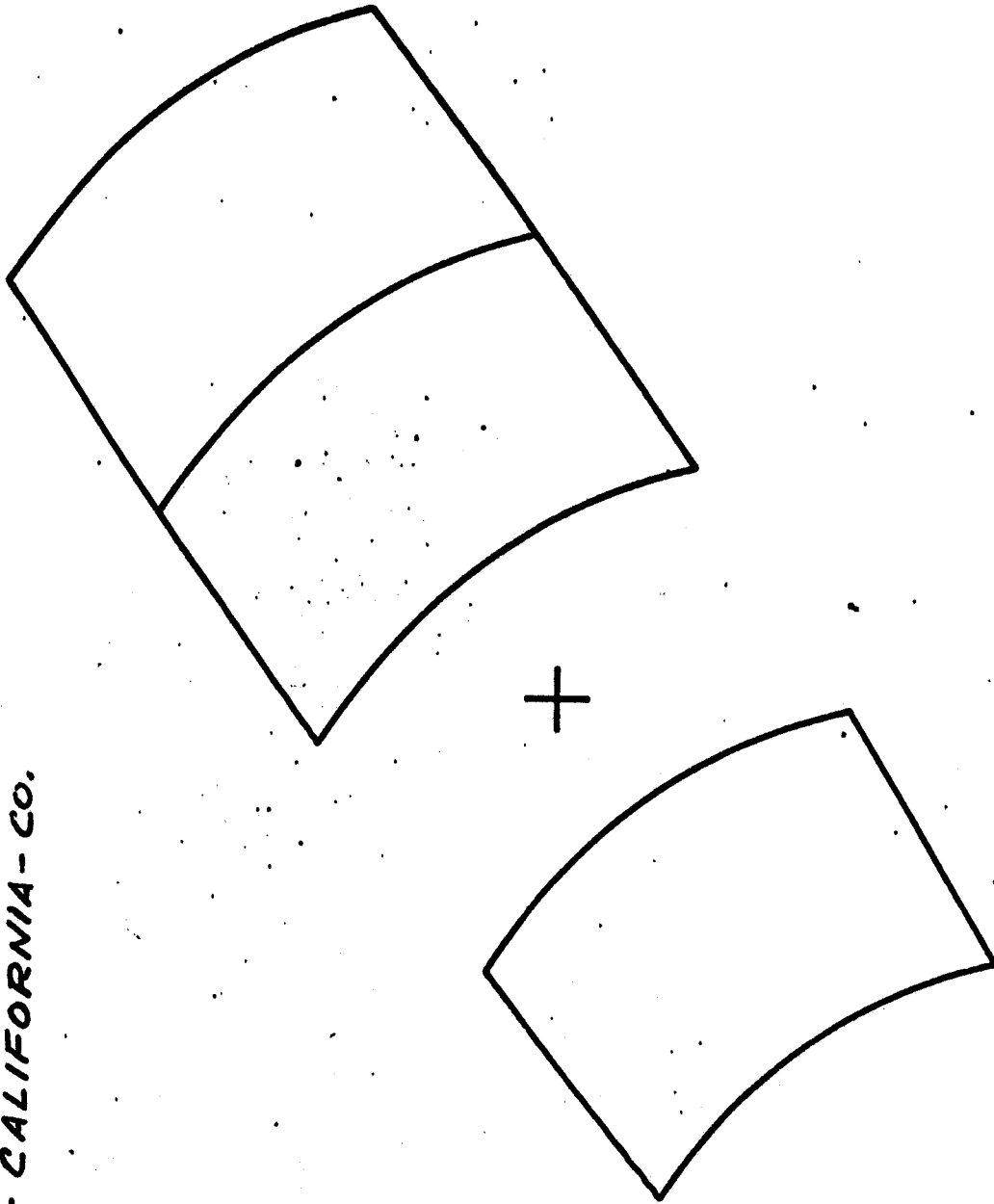
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Page 1  
M. A. Dincau

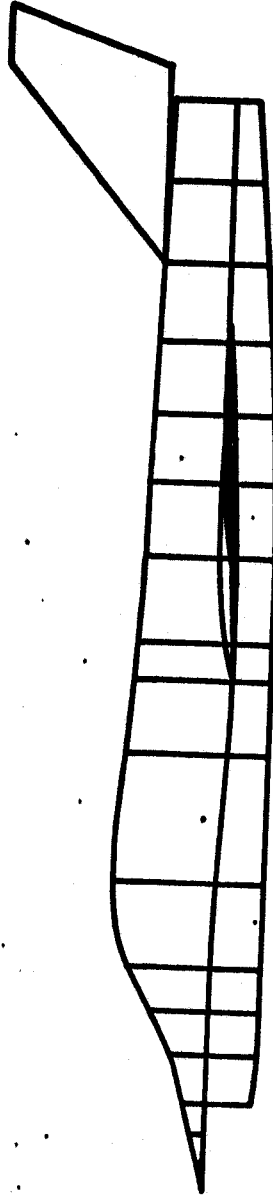
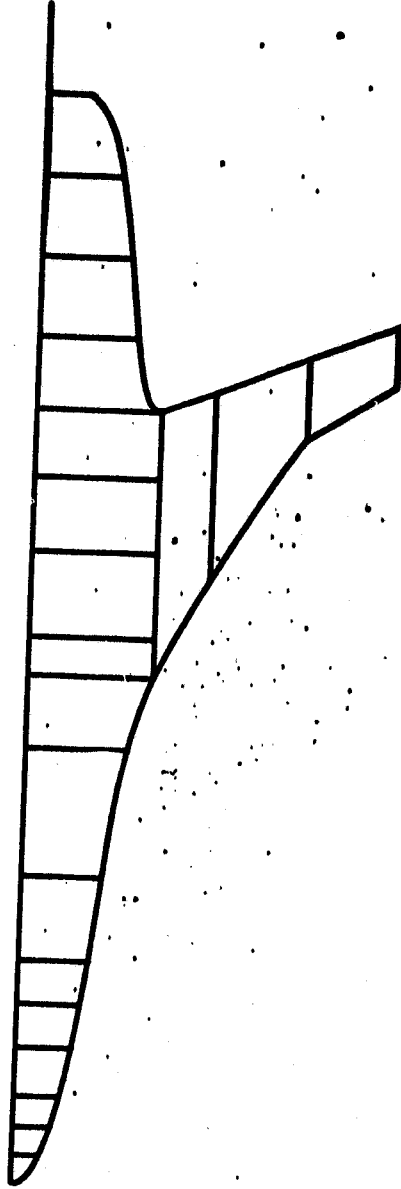
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18

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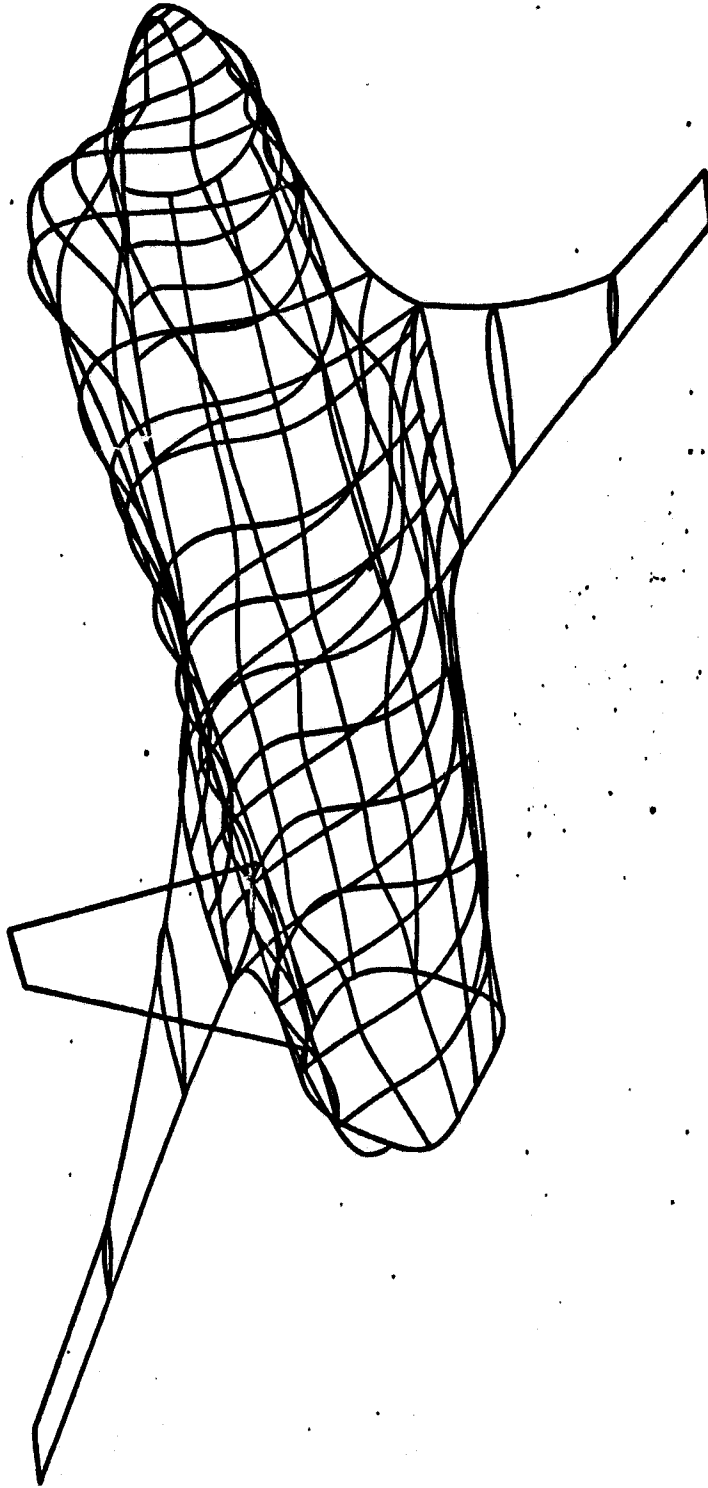
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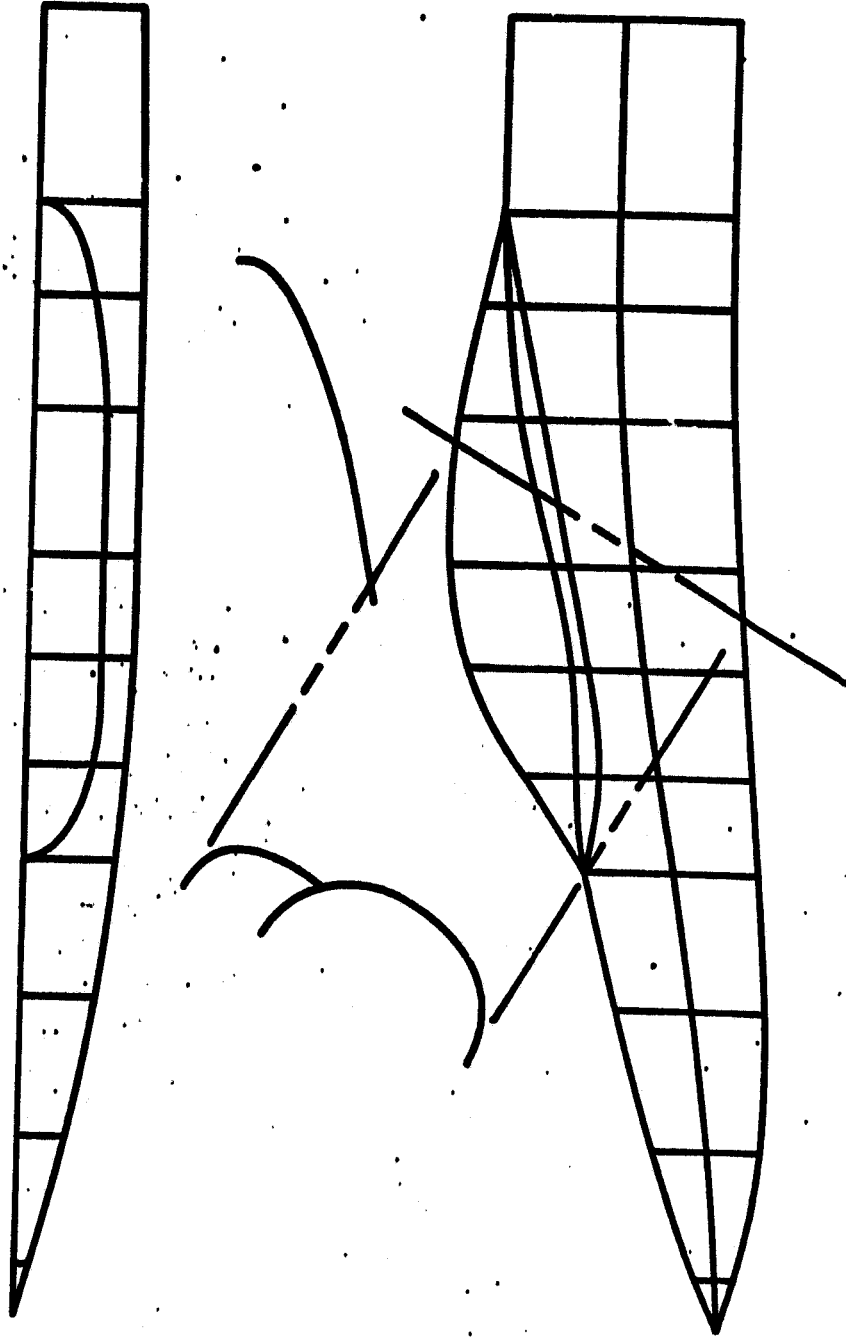
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Page 3  
M. A. Dincan

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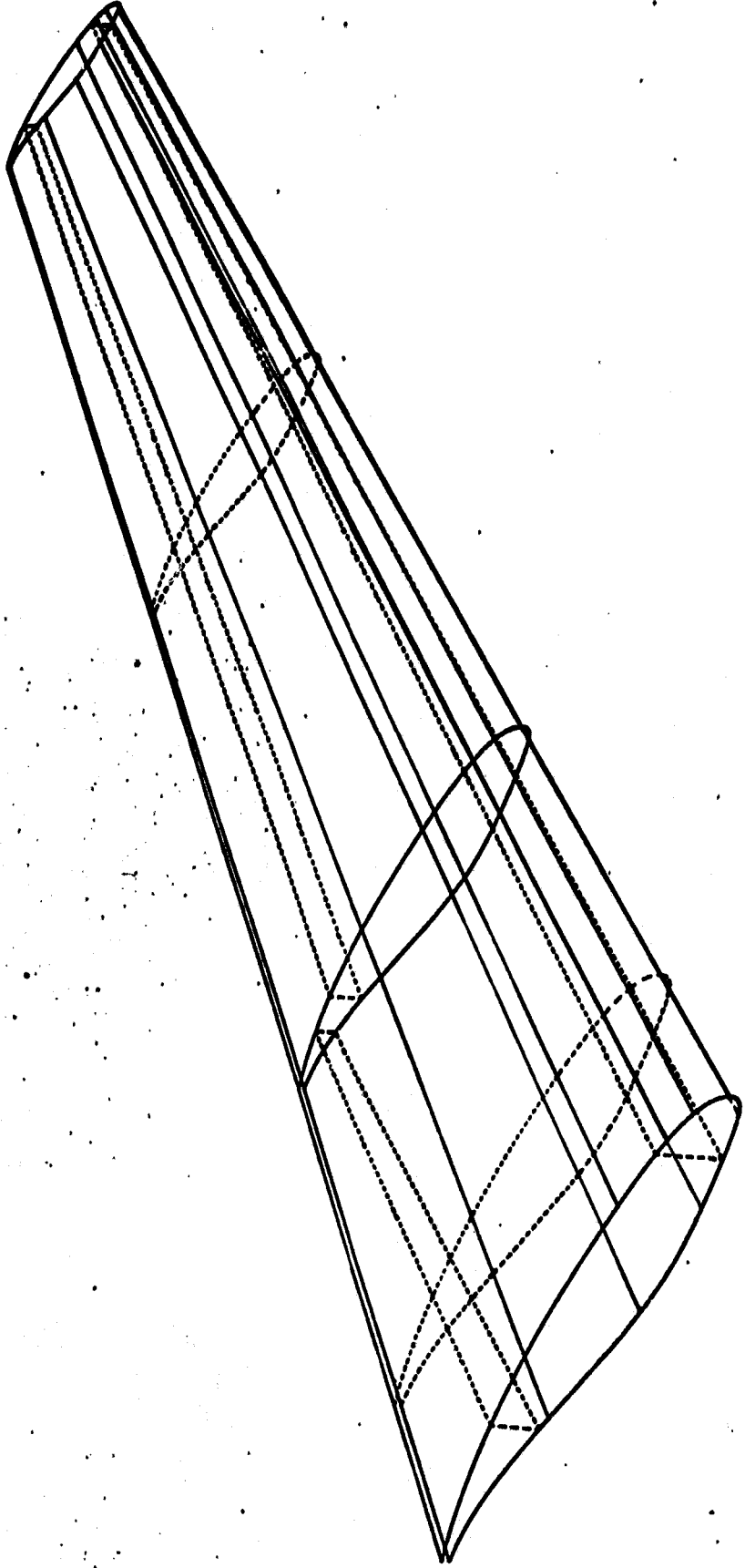
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Page 5  
M. A. Dincan

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LOCKHEED - CALIFORNIA - CO.



Page 6  
M. A. Dincan

DINCAN 6

14

**INTERFACING AERODYNAMIC PROGRAMS TO AVID**

by Alan M. White

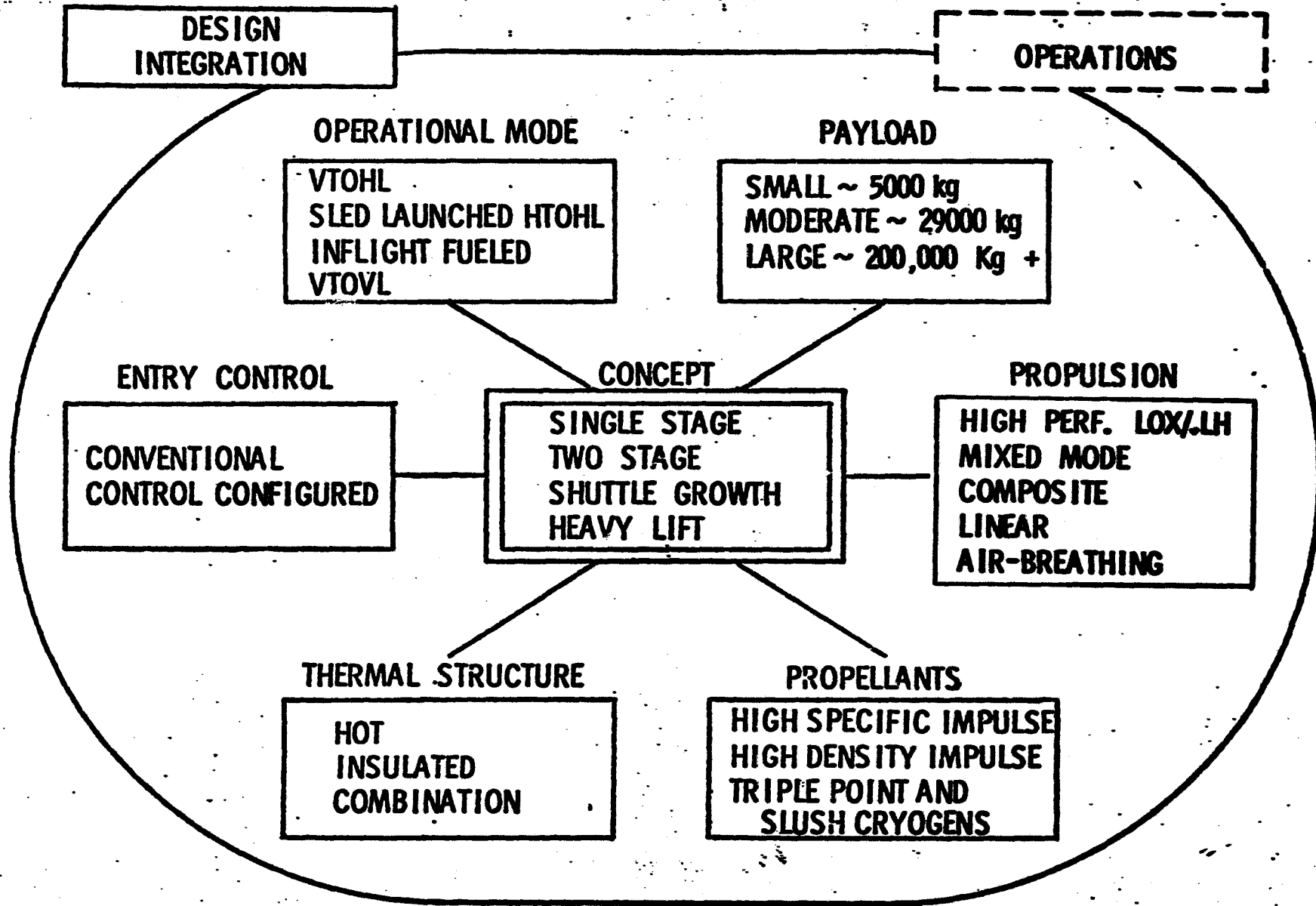
WHITE

## **FUTURE SPACE TRANSPORTATION STUDIES**

Since the early seventies, the Space Systems Division has been studying advanced space transportation systems to define critical technology areas which need to be developed in order to direct present funding plans. In order to evaluate the impact of a technology advancement on the total vehicle system, all of the technical disciplines--structures, propulsion, subsystems, aerothermodynamics, and cost--must be integrated into a complete design synthesis. Due to the many concepts being studied, a general computer-aided design system was developed to handle the analysis. Aerodynamics are an integral part of the design process since aerodynamic surface mass comprises approximately 25 percent of the total vehicle dry mass. This percentage can vary greatly depending upon center-of-gravity position and operational mode of the vehicle.



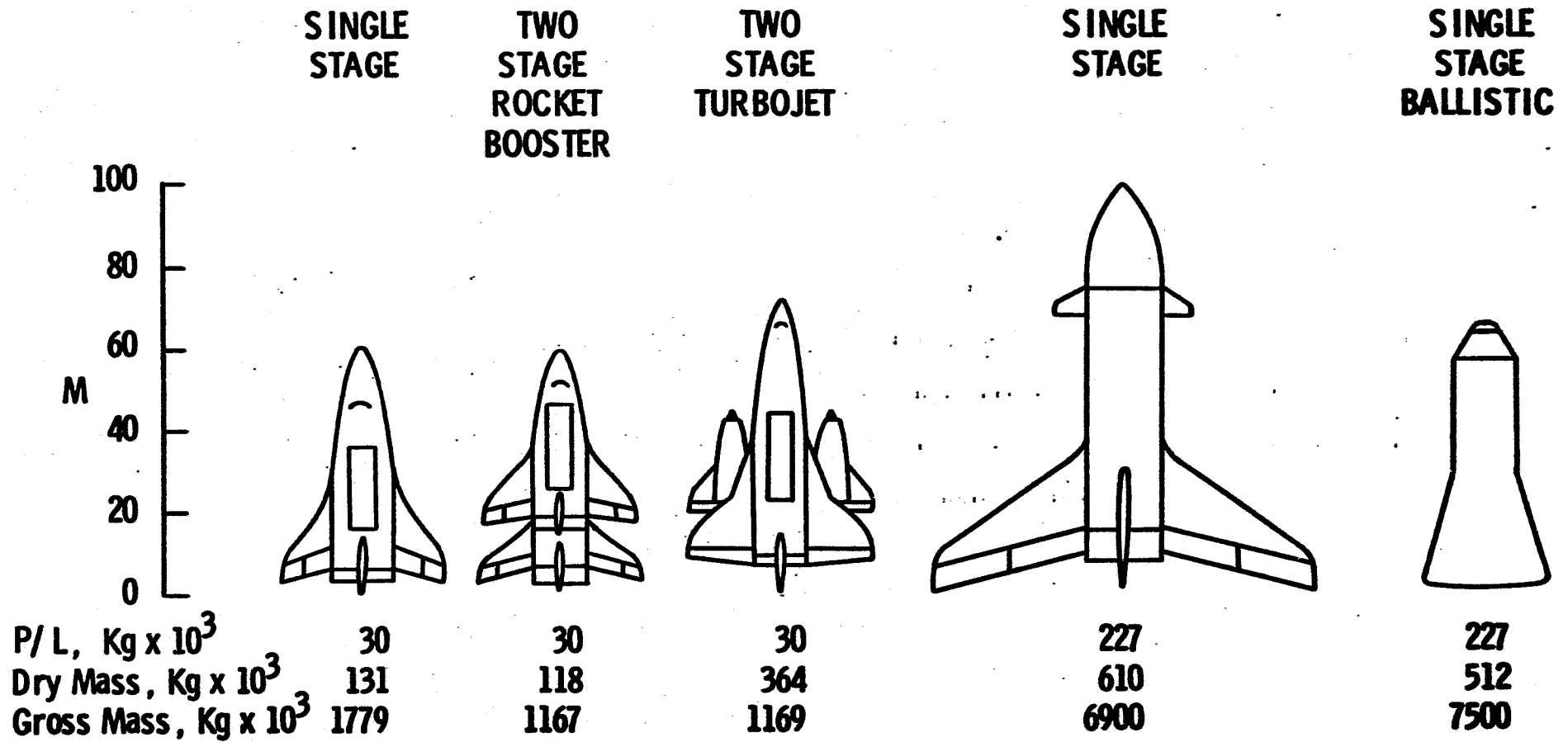
# FUTURE SPACE TRANSPORTATION TECHNOLOGY STUDIES



### FUTURE SPACE TRANSPORTATION CONCEPTS

Space transportation concepts have ranged from single-stage rocket vehicles to a two-stage concept with twin turbojet boosters and a rocket second stage. For heavy-lift missions, both winged and ballistic vehicles have been studied. Each concept is being evaluated through the speed regime basically for hypersonic trim and L/D, and subsonic stability, trim, L/D, and design landing speed. A main problem area is predicting subsonic stability for the large bluff body-wing combinations.

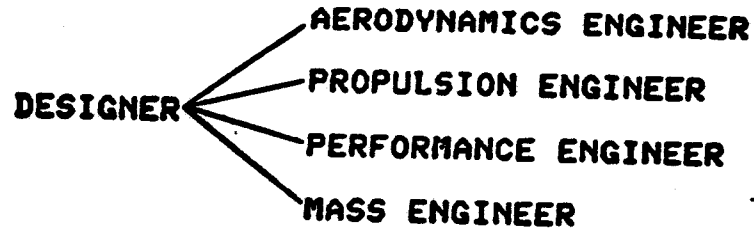
# FUTURE SPACE TRANSPORTATION CONCEPTS



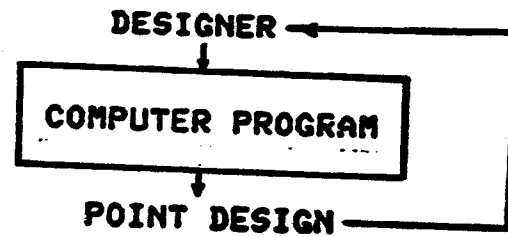
## HISTORY OF COMPUTER-AIDED DESIGN

The development of a new computer-aided design (CAD) system at Langley was initiated due to a lack of capability of any one present method. Due to the variation of concepts--launch vehicles and orbit transfer vehicles--a general and flexible system was needed and the designer must be given complete control over the design process, much like the design team approach. Since the impact of an advancement of one technology area on the complete vehicle system must be evaluated, the technical disciplines needed to be integrated into a complete vehicle synthesis much like ODIN. Finally, the speed of the hardwired single-program synthesis techniques was needed for optimization. The Aerospace Vehicle Interactive Design (AVID) system development was based on integrating all these requirements into a single design system.

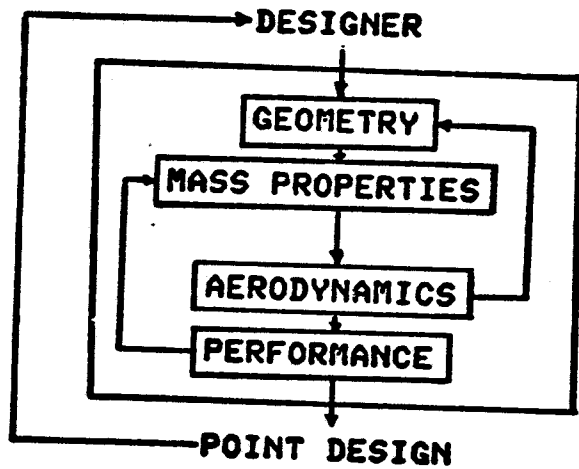
# HISTORY OF COMPUTER AIDED DESIGN



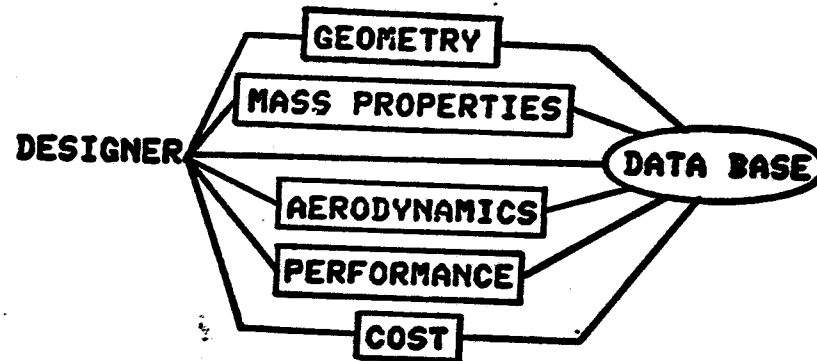
STAGE 1 - DESIGN TEAM SYNTHESIS



STAGE 2 - HARDWIRED SINGLE PROGRAM SYNTHESIS



STAGE 3 - PROGRAMMED MULTI-PROGRAM SYNTHESIS (ODIN)



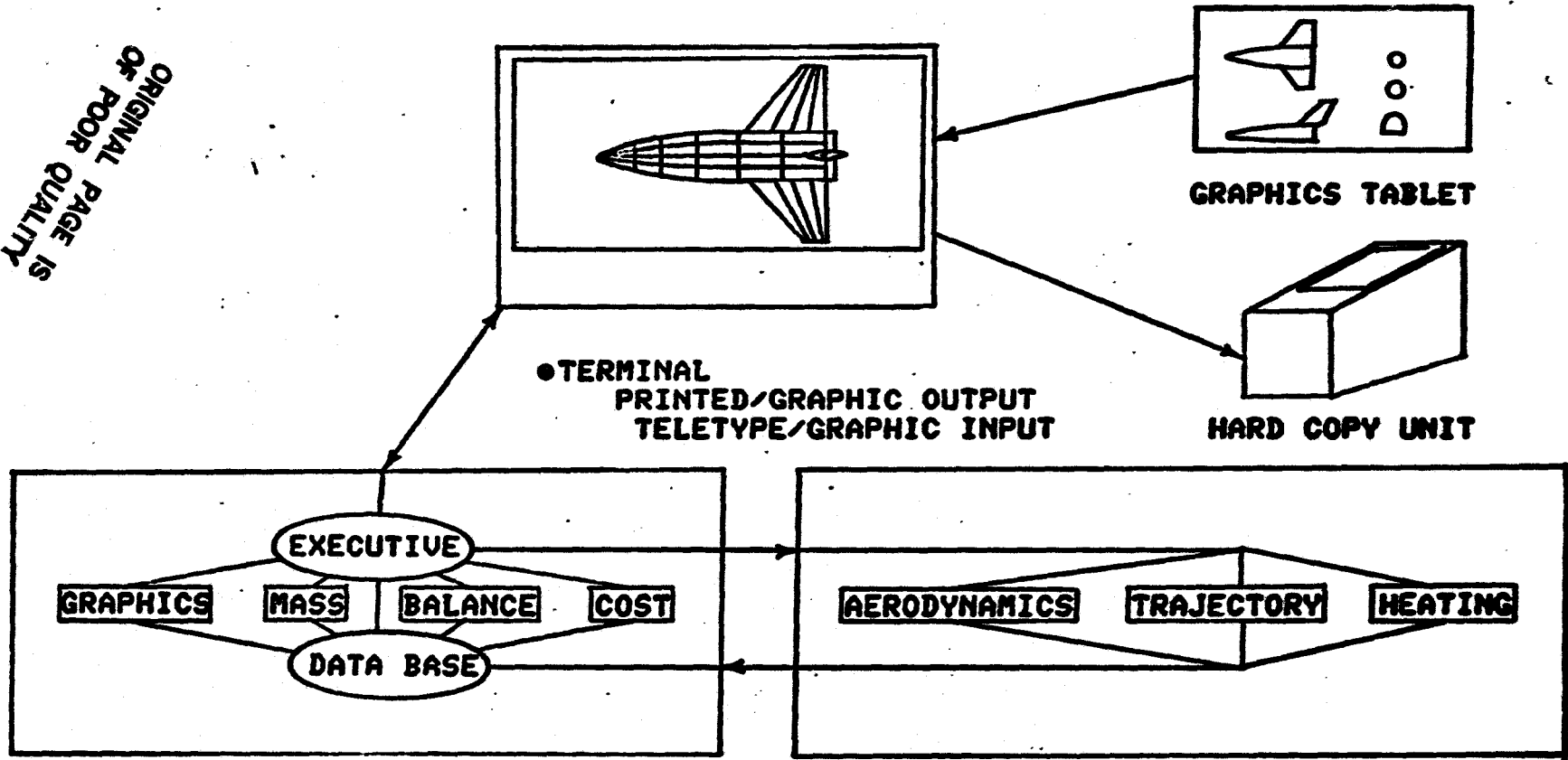
STAGE 4 - INTERACTIVE MULTI-PROGRAM SYNTHESIS (AVID)

### AVID SYSTEM

The hardware of the AVID system consists of Tektronix terminal equipment, a Prime mini-computer (192K bytes memory), and a CDC 6600 host computer. The computer protocol is RJE ("quick batch"). The executive, data base, geometry, and fast-computing technology programs are executed on the mini-computer. The large technology programs, such as large aerodynamic programs, trajectory, and aerodynamic heating, are executed on the host.

# AEROSPACE VEHICLE INTERACTIVE DESIGN (AVID) SYSTEM.

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● MINI COMPUTER  
 INTERACTIVE - DIRECT COMPUTER ACCESS  
 SMALL TECHNOLOGY PROGRAMS  
 GRAPHICS SUBSYSTEM

● HOST COMPUTER  
 INDIRECT COMPUTER ACCESS  
 LARGE TECHNOLOGY PROGRAMS

6 L

### MENU OF AVID PROGRAMS

To execute any program, the user only has to hit the appropriate key at the terminal. At the end of a design session, the data base and geometry data can be saved. At a later time, the design can be retrieved for future analysis in any technical area.



## AVID PROGRAMS

### INPUT LETTER OF PROGRAM TO EXECUTE

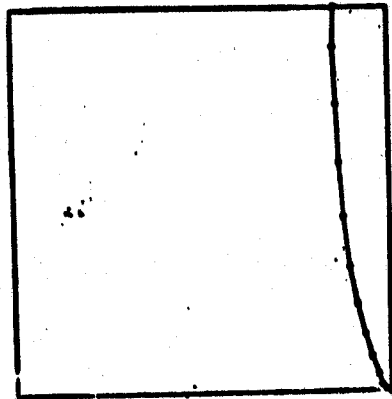
- A - RESTORE PREVIOUSLY SAVED SIMULATION
- B - DIGITIZE BODY SHAPE
- C - PLOT BODY SHAPE (AWW IMAGE)
- D - VOLUMES AND AREAS (WAB)
- E - HYPERSONIC AERODYNAMICS (AWW NEWTONIAN)
- F - HYPERSONIC AERODYNAMICS (HABACP)
- G - SUBSONIC AERODYNAMICS (DATCOM)
- H - SUBSONIC AERODYNAMICS (VORTEX LATTICE)
- I - PROPULSION SYSTEM CHARACTERISTICS
- J - TRAJECTORY CALCULATION (REHDER MINI-TRAJ)
- K - MASS BREAKDOWN (MARTIN TASK II BASELINE)
- L - MASS BREAKDOWN (MARTIN TASK II W/CG)
- M - INTERACTIVE DATA BASE
- N - COST (JAM VERSION OF WILCOX)
- O - LIFE CYCLE COST (JAM)
- P - SCREEN REPORT (GEOMETRY SIZED)
- Q - SAVE THIS SIMULATION
- R - SEQUENCE MODE
- S - ENDS EXECUTION OF AVID

7.

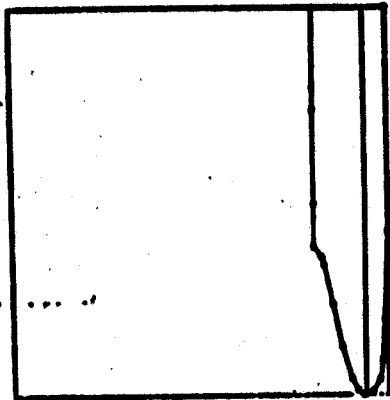
### BODY DIGITIZING

The interactive digitizing system was designed for speed and simplicity of input although every coordinate point on the vehicle body can be specified. One to thirty body cross sections can be input and from 3 to 20 points per cross section. A spline under tension routine allows the input of a minimum number of cross-sectional points. The tension can be tightened or loosened to give the desired cross-sectional curvature. To interpolate between cross sections or for the case with one cross section, both the body planform and side view are digitized.

# BODY DIGITIZING

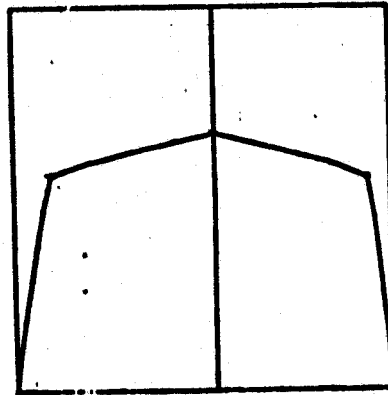


PLATFORM

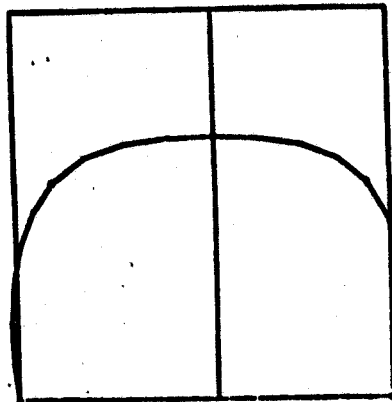


SIDE VIEW

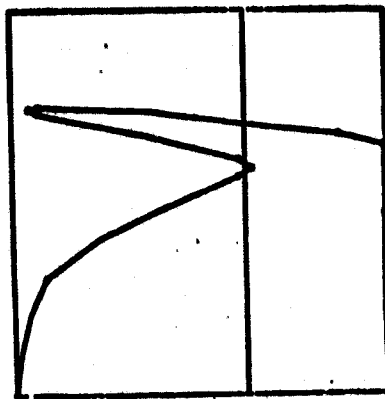
CROSS SECTIONS



DIGITIZED POINTS



SPLINE UNDER TENSION

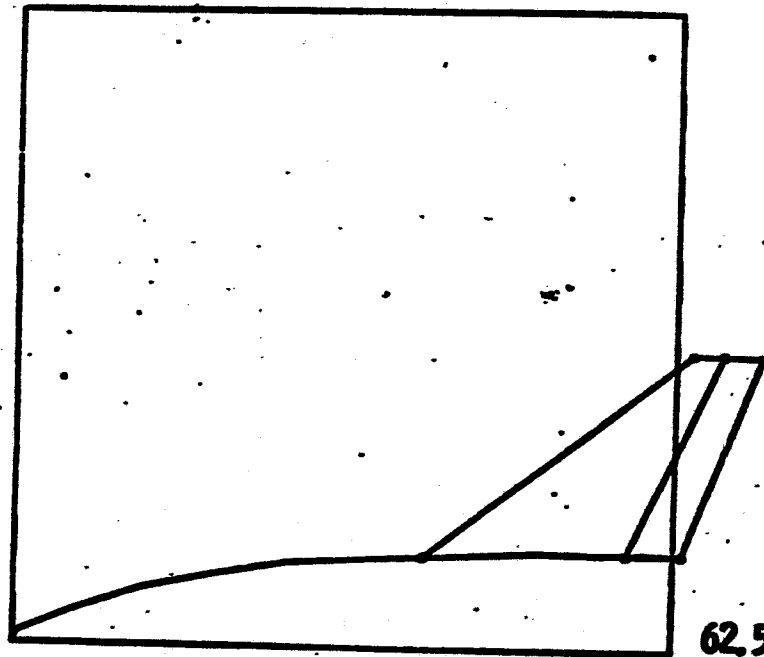


ARBITRARY SHAPE

### WING DIGITIZING

For the wing the planform is digitized. Incidence, dihedral, and airfoil shape (either standard NACA or arbitrary) are input by TTY; the body is sliced at the point of the maximum root airfoil thickness in order to place the wing in the Z direction with the terminal cursor. Horizontal and vertical surfaces are handled similarly.

# WING DIGITIZING



INPUT CR - INPUT IS CORRECT

RD - RE-DIGITIZE

GM - GLOBAL MOVE

PM - POINT MOVE

GS - GLOBAL SCALE

PX - X SCALE

PY - Y SCALE

## TTY INPUT

● INCIDENCE

● AIRFOIL

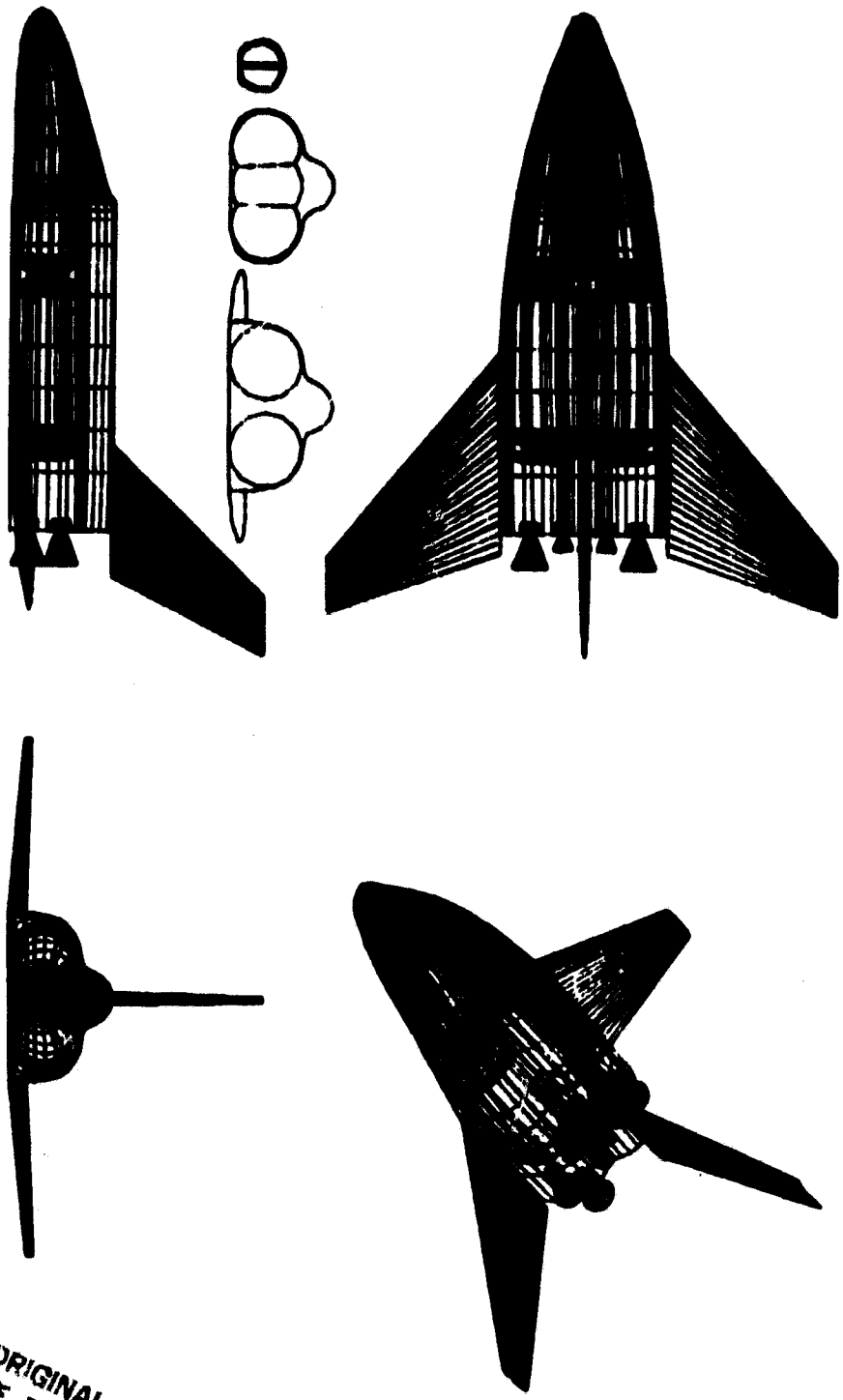
● STANDARD NACA

● SPECIFY ABSCISSA AND ORDINATES

### VEHICLE MODELING

Both the external and internal geometry can be modeled with the AVID interactive geometry system. The external geometry was modeled with 3 cross sections located in the nose, start of the payload bay, and wing junction. This external configuration was digitized and plotted in less than 15 minutes. If every point on the vehicle were digitized, a configuration could be generated in 1 to 2 hours. Internal geometry is digitized in about the same time as the external geometry. The internal geometry is used for tankage arrangement, volume allocations, and rocket engine placement.

MARTIN SINGLE STAGE SHUTTLE  
(Modeled with AVID)



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### AERODYNAMIC PROGRAMS

AVID is mostly used for conceptual and preliminary design. Very fast programs (>5 sec) which use only a gross definition of the vehicle are used for conceptual systems. For preliminary design, programs which use X, Y, Z coordinates are used (>5 min). The more detailed programs have not yet been integrated into the AVID system.



## AERODYNAMIC PROGRAMS

### DESIGN LEVEL

### PROGRAMS

### INPUT

#### LEVEL I (CONCEPTUAL)

- DATCOM I
- DATCOM II
- HYPER
- SKIN FRICTION

- GROSS
- $S_{ref}$ ,  $\Delta_{te}$ ,  
 $\Delta_{te}$ , etc.

#### LEVEL II (PRELIMINARY)

- HABACP
- VORTEX LATTICE
- WAVE DRAG

- NUMERICAL
- HARRIS
- X, Y, Z

#### LEVEL III\* (DETAILED)

- STEIN
- HESS
- WOODWARD

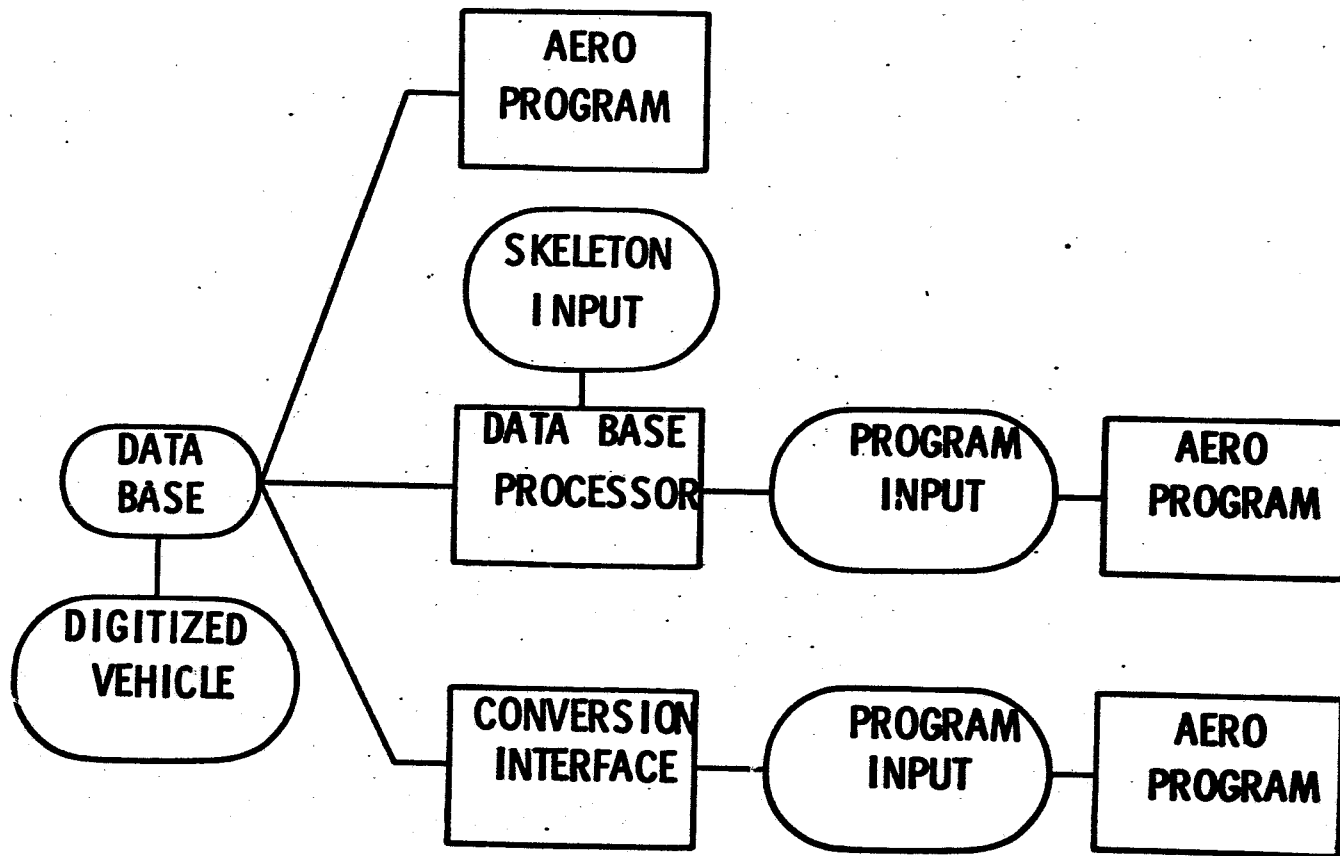
- NUMERICAL  
AND LOFTING

\* NOT AVAILABLE WITH AVID

## PROGRAM INTERFACING TECHNIQUES

Three methods of interfacing programs with AVID exist. The first method is direct data transfer to the program. This method is the most efficient but is not used for aerodynamic programs due to the complexity of the input. The second method uses a data base processor and a skeleton input for a particular program. The processor retrieves data from the data base to replace data base commands in the skeleton input to create an input file that the program uses. The last method is a separate program which operates with the data base to create an input file. This latter method has been used recently to give greater control and more flexibility in the type of configurations that can be analyzed.

# AVID PROGRAM INTERFACING TECHNIQUES



● DIRECT DATA TRANSFER

● DATA MANIPULATION WITH DATA BASE PROCESSOR

● SEPARATE CONVERSION PROGRAM

## SUMMARY

- AVID IS USED FOR INTERACTIVE VEHICLE SYNTHESIS
- SEVERAL AERODYNAMIC PROGRAM OPTIONS ARE AVAILABLE FOR VARIOUS LEVELS OF DESIGN
- THE AVID SYSTEM, WITH ITS INTERACTIVE GRAPHICS SYSTEM, HAS DRASTICALLY-REDUCED DESIGN CYCLE TIME

( $\approx$  30 MINUTES TO DIGITIZE VEHICLE)

( $\approx$  10-30 SEC FOR LEVEL 1 AERODYNAMICS)

( $\approx$  5 MINUTES FOR LEVEL 2 AERODYNAMICS)

## PROBLEM AREAS

- DIFFERENT GEOMETRY DEFINITION FOR EVERY AERODYNAMIC PROGRAM
- SENSITIVITY OF RESULTS TO MODELING
- PREDICTION OF SUBSONIC STABILITY OF VEHICLES WITH NONSLENDER BODIES
- GEOMETRIC DEFINITION, AERODYNAMIC COMPUTATION, AND AERODYNAMIC GRAPHICAL OUTPUT INTEGRATED INTO ONE PROGRAM
- QUICK ARBITRARY HYPERSONIC ANALYSIS PROGRAM

## RECOMMENDATIONS

- STANDARDIZED GEOMETRY FOR AERODYNAMIC PROGRAMS
- DEVELOP INDEPENDENT PROGRAMS FOR GEOMETRY INPUT, AERODYNAMIC COMPUTATION, AND GRAPHICAL OUTPUT
  - DEVELOPMENT SIMPLIFIED
  - MODIFICATIONS ARE EASIER
  - ALLOWS MINI-COMPUTER GRAPHICS AND HOST COMPUTER COMPUTATIONS

PANEL 3: SYSTEMS IN USE

1. Is it possible for the panel members to summarize the attributes in each system? For example, a chalkboard could be used to list them.
2. Are there significant differences in direction between the systems described? Can they be summarized by the panel?
3. Is there a need for better display of surfaces?
  - (a) Hidden line removal? Adequate?
  - (b) Shading?
  - (c) Color?
4. Is it time to standardize?
5. What are the items in surface representation that the Workshop overlooked?

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## WORKSHOP COMMENTS & OBSERVATIONS DURING THE SUMMARY SESSION

### 1. STANDARDIZATION

"Not needed (yet)."

"Needed when there is significant information exchange (later?)".

"List needed functions instead".

"Observe CAMI and ANSI Standards Committee progress".

### 2. INFORMATION EXCHANGE

"Several programs/systems are available, e.g., QUICK, ICAD, iPEGS, etc. but require dedication to adopt/install elsewhere".

"Parts of systems are available, e.g., point thinning, patch intersection, etc.".

"Minicomputers and graphics terminals are an important part of a system".

"Advantages and limitations of various methods were surveyed, e.g. Staley's paper".

"Items missed in the Workshop..."Fairing" methods".

### 3. UNDERSTANDING THE ISSUES

"Conics, cubics, quintics all have a place (a defender)".

"Interpolation with polynomials causes spurious waviness".

"Non-Interpolative methods are an alternative".

"Wind tunnel model builders want equation representation of surfaces not coordinate points".

"Interpolation with polynomials is the basis for most current systems".

"Separate geometry, aerodynamics, graphics".

"Aerodynamics can be sensitive to small changes in the surface in special regions/flow conditions".



4. NASA'S ROLE IN SURFACE REPRESENTATION

"Provide a small package for those who don't have their own".

"All major companies will have their own system no matter what NASA does".

"Survey the companies for a list of needed functions (utilities)".

"Communicate aircraft geometry by points...the common denominator".

"Need to communicate slopes and curvature too".

"Need to know the difference (tolerance) between one form of representation and another".

National Aeronautics and  
Space Administration

Ames Research Center  
Moffett Field, California  
94035



Reply to Attn of: FAE:227-2

December 29, 1977

On March 1-2, 1978, NASA-Ames Research Center will host a workshop on Aircraft Surface Representation for Aerodynamic Computation. The purpose of the workshop is to exchange information on converting aircraft geometry into the form needed by aerodynamic computation programs. Primary emphasis will be on aircraft surface specification for linear aerodynamics paneling programs, but some time will be allotted to discuss areas of commonality with aerodynamic flow-field mesh generation and possibly with computerized lofting systems.

We propose to include presentations in three topic areas: (1) Geometry requirements in aerodynamic computation, (2) Current or proposed geometry methods, and (3) Use of interactive graphics. The presentations will be followed by panel discussions designed to explore the user's common desires and concerns. A summary of each discussion and the visual material used will be published by NASA.

You and/or members of your staff are invited to participate in the workshop by presenting material and/or entering the discussions. If you wish to attend, please address all proposed presentation material, comments or questions by January 23, 1978 to:

Thomas J. Gregory or  
Captain John Ashbaugh, USAF  
NASA-Ames Research Center, M.S. 227-2  
Moffett Field, CA 94035  
Telephone: (415) 965-5881

We are looking forward to an open communication of ideas at the workshop and will be pleased if you can attend.

Sincerely yours,

  
C. A. Syvertson  
Acting Director

National Aeronautics and  
Space Administration



Ames Research Center  
Moffett Field, California  
94035

Reply to Airm of: FAE:227-2


Dear Attendee:

Thank you for your interest in the Ames Workshop on "Aircraft Surface Representation for Aerodynamic Computation." On the basis of conversations and draft material from each presenter we have prepared a preliminary program (Enclosure 1) that includes both presentations and panel sessions. Possible questions or topics for the panel sessions are listed in Enclosure 2.

The Workshop will be held in the Ames Research Center Auditorium (Building N-201) (Enclosures 3 and 4) and start promptly at 8:30 a.m. Please register early at the Visitor Reception Building (N-253) and proceed to the Workshop parking lot as shown on the Enclosure 4. The Auditorium is a short walk (approximately 100 yds.). Lunch is planned at the Ames Cafeteria, another short walk of approximately 200 yds. A list of area motels and restaurants is on the back of the Enclosure 3.

There will be an incoming message board (telephone (415) 965-5256) and pay telephone available in the Auditorium Lobby.

Thank you again for your interest and please call (415) 965-5881 if you have questions.

  
Thomas J. Gregory  
Chief, Aircraft Aerodynamics  
Branch

  
Capt. John Ashbaugh, USAF

Enclosures:

1. Preliminary Program
2. Topics for Panels
3. Map of Sunnyvale & Mt. View Area
4. Ames Research Center Map

National Aeronautics and  
Space Administration



Ames Research Center  
Moffett Field, California  
94035

Reply to Attn of: FAE:227-2

Dear Presenter:

Thank you for agreeing to present material at the Ames Workshop on "Aircraft Surface Representation for Aerodynamic Computation." On the basis of conversations and draft material supplied by each presenter, we have prepared a preliminary program (Enclosure 1) that identifies the presenter, his organization and a title or topic to be emphasized. While much of the initial material supplied was very broad in scope, subsequent discussion suggested that the attendees at this Workshop will benefit most from presentations that are focused on key topics. Therefore, we are requesting that you concentrate your presentation on the titles listed in the preliminary agenda.

Panel sessions are planned after each session and will address issues or questions that appear to be of interest. Enclosure 2 is a list of questions which you may want to consider prior to participating in a panel or commenting from the audience.

In preparing your presentation please keep in mind that a workshop environment encourages dialog and interaction between the audience, the presenters and the panels. To provide adequate time for the panel sessions, it is very important to stay within presentation time limits so that we derive this important benefit from the Workshop.

Please bring one xerox copy of your presentation visual material and a companion paragraph for each vugraph or slide. Please insure that the last name of the presenter and a page number appears on each page. NASA will provide a copy of this material to each attendee near the end of the Workshop. These may be mailed to attendees after the Workshop if printing is delayed.

The Workshop will be held in the Ames Research Center Auditorium (Building N-201) (Enclosures 3 and 4), and start promptly at 8:30 a.m. Please register early at the Visitor Reception Building (N-253) and proceed to the Workshop parking lot as shown on the Enclosure 4. The Auditorium is a short walk (approximately 100 yds.). Lunch is planned at the Ames Cafeteria, another short walk of approximately 200 yds. A list of area motels and restaurants is on the back of the Enclosure 3.

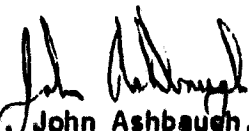
FAE:227-2

2.

There will be an incoming message board (telephone (415) 965-5256) and pay telephone available in the Auditorium Lobby.

Thank you again for your response and please call (415) 965-5881 if you have questions.

  
Thomas J. Gregory  
Chief, Aircraft Aerodynamics  
Branch

  
Capt. John Ashbaugh, USAF

Enclosures:

1. Preliminary Program
2. Topics for Panels
3. Map of Sunnyvale and Mt. View Area
4. Ames Research Center Map

## ATTENDEES

### NASA-Ames Research Center

Arild Bertelrud, M. S. 229-1, Ph. (415) 965-6156  
Reese Sorenson, M. S. 202-1, Ph. (415) 965-6416  
Herbert Hoy, M. S. 210-5, Ph. (415) 965-5320  
Joe Steger, M. S. 202-1, Ph. (415) 965-6417  
Harve Lomax, M. S. 202-1, Ph. (415) 965-5124  
F. R. Bailey, M. S. 202-1, Ph. (415) 965-6419  
W. P. Jones, M. S. 233-10, Ph. (415) 965-6482  
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J. Rakich, M. S. 229-1, Ph. (415) 965-6192  
J. Murphy, M. S. 227-8, Ph. (415) 965-5655  
R. Carmichael, M. S. 227-2, Ph. (415) 965-6216  
Terry Holst, M. S. 202-1, Ph. (415) 965-6032  
Tom Pullian, M. S. 202-1, Ph. (415) 965-6417  
John Viegas, M. S. 229-1, Ph. (415) 965-6200  
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