N95- 23415

53-61

~~43778~~
P_33

1995116995

IGES TRANSFORMER AND NURBS IN GRID GENERATION

by

TZU-YI YU , Bharat K. Soni

NSF/ERC For Computational Field Simulation

Mississippi State University, MS39762

ABSTRACT

In the field of Grid Generation and the CAD/CAM , there are numerous geometry output formats which require the designer to spend a great deal of time manipulating geometrical entities in order to achieve a useful sculptured geometrical description for grid generation. Also in this process , there is a danger of loosing fidelity of the geometry under consideration. This stresses the importance of a standard geometry definition for the communication link between varing CAD/CAM and grid system . The IGES (Initial Graphics Exchange Specification) (Ref1) file is a widely used communication between CAD/CAM and the analysis tools . The scientists at NASA Research Centers - including NASA Ames,NASA Langley, NASA Lewis and NASA Marshall - have recognized this importance and therefore, in 1992 they formed the committee of the "NASA-IGES" which is the subset of the standard IGES . This committee stresses the importance and encourage the CFD community to use the standard IGES file for the interface between the CAD/CAM and CFD analysis . Also two of the IGES entities -- the NURBS Curve (Entity 126) and NURBS Surface (Entity 128) -- which have many useful geometric properties -- like the convex hull property , local control property and affine invariance, also widely utilized analytical geometries can be accurately represented using NURBS. This is improtant in today grid generation tools because of the emphasis of the interactive design.

To satisfy the geometry transformation between the CAD/CAM system and Grid Generation field , the CAGI-- Computer Aided Geometry Design is developed , which include the Geometry Transformation , Geometry Manipulation and Geometry Generation as well as the user interface . A self explanatory pictorial views of CAGI modules and links is shown in Figure 1 .

This paper will present the successful development IGES file transformer and application of NURBS definition (Ref 3) in the grid generation (Ref 4,5) .

PRECEDING PAGE BLANK NOT FILMED

PAGE 1020 INTENTIONALLY BLANK

IGES TRANSFORMER AND NURBS

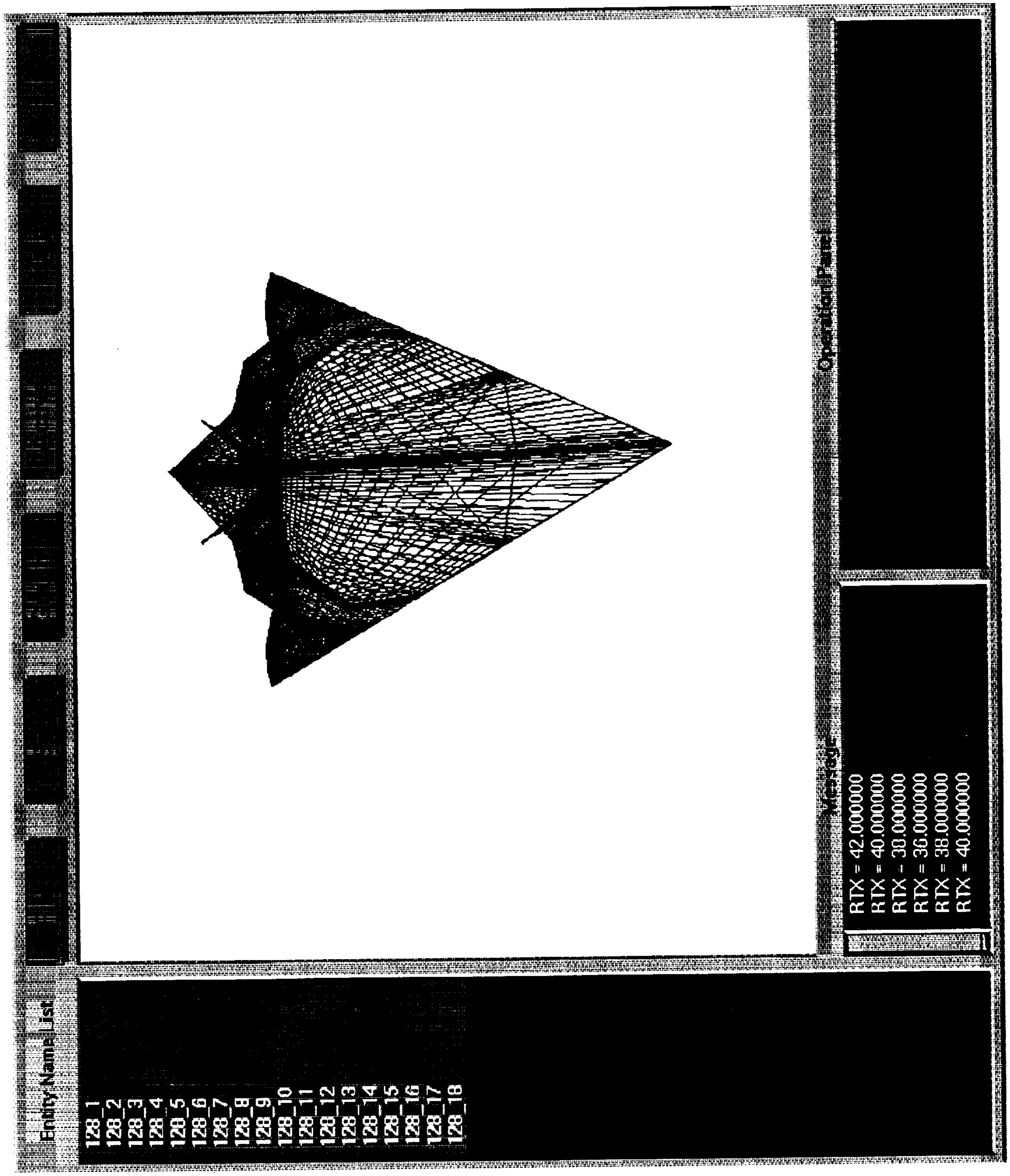
IN

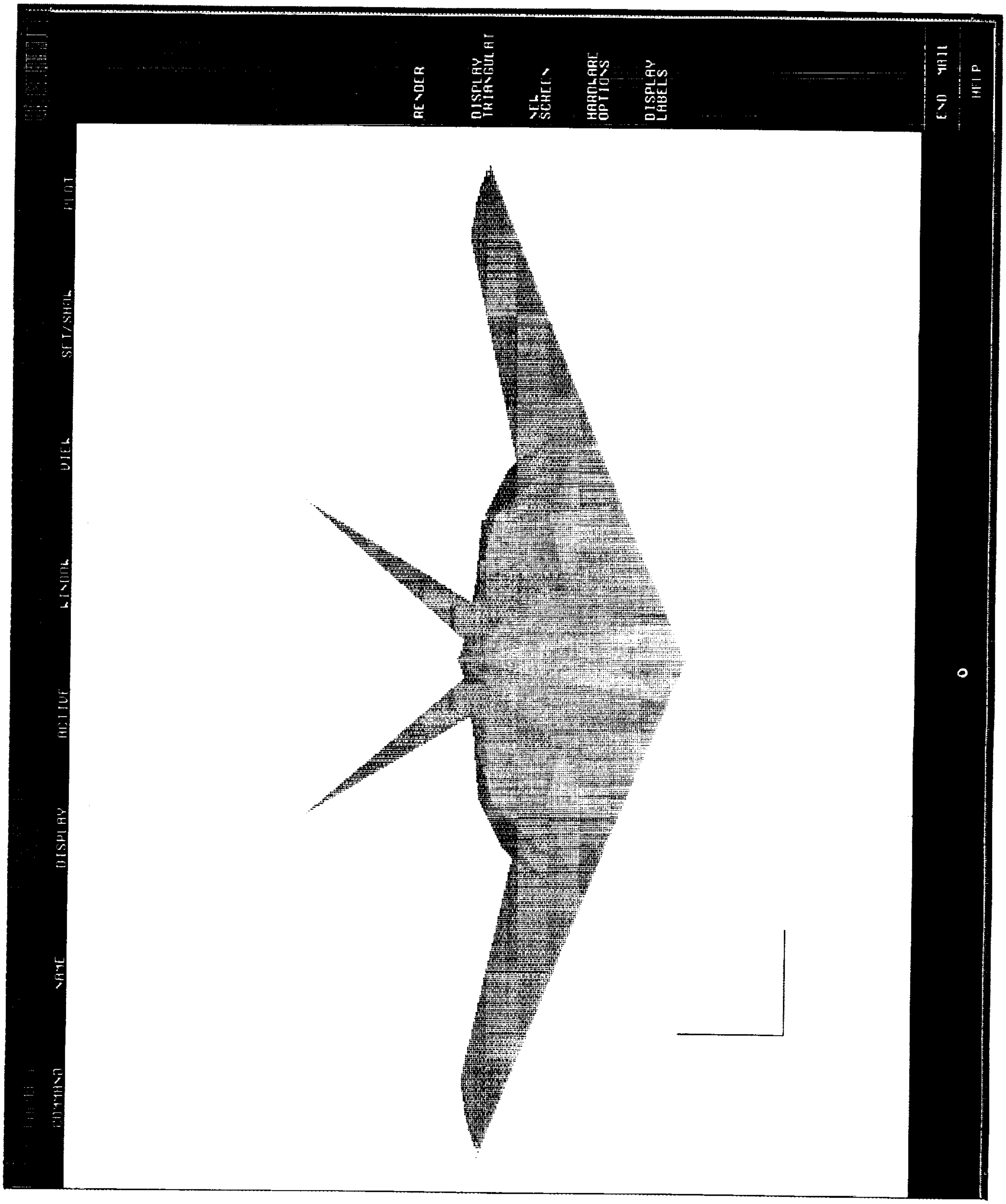
GRID GENERATION

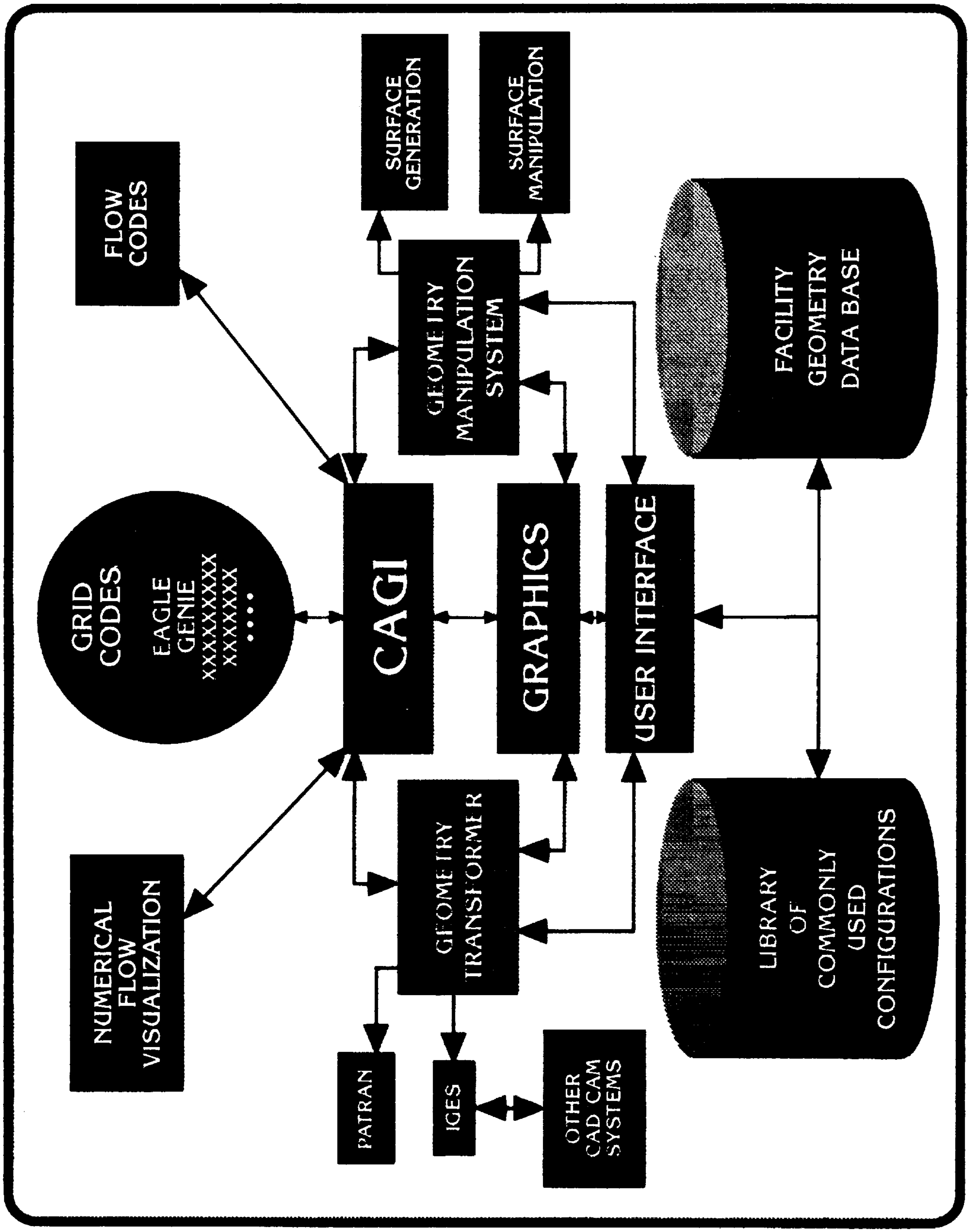
Graduate Student : Tzu - Yi YU

Advisor : Dr. Bharat K. Soni

Sponsor :NASA/Marshall Space Flight Center


Entity Name List
128_1
128_2
128_3
128_4
128_5
128_6
128_7
128_8
128_9
128_10
128_11
128_12
128_13
128_14
128_15
128_16
128_17
128_18
Message
RTX = 42.000000
RTX = 40.000000
RTX = 38.000000
RTX = 36.000000
RTX = 38.000000
RTX = 40.000000
Operation Panel


RENDER
DISPLAY TRIANGULAT
HARDWARE OPTIONS
DISPLAY LABELS
HELP
DISPLAY
SET/SHAD


NUMERICAL FLOW VISUALIZATION
GRID CODES
EAGLE
GENIE
XXXXXXXXX
XXXXXXX
• • • •
FLOW CODES
CAGI
GRAPHICS
USER INTERFACE
GEOMETRY TRANSFORMER
GEOMETRY MANIPULATION SYSTEM
SURFACE GENERATION
SURFACE MANIPULATION
PATRAN
IGES
OTHER CAD CAM SYSTEMS
LIBRARY OF COMMONLY USED CONFIGURATIONS
FACILITY GEOMETRY DATA BASE

MOTIVATION :

- **Follow the National Standard and set the communication between CAD/CAM and the Grid Generation Tools**
- **Apply the NURBS definition to Grid Generation**

STRATEGY :

- **Develop the integrated computer program — CAGI : Computer Aided Grid Interface**

WHY IGES ?

. . . IGES - ->

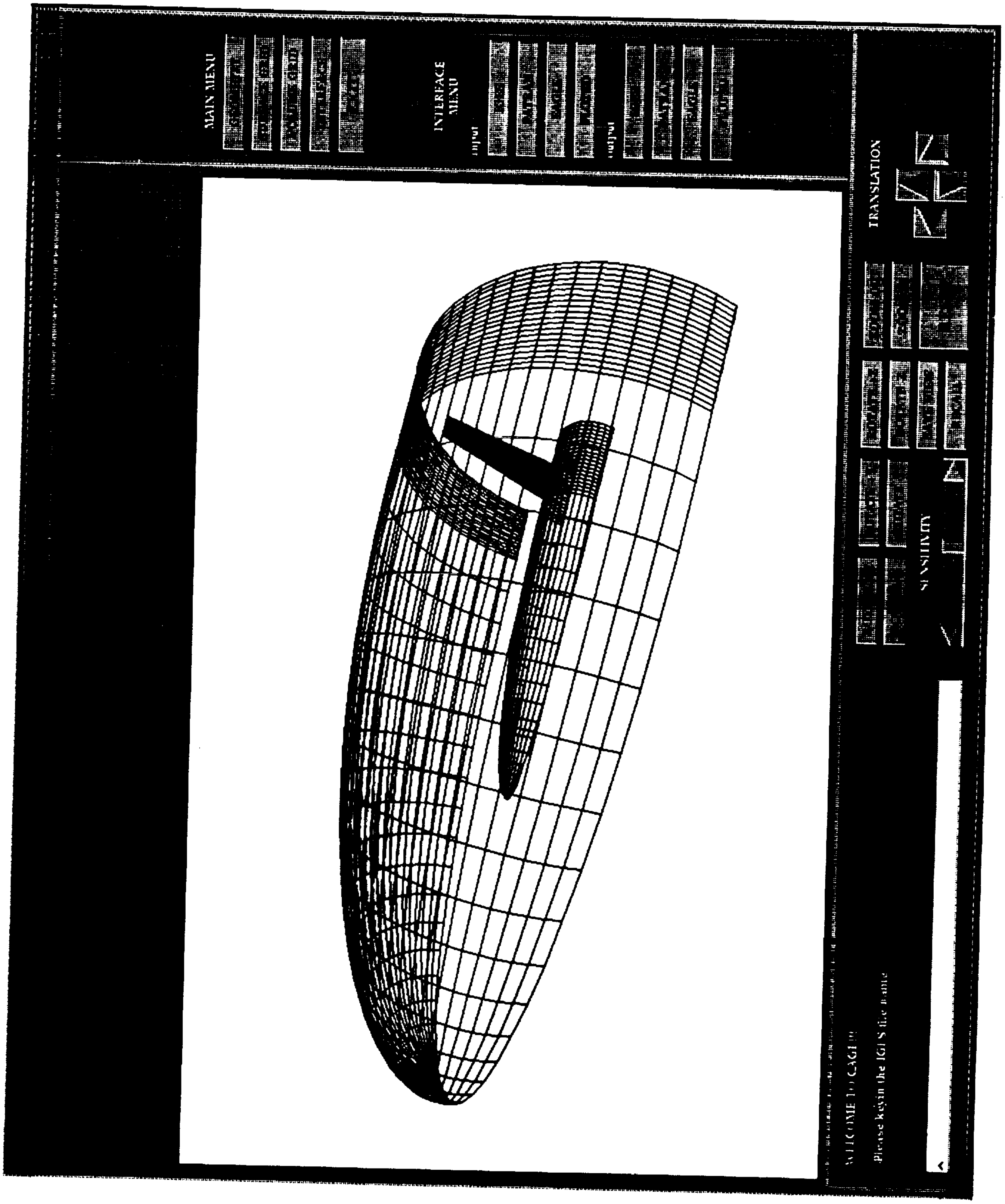
Initial Graphics Exchange Specification

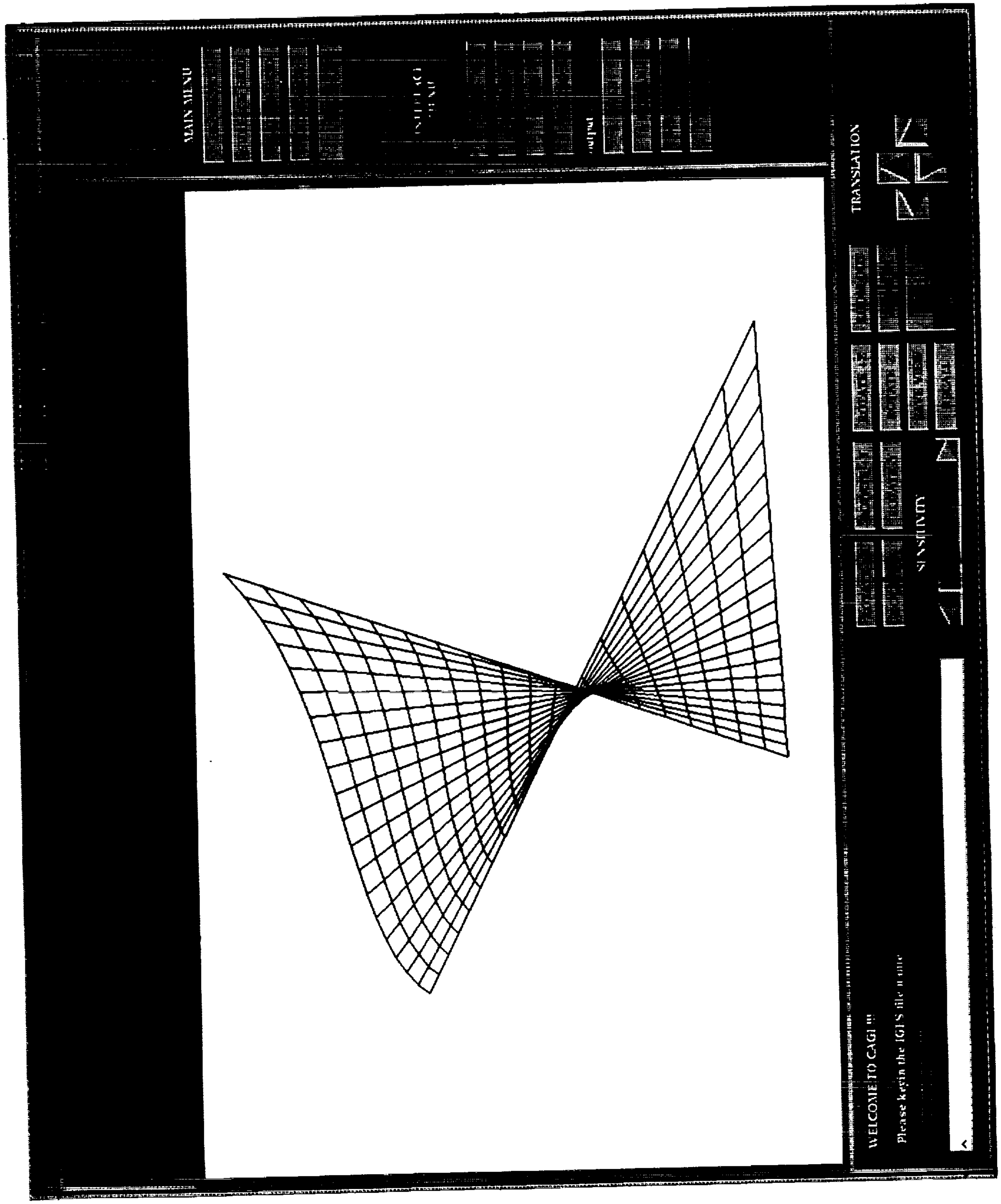
. . . . . . **National Standard**

. . . . . . **All-inclusive**

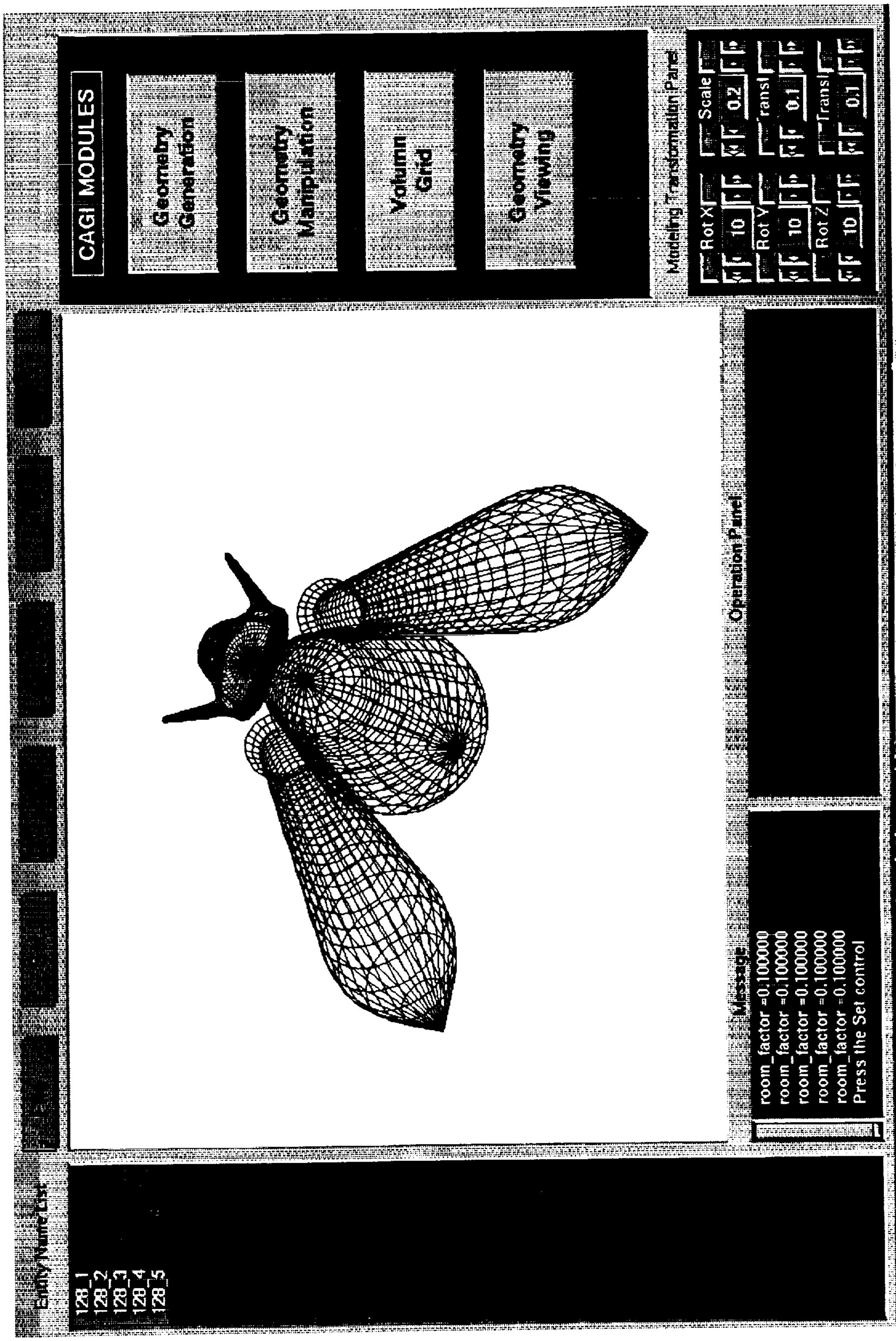
NASA IGES

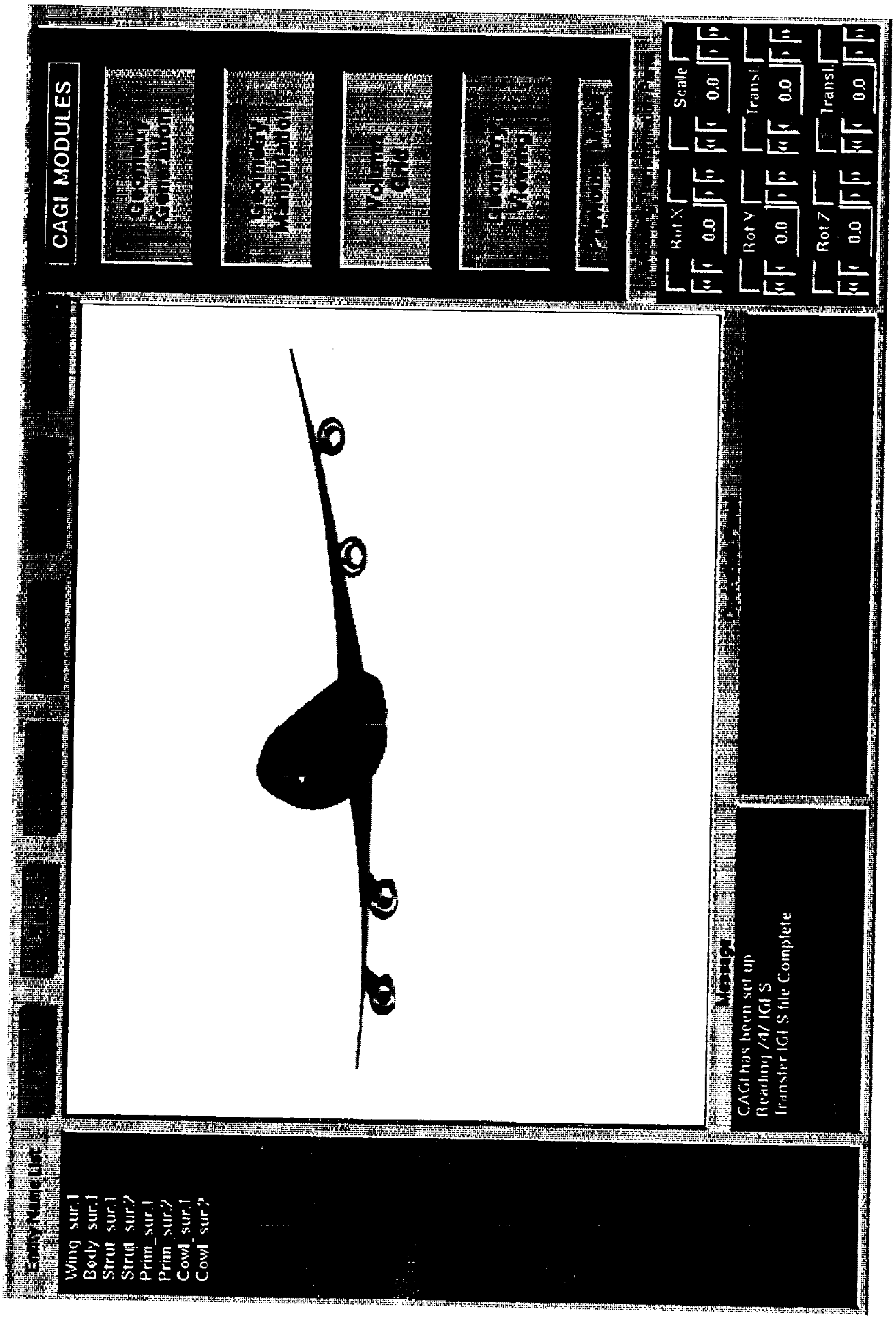
Entity Type Number	Entype Type	CAGI	NASA-IGES
100	Circular Arc	*	**
102	Composite Curve	*	**
104	Conic Arc	*	**
106	Copious Data	*	**
108	Plane	*	**
110	Line	*	**
112	Parametric Spline Curve	*	
114	Parametric Spline Surface	*	
116	Point	*	**
118	Ruled Surface	*	
120	Surface of Revolution	*	
122	Tabulated Cylinder	*	
124	Transformation Matrix	*	**
125	Flash		
126	Rational B-Spline Curve	*	**
128	Rational B-Spline Surface	*	**
130	Offset Curve		
140	Offset Surface		
141	Boundary		**
142	Curve on a Parametric Surface		**
143	Bounded Surface		**
144	Trimmed Parametric Surface		


MAIN MENU
INTERFACE MENU
TRANSLATION
SENSITIVITY


MAIN MENU
TRANSLATION
SENSITIVITY
WELCOME TO CAGI !!!
Please keyin the IGES file name

Entity Type Number	Entype Type	CAGI NURB	NASA-NURB-ONLY
100	Circular Arc	*	
102	Composite Curve		**
104	Conic Arc	*	
106	Copious Data		
108	Plane		
110	Line	*	
112	Parametric Spline Curve	*	
114	Parametric Spline Surface	*	
116	Point		
118	Ruled Surface		
120	Surface of Revolution	*	
122	Tabulated Cylinder		
124	Transformation Matrix	*	**
125	Flash		
126	Rational B-Spline Curve	*	**
128	Rational B-Spline Surface	*	**
130	Offset Curve		
140	Offset Surface		
141	Boundary		**
142	Curve on a Parametric Surface	*	**
143	Bounded Surface		**
144	Trimmed Parametric Surface		


CAGI MODULES
Geometry Generation
Geometry Manipulation
Volumn Grid
Geometry Viewing
Modeling Transformation Panel
Rot X
Rot Y
Rot Z
Scale
Transl
10
0.2
0.1
Operation Panel
Message
room_factor =0.100000
room_factor =0.100000
room_factor =0.100000
room_factor =0.100000
room_factor =0.100000
Press the Set control
Entity Name List
128_1
128_2
128_3
128_4
128_5


CAGI MODULES
Wing_sur.1
Body_sur.1
Strut_sur.1
Strut_sur.2
Prim_sur.1
Prim_sur.2
Cowl_sur.1
Cowl_sur.2
Message
CAGI has been set up
Transfer IGES file Complete
Rot X
Rot Y
Rot Z
Scale
Transl.
Transl.
0.0

Geometry Generation :

- Point , Line , Parametric Curve , Bezier Curve
  NURBS Curve
  TFI , NURBS Surface , Bezier Surface
  Surface of Revolution

Geometry Manipulation :

- Picking , Changing the definition of NURBS
  Redistuibute the existing geometry

Geometry Generation :

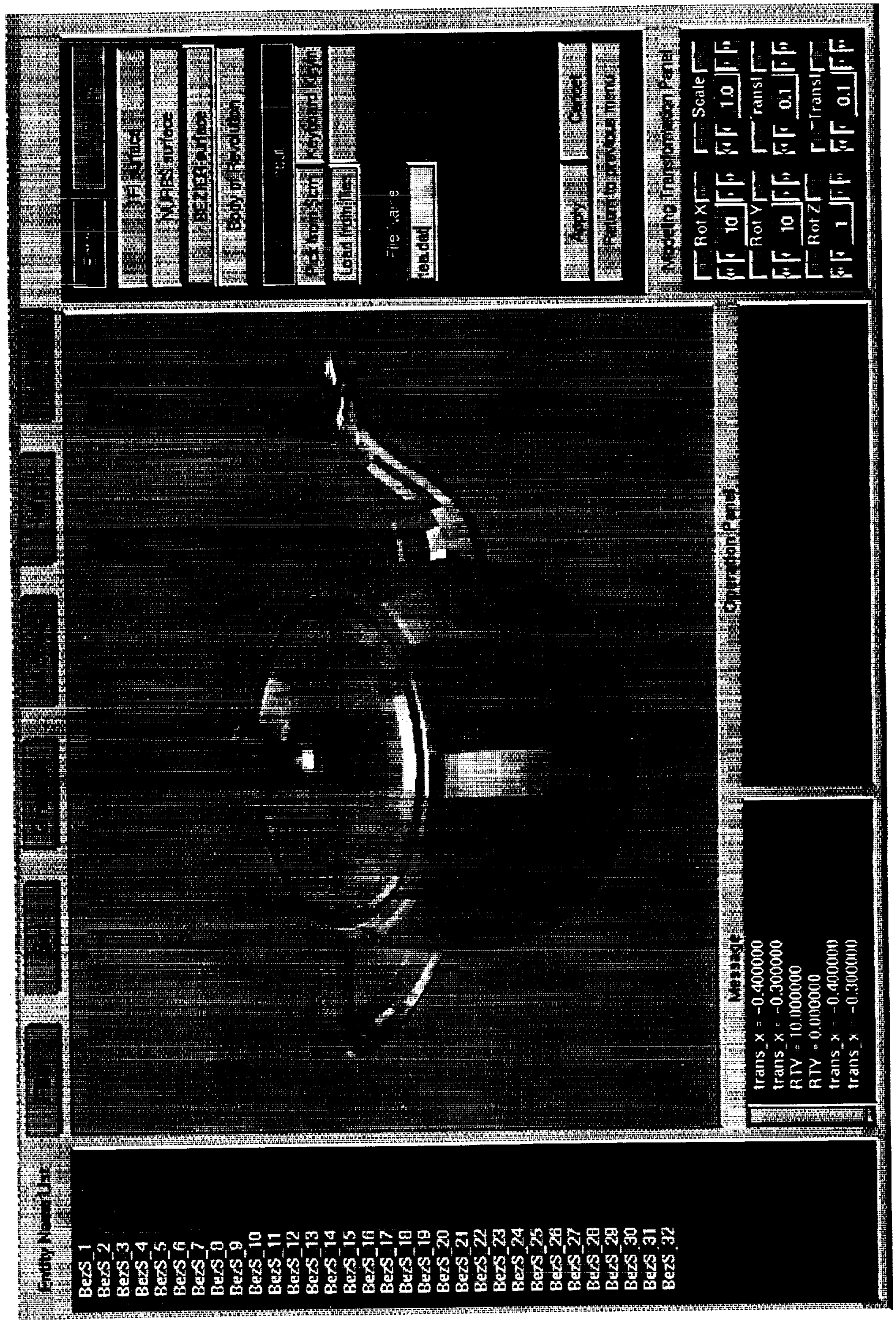
- Point , Line , Parametric Curve , Bezier Curve
  NURBS Curve

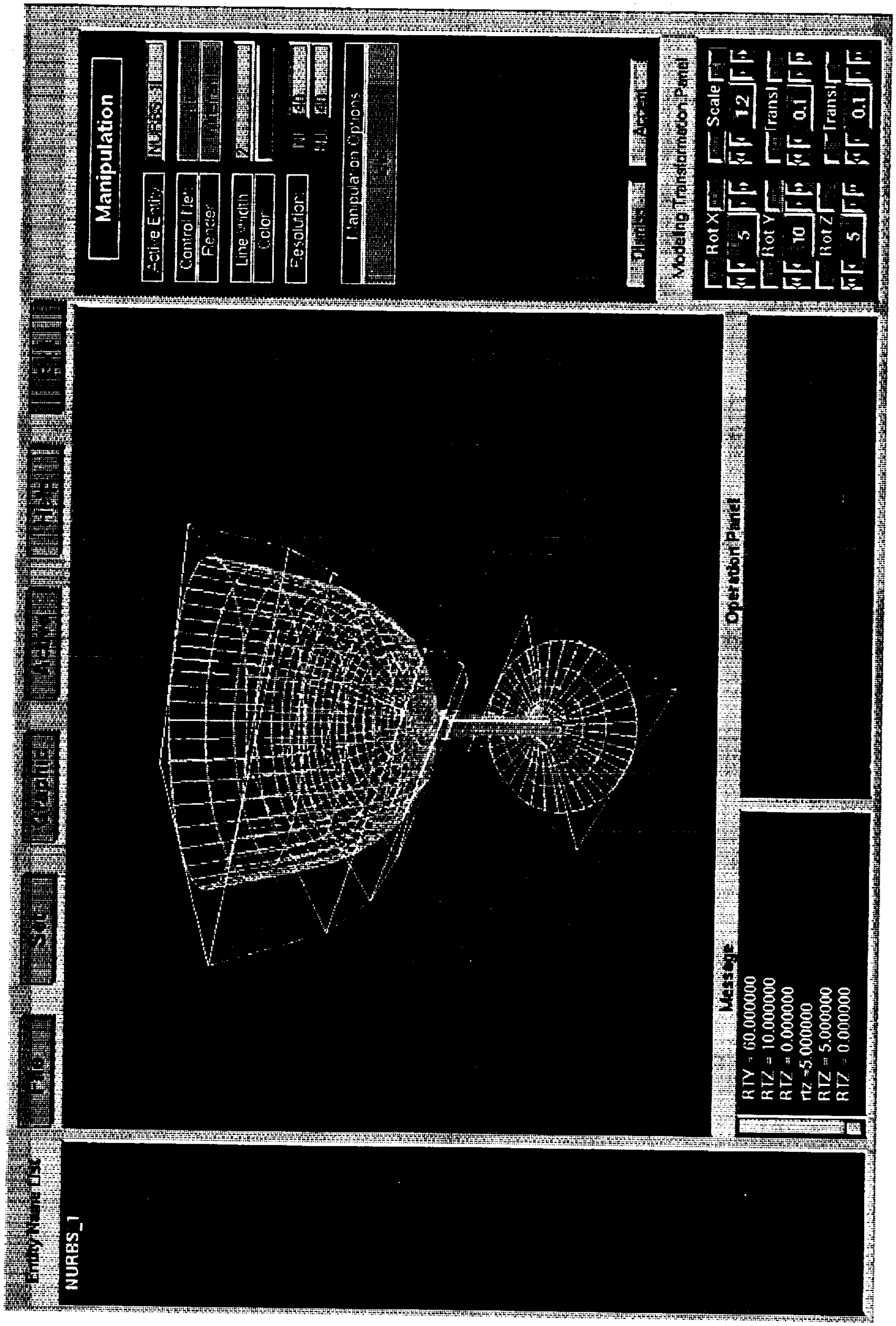
  TFI , NURBS Surface , Bezier Surface

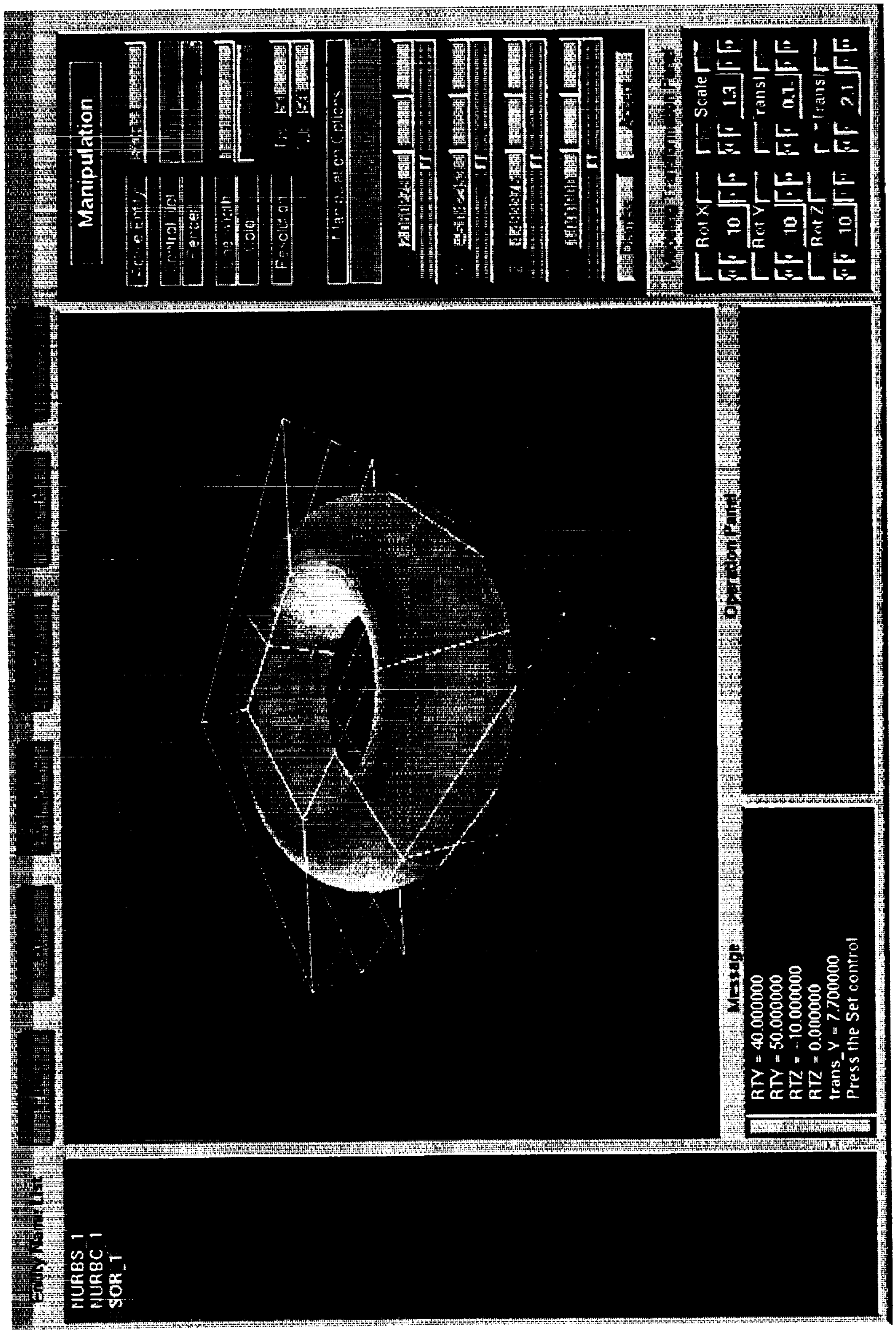
  Surface of Revolution

Geometry Manipulation :

- Picking , Changing the definition of NURBS
  Redistuibute the existing geometry


BezS_1
BezS_2
BezS_3
BezS_4
BezS_5
BezS_6
BezS_7
BezS_8
BezS_9
BezS_10
BezS_11
BezS_12
BezS_13
BezS_14
BezS_15
BezS_16
BezS_17
BezS_18
BezS_19
BezS_20
BezS_21
BezS_22
BezS_23
BezS_24
BezS_25
BezS_26
BezS_27
BezS_28
BezS_29
BezS_30
BezS_31
BezS_32
trans_x = -0.400000
trans_x = -0.300000
RTY = 10.000000
RTY = 0.000000
Apply
Cancel
Scale
Rot X
Rot Y
Rot Z


Entity Name List
NURBS_1
Manipulation
Active Entity
Control Net
Render
Line Width
Color
Resolution
Manipulation Options
Modeling Transformation Panel
Rot X
Scale
Rot Y
Transl
Rot Z
5
12
10
0.1
5
0.1
Operation Panel
Message
RTY = 60.000000
RTZ = 10.000000
RTZ = 0.000000
rtz =5.000000
RTZ = 5.000000
RTZ = 0.000000


Manipulation
Operation Panel
Message
RTY = 40.000000
RTY = 50.000000
RTZ = -10.000000
RTZ = 0.000000
trans_Y = 7.700000
Press the Set control
Entity Name List
NURBS_1
NURBC_1
SOR_1
Rot X
Rot Y
Rot Z
Scale
Transl

- **NURBS Curve**

> **Entity type = 126**

$$C(t) = \frac{\sum_{i=0}^{K} W(i)P(i)b_i(t)}{\sum_{i=0}^{K} W(i)b_i(t)}$$

W(i) : the weights

P(i) : the control points

$b_i(t)$ **: the basis functions**

$$b_{i,k}(t) = \frac{(t - T(i))b_{i,k-1}(t)}{T(i + k - 1) - T(i)} + \frac{(T(i + k) - t)b_{i+1,k-1}(t)}{T(i + k) - T(i + 1)}$$

where subscript k is the order of the curve

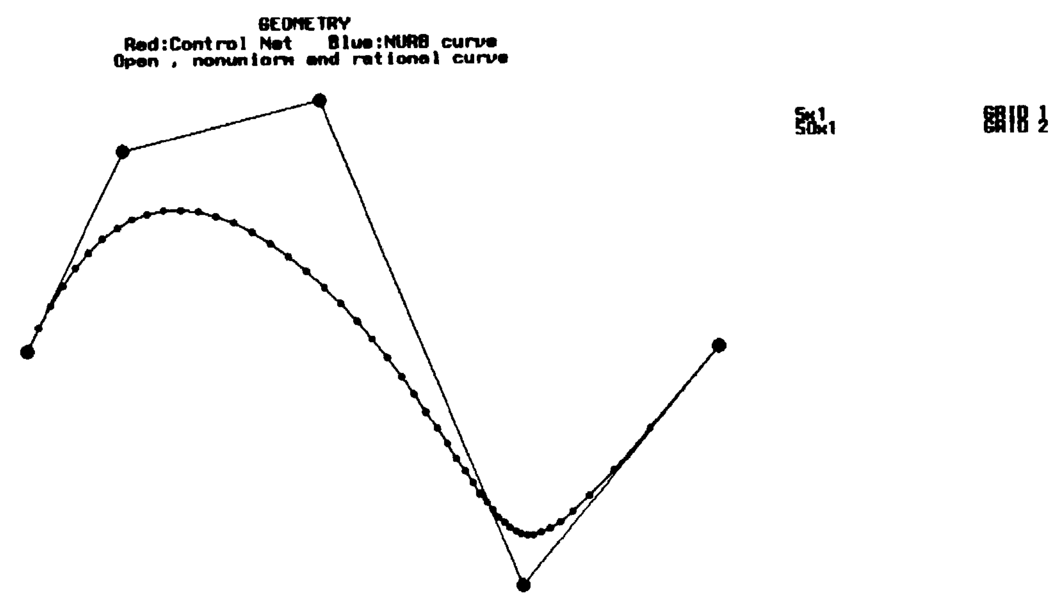
and $b_{i,1}(t) = 1$ if $T(i) \leq t < T(i + 1)$

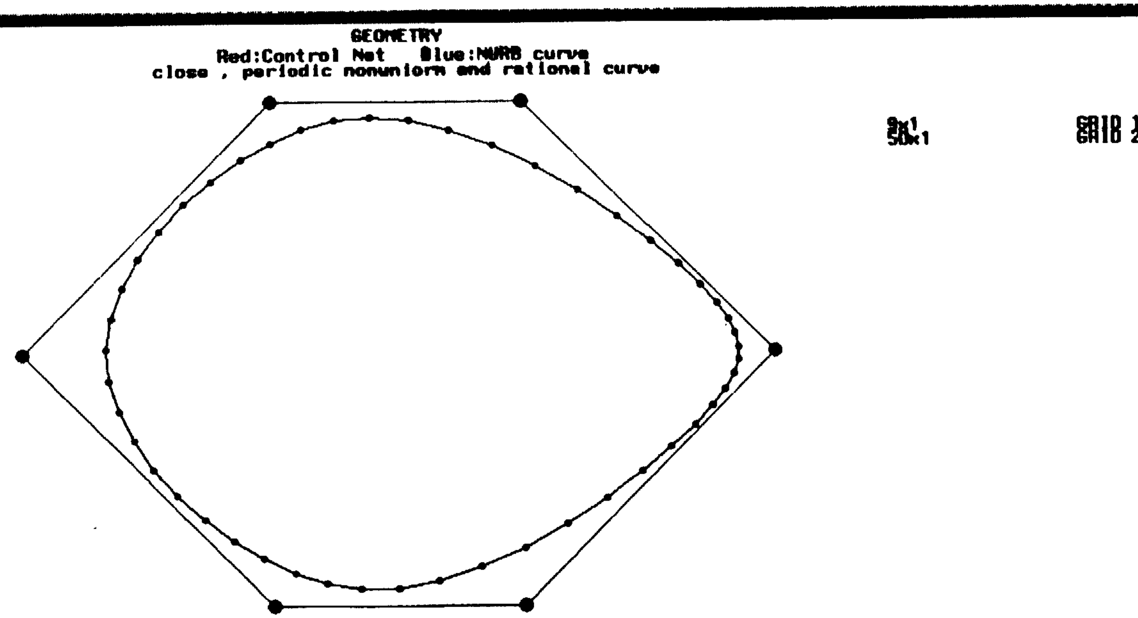
$= 0$ otherwise

$M = k - 1$, $N = K - M + 1$

knot sequence :

T(-M) .... T(0) .... T(N+M)


GEOMETRY
Red:Control Net   Blue:NURB curve
Open , nonuniform and rational curve
5x1
50x1
GRID 1
GRID 2


GEOMETRY
Red:Control Net   Blue:NURB curve
close , periodic nonuniform and rational curve
9x1
50x1
GRID 1
GRID 2

• NURBS Surface

> Entity type = 128

$$S(s,t) = \frac{\sum_{i=0}^{K1}\sum_{j=0}^{K2} W(i,j)P(i,j)b_i(s)b_j(t)}{\sum_{i=0}^{K1}\sum_{j=0}^{K2} W(i,j)b_i(s)b_j(t)}$$

W(i,j) = weights

P(i,j) = control points

$b_i\ (s)\ ,\ b_j\ (t)$: the basis functions in

$$b_{i,k1}(s) = \frac{(s - S(i))b_{i,k1-1}(s)}{S(i + k1 - 1) - S(i)} + \frac{(S(i + k1) - s)b_{i+1,k1-1}(s)}{S(i + k1) - S(i + 1)}$$

where $k1$ is the order of the surface in I direction

and $b_{i,1}(s) = 1$ if $S(i) \leq s < S(i + 1)$

$= 0$ otherwise

$M1 = k1 - 1$, $N1 = K1 - M1 + 1$

knot sequence :

S(-M1) . . .S(0) . . . S(N1+M1)

$$b_{i,k2}(t) = \frac{(t - T(i))b_{i,k2-1}(t)}{T(i + k2 - 1) - T(i)} + \frac{(T(i + k2) - t)b_{i+1,k2-1}(t)}{T(i + k2) - T(i + 1)}$$

where $k2$ is the order of the surface in J direction

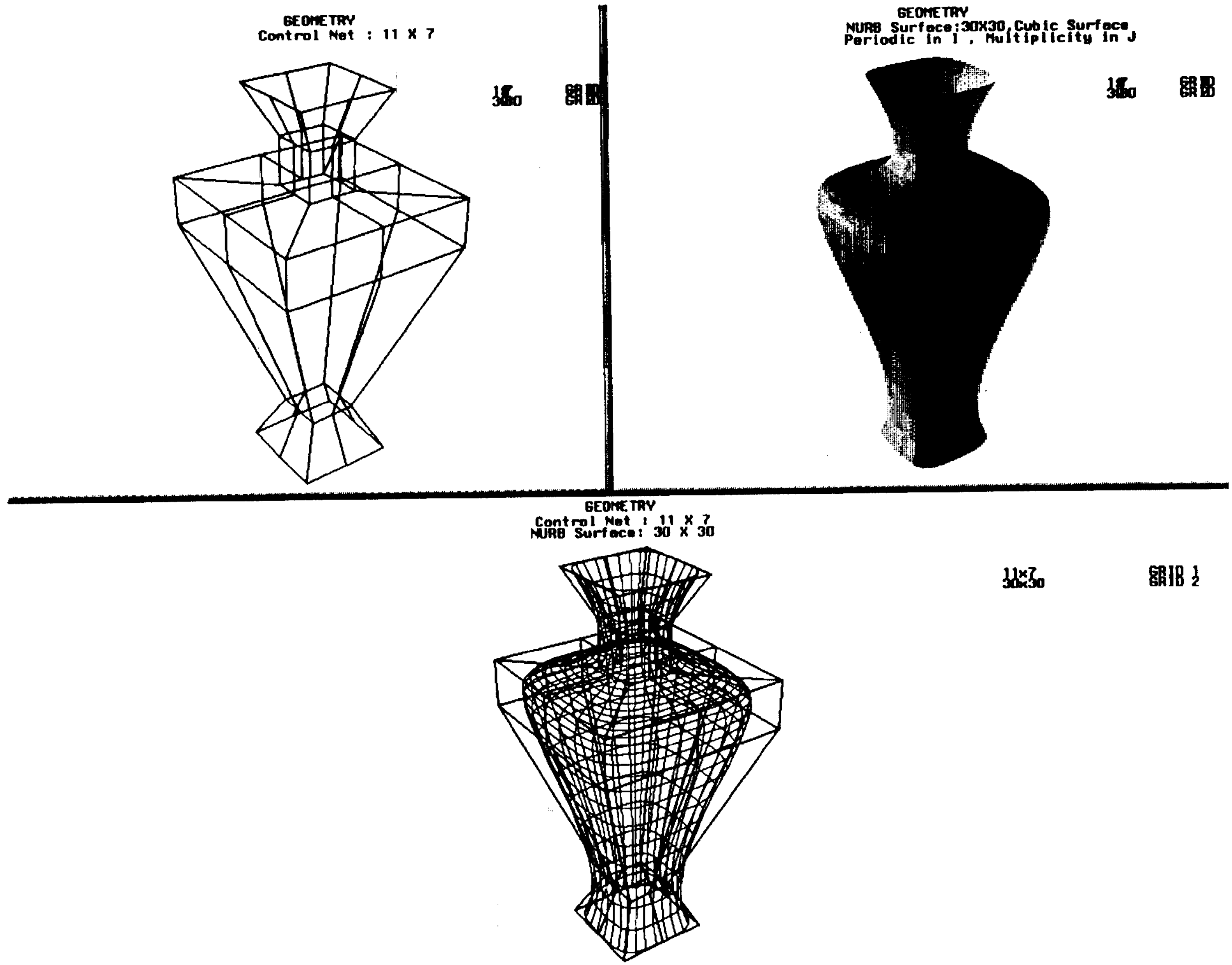
and $b_{i,1}(t) = 1$ if $T(i) \leq t < T(i + 1)$

$= 0$ otherwise

M2 = $k2$ – 1 , N2 = K2 – M2 +1

knot sequence :

T(–M2) . . . T(0) . . . T(N2+M2)


GEOMETRY
Control Net : 11 X 7
GEOMETRY
NURB Surface:30X30,Cubic Surface
Periodic in I , Multiplicity in J
GEOMETRY
Control Net : 11 X 7
NURB Surface: 30 X 30
11x7
30x30
GRID 1
GRID 2

• NURBS Volume

$$V(s,t,w) = \frac{\sum_{i=0}^{K1}\sum_{j=0}^{K2}\sum_{k=0}^{K3} W(i,j,k)P(i,j,k)b_i(s)b_j(t)b_k(u)}{\sum_{i=0}^{K1}\sum_{j=0}^{K2}\sum_{k=0}^{K3} W(i,j,k)b_i(s)b_j(t)b_k(u)}$$

W(i,j,k) = the weights of the control volume

P(i,j,k) = the control points of the volume

$b_i(s), b_j(t), b_k(u)$: the basis functions in I J K direction

$$b_{i,k1}(s) = \frac{(s - S(i))b_{i,k1-1}(s)}{S(i + k1 - 1) - S(i)} + \frac{(S(i + k1) - s)b_{i+1,k1-1}(s)}{S(i + k1) - S(i + 1)}$$

where $k1$ is the order of the volume in I direction

and $b_{i,1}(s) = 1$ if $S(i) \le s < S(i + 1)$
$= 0$ otherwise

$M1 = k1 - 1$, $N1 = K1 - M1 + 1$

knot sequence :

S(−M1) . . .S(0) . . . S(N1+M1)

$$b_{i,k2}(t) = \frac{(t - T(i))b_{i,k2-1}(t)}{T(i + k2 - 1) - T(i)} + \frac{(T(i + k2) - t)b_{i+1,k2-1}(t)}{T(i + k2) - T(i + 1)}$$

where $k2$ is the order of the volume in J direction

and $b_{i,1}(t) = 1$ if $T(i) \le t < T(i + 1)$
$= 0$ otherwise

M2 = $k2$ − 1 , N2 = K2 − M2 +1

knot sequence :

T(−M2) . . . T(0) . . . T(N2+M2)

$$b_{i,k3}(u) = \frac{(u - U(i))b_{i,k3-1}(u)}{U(i + k3 - 1) - U(i)} + \frac{(U(i + k3) - u)b_{i+1,k3-1}(u)}{U(i + k3) - U(i + 1)}$$

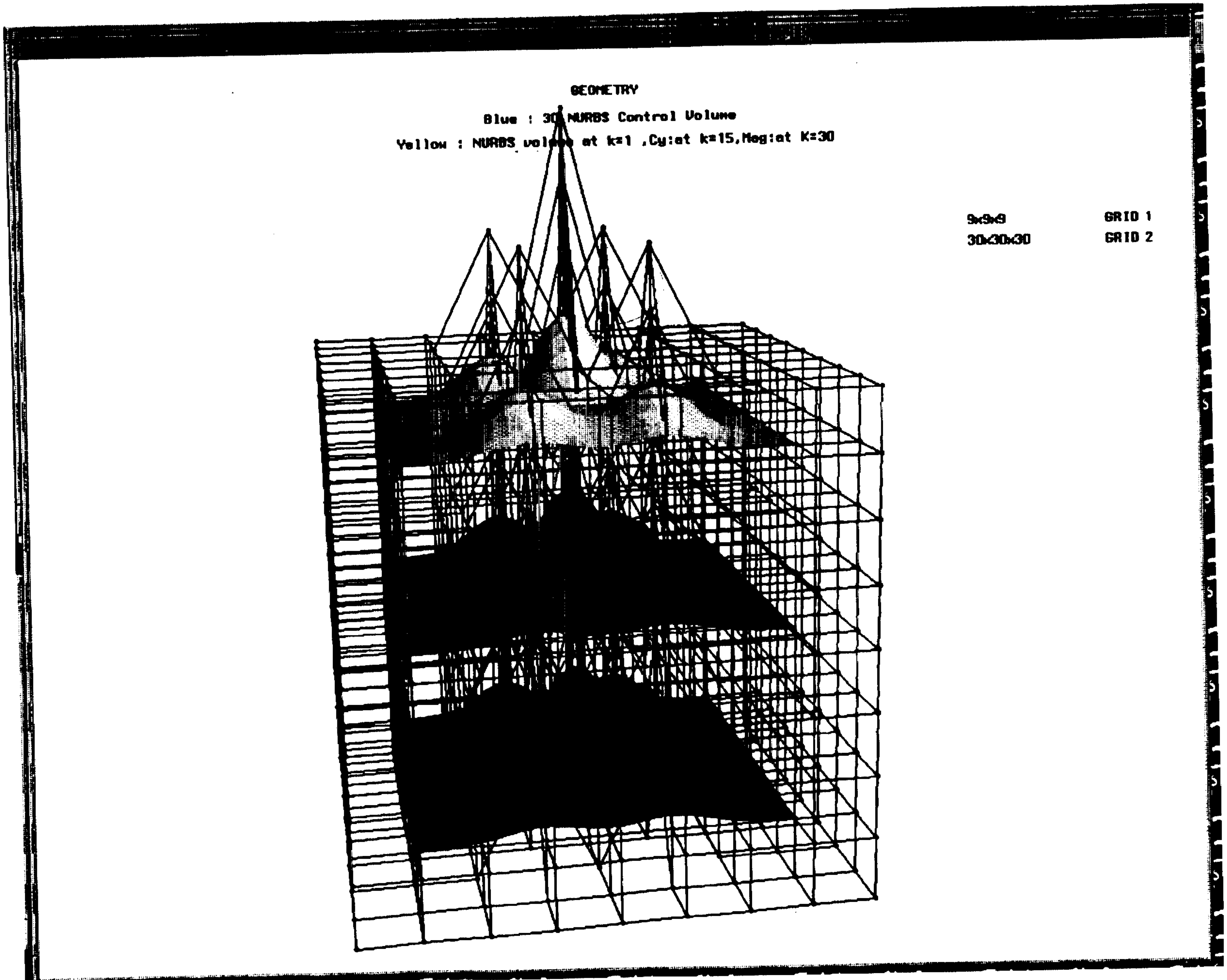
where $k3$ is the order of the volume in K direction

and $b_{i,1}(u) = 1$ if $U(i) \le u < U(i + 1)$
$= 0$ otherwise

M3 = $k3$ − 1 , N3 = K3 −M3 + 1

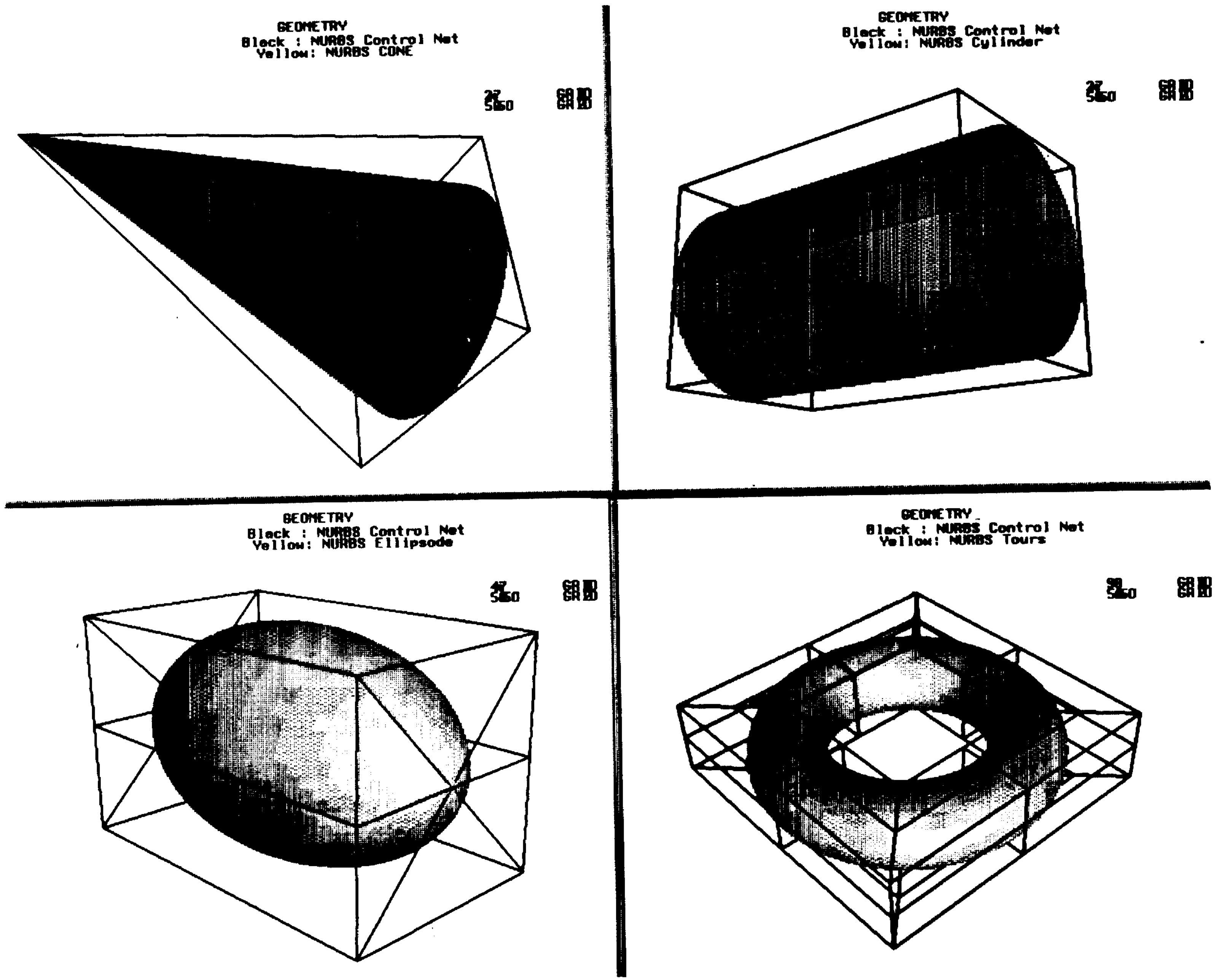
knot sequence :

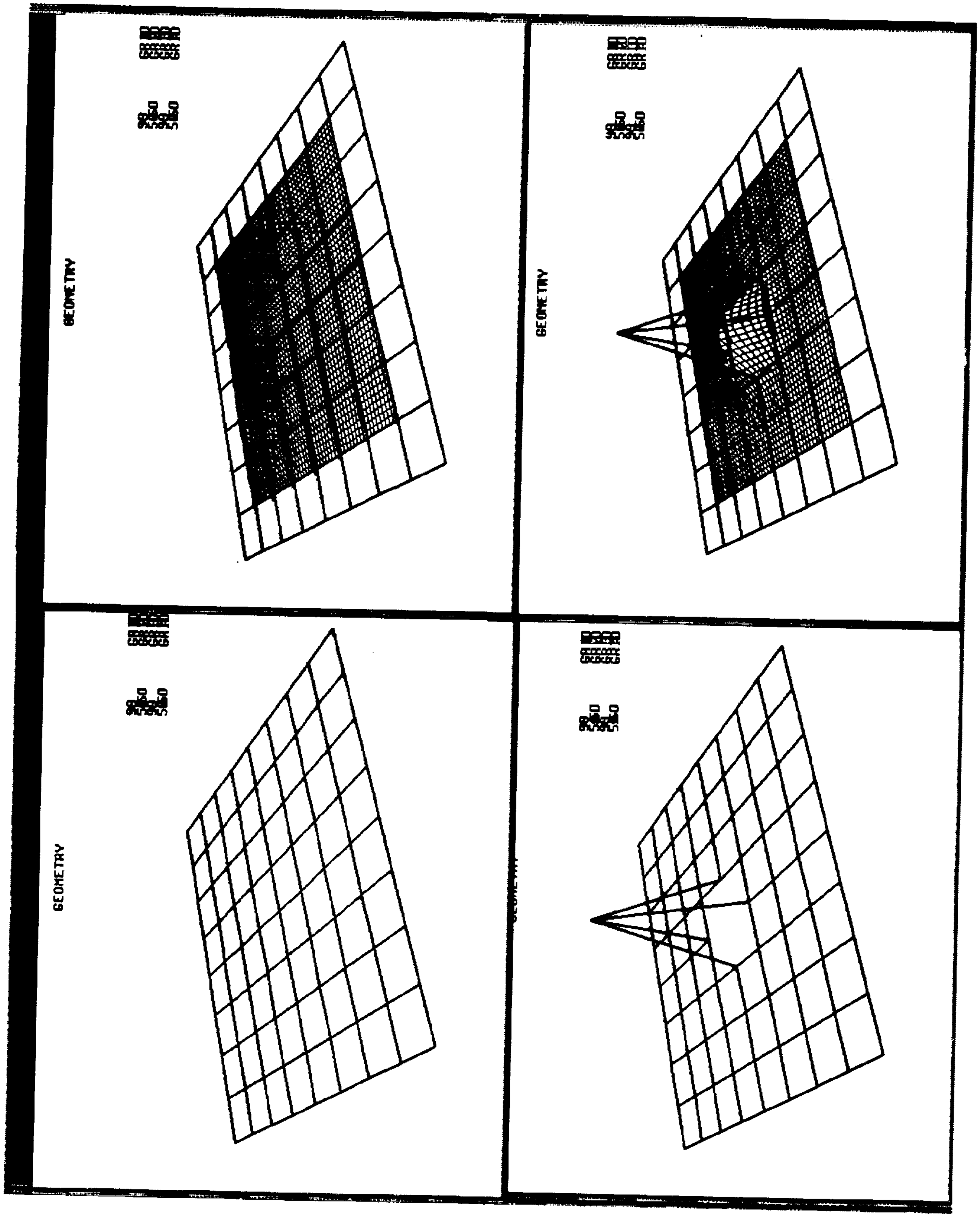
U(−M3) ... U(0) . . . U(N2+M2)


GEOMETRY
Blue : 3D NURBS Control Volume
Yellow : NURBS volume at k=1 ,Cy:at k=15,Mag:at K=30
9x9x9 GRID 1
30x30x30 GRID 2

- **WHY NURBS**

  - **Local control**
  - **stable**
  - **describe the analytic geometry**
  - **flexible and efficient data structure**


GEOMETRY
Black : NURBS Control Net
Yellow: NURBS CONE
GEOMETRY
Black : NURBS Control Net
Yellow: NURBS Cylinder
GEOMETRY
Black : NURBS Control Net
Yellow: NURBS Ellipsode
GEOMETRY
Black : NURBS Control Net
Yellow: NURBS Tours


GEOMETRY
GEOMETRY
GEOMETRY

• Inverse Approach

>. Given input curve $X_0 , X_1 \dots \dots X_L$
determine the control points $d_{-1} , d_0 , \dots . d_l$

>. Knot sequence : by chord length or centripetal

$$\begin{bmatrix} 1 & & & & & \\ \alpha_1 & \beta_1 & \gamma_1 & & & \\ & \alpha_2 & \beta_2 & \gamma_2 & & \\ & & & \ddots & & \\ & & & \alpha_{L-1} & \beta_{L-1} & \gamma_{L-1} \\ & & & & 0 & 1 \end{bmatrix} \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ \vdots \\ d_{L-1} \\ d_L \end{bmatrix} = \begin{bmatrix} r_0 \\ r_1 \\ r_2 \\ \vdots \\ r_{L-1} \\ r_L \end{bmatrix}$$

$$\begin{bmatrix} \beta_0 & \gamma_0 & & & & \alpha_0 \\ \alpha_1 & \beta_1 & \gamma_1 & & & \\ & \alpha_2 & \beta_2 & \gamma_2 & & \\ & & & \ddots & & \\ & & & \alpha_{L-2} & \beta_{L-2} & \gamma_{L-2} \\ \gamma_0 & & & & \alpha_{L-1} & \beta_{L-1} \end{bmatrix} \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ \vdots \\ d_{L-2} \\ d_{L-1} \end{bmatrix} = \begin{bmatrix} r_0 \\ r_1 \\ r_2 \\ \vdots \\ r_{L-2} \\ r_{L-1} \end{bmatrix}$$

$$\alpha_i = \frac{\Delta_i^2}{\Delta_{i-2} + \Delta_{i-1} + \Delta_i} \qquad \beta_i = \frac{\Delta_i(\Delta_{i-2} + \Delta_{i-1})}{\Delta_{i-2} + \Delta_{i-1} + \Delta_i} + \frac{\Delta_{i-1}(\Delta_i + \Delta_{i+1})}{\Delta_{i-1} + \Delta_i + \Delta_{i+1}} \qquad \gamma_i = \frac{\Delta_{i-1}^2}{\Delta_{i-1} + \Delta_i + \Delta_{i+1}}$$

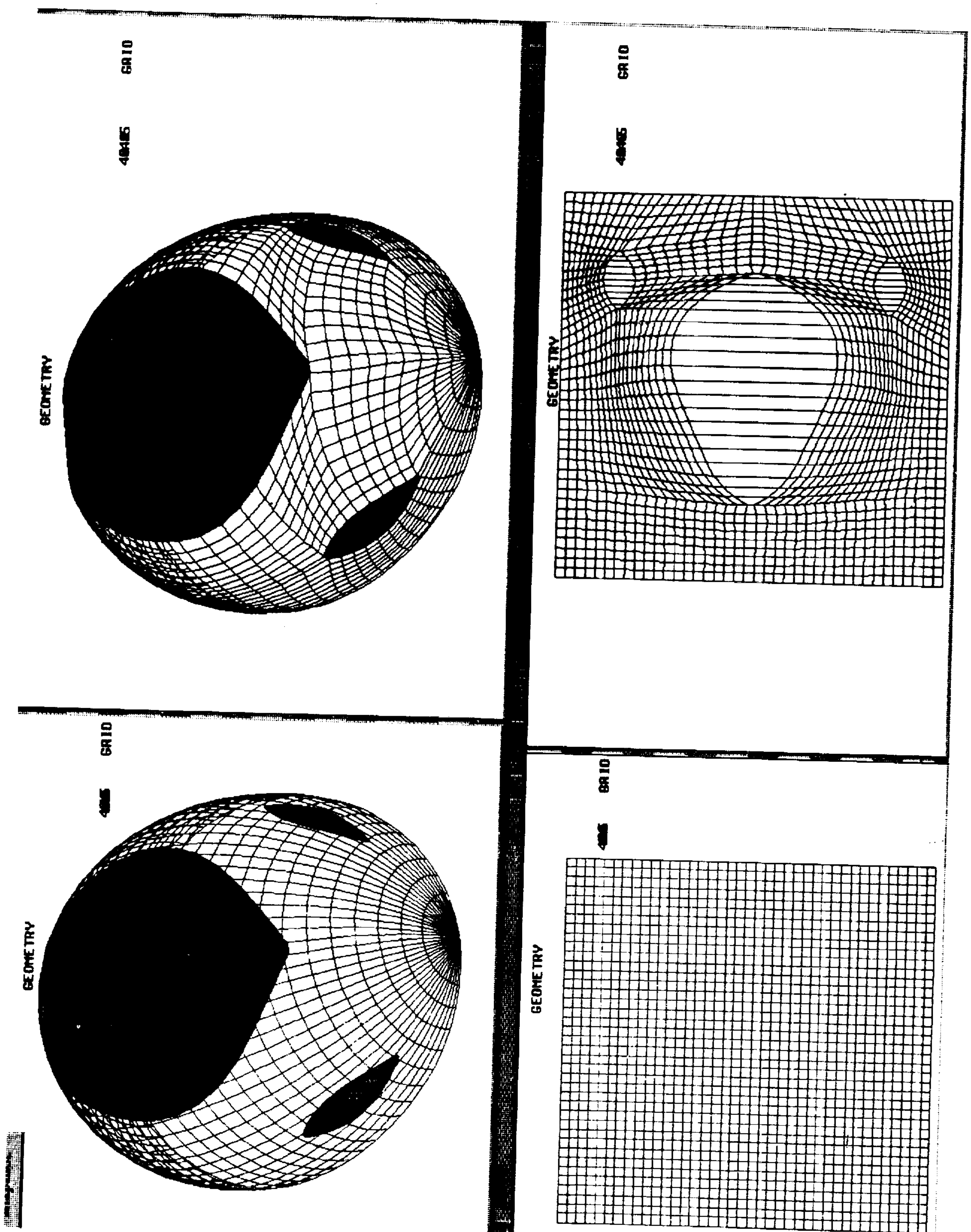
r_0 , r_L could be arbitrarily set

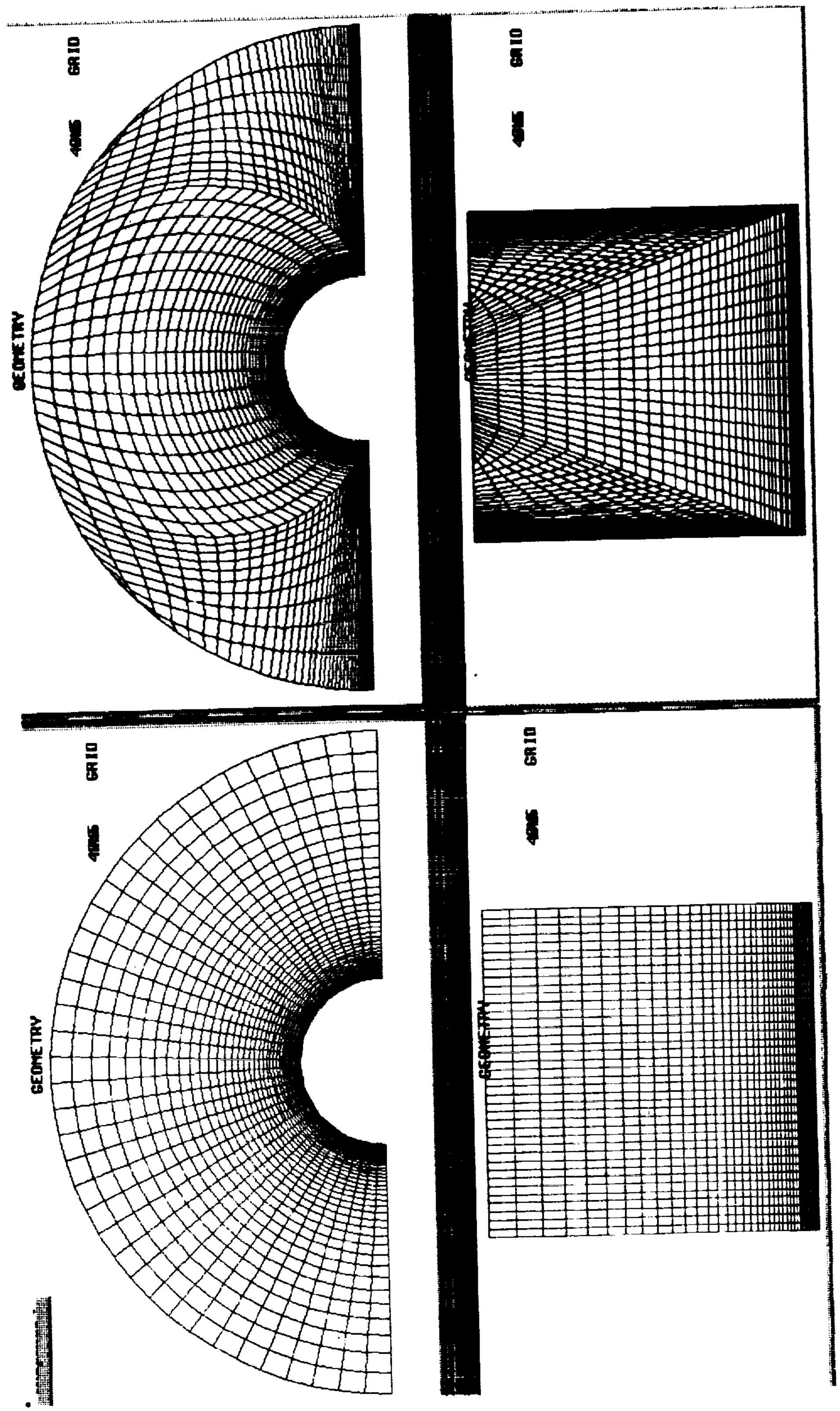
$r_i = (\Delta_{i-1} + \Delta_i)x_i$

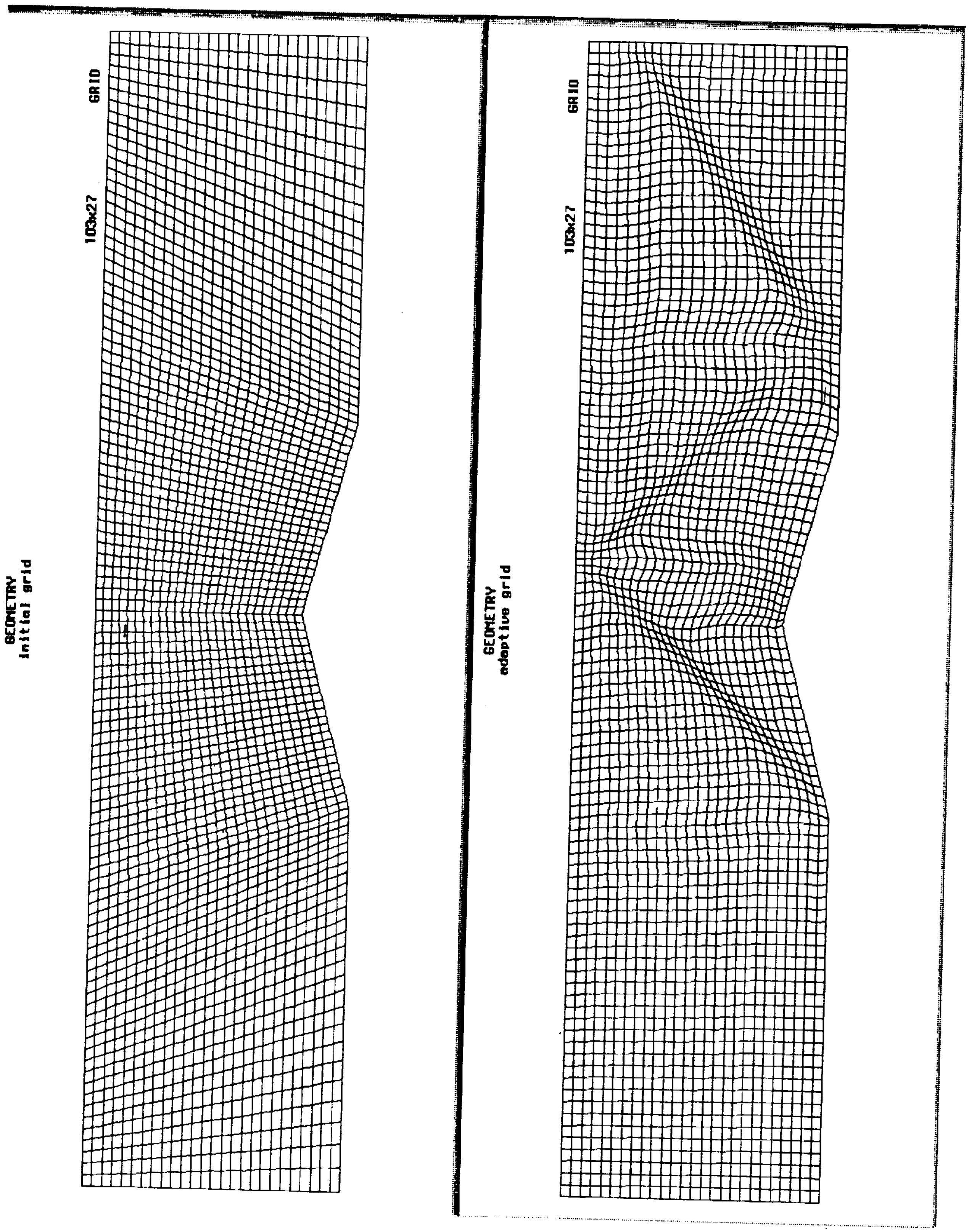
and we set $\Delta_{-1} = \Delta_L = 0$

$\Delta_{-1} = \Delta_{L-1}$, $\Delta_{-2} = \Delta_{L-2}$

$r_i = (\Delta_{i-1} + \Delta_i)x_i$


GEOMETRY
GRID
GEOMETRY
GRID
GEOMETRY
GRID
GEOMETRY
GRID


GEOMETRY
GRID
GEOMETRY
GRID


GEOMETRY
initial grid
103x27
GRID
GEOMETRY
adaptive grid
103x27
GRID

Conclusion :

- Importance of Geometry Transformation between different system
- NURBS provide robust Geometry data structure

Future Work :

- Geometry Generation / Manipulation
- IGES Entities with NURBS form

References

1. Initial Graphics Exchange Specification (IGES) Version 5.1 , distributed by 'the National Computer Graphics Association (NCGA) , Technical Services and Standards , IPO Administrator , 2722 Merrilee Drive , Suite 200, Fairfax, VA 22031.

2. Matthew W. Blake , Project Leader ,"NASA Geometry Specification for Computational Fluid Dynamics (draft)" ,CFD workshop for software System for Surface Modeling and Grid Generation at NASA Langley, April 28 , 1992 .

3. Farin, Gerald, *Curves and Surfaces for Computer Aided Geometric Design : A Practical Guide*, third Edition,

4. Yu,T.Y., "IGES Transformer and NURBS in Grid Generation ", Master's thesis , Mississippi State University, August 1992 .

5. Soni, B. K., "Grid Generation for Internal Flow Configurations", *Journal of Computers and Mathematics with Applications, 1991.*

6. Bartels/Beatty/Barsky:" An Introduction to Splines for the Use in Computer Graphics and Geometric Modeling" Morgan Kaufmann Publishers , 1987 .

7. Yamaguchi:"Curves and Surfaces for Computer Aided Geometric Design" , Springer-Verlag , 1988.