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ENVIRONMENTAL DATA BASE DEVELOPMENT PROCESS FOR THE  
ASUPT CIG SYSTEM

Eric G. Monroe

Air Force Human Resources Laboratory  
Brooks Air Force Base, Texas

August 1975

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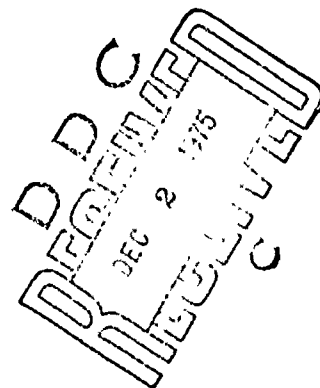
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**ENVIRONMENTAL DATA BASE DEVELOPMENT  
PROCESS FOR THE ASUPT CIG SYSTEM**

By  
**Eric G. Monroe**

**FLYING TRAINING DIVISION  
Williams Air Force Base, Arizona 85224**

August 1975



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**LABORATORY**

**AIR FORCE SYSTEMS COMMAND  
BROOKS AIR FORCE BASE, TEXAS 78235**

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Item 20 (Continued):

immediately preceding it in the sequence. The detailed definition of each item is transferred from the coding forms prepared by the modeler to computer input cards. These cards serve as the computer source input. The offline software algorithms perform validation checks on this input. Error messages are related through the teletype and line printer. Valid data is stored as libraries of objects, models and environments on magnetic tapes, and the appropriate environment is restored on disc by a media conversion from tape to disc.

102

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This final report was submitted by Flying Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, under project 1192, with Hq Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235. Mr. Eric G. Monroe, Systems Engineering Branch, was the task scientist.

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This technical report has been reviewed and is approved.

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Flying Training Division

Approved for publication.

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Commander

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## PREFACE

This report was completed under Project 1192. The research equipment discussed within the report was procured under Task 119202, Advanced Simulation in Undergraduate Pilot Training.

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# ENVIRONMENTAL DATA BASE DEVELOPMENT PROCESS FOR THE ASUPT CIG SYSTEM

## I. INTRODUCTION

The Advanced Simulator for Undergraduate Pilot Training (ASUPT) Computer Image Generation System (CIG) is one in which the visual environment is defined mathematically in a three-dimensional reference system, stored as numerical data in computer memory, retrieved in real time (30 frames/second), and projected according to its visibility from the current unrestricted viewpoint, position and attitude as a perspective image on two-dimensional viewing planes (Figure 1).

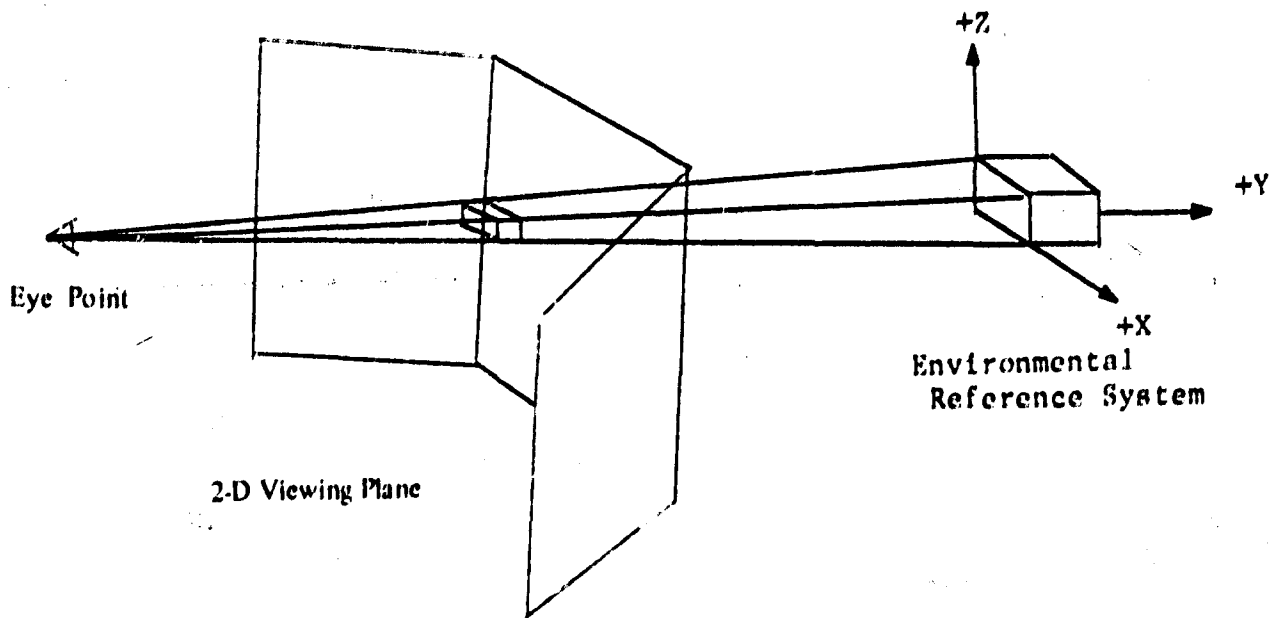


Figure 1. Projected perspective image.

This report concerns itself with the off-line processes involved in creating a mathematically modeled environmental data base in a form ready for processing by the off-line software programs and validation algorithms.

## II. MODELING

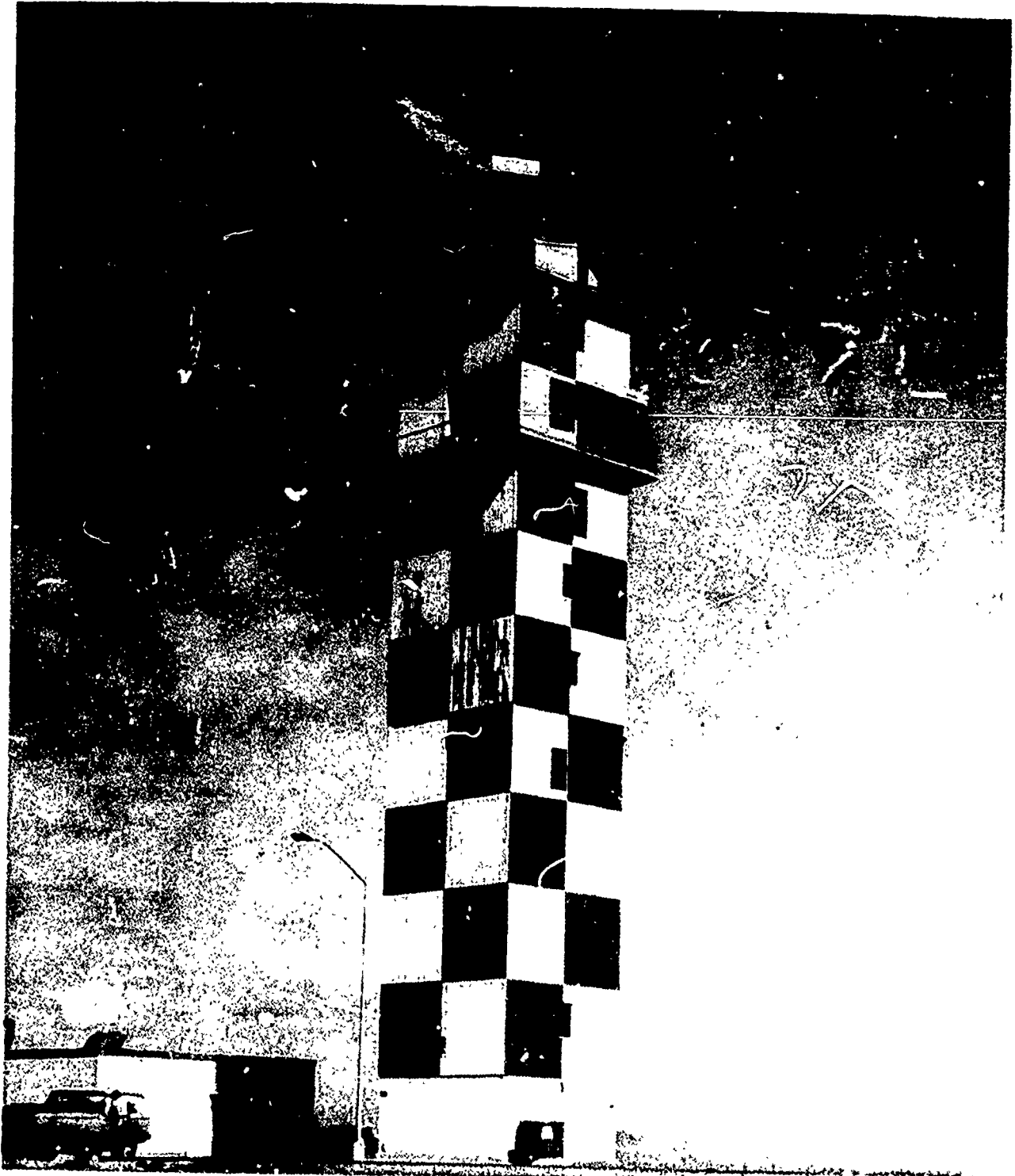
### Overview

The art of defining and storing the visual environment as numerical data in computer memory is called modeling. Once the key visual cues of the real world are identified as a necessary part of the environmental data base (such as the control tower at Williams AFB, Arizona, as shown in Figure 2) the modeler then proceeds to define these features in a three-dimensional orthogonal coordinate system.

Items such as maps, photographs, scale drawings, and blueprints serve as source data (Figure 3). Sketches (Figure 4) are made approximating each feature with a set of straight line segments or edges. A closed convex set of coplanar edges describes a face to which a gray shade is assigned (Figure 5).

Sets of faces are used to define objects. A two-dimensional object is formed with a set of non-overlapping coplanar faces whereas a three-dimensional object is a set of faces forming a closed, convex, polyhedron (Figure 6).

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*Figure 2. Control tower at Williams AFB, Arizona.*

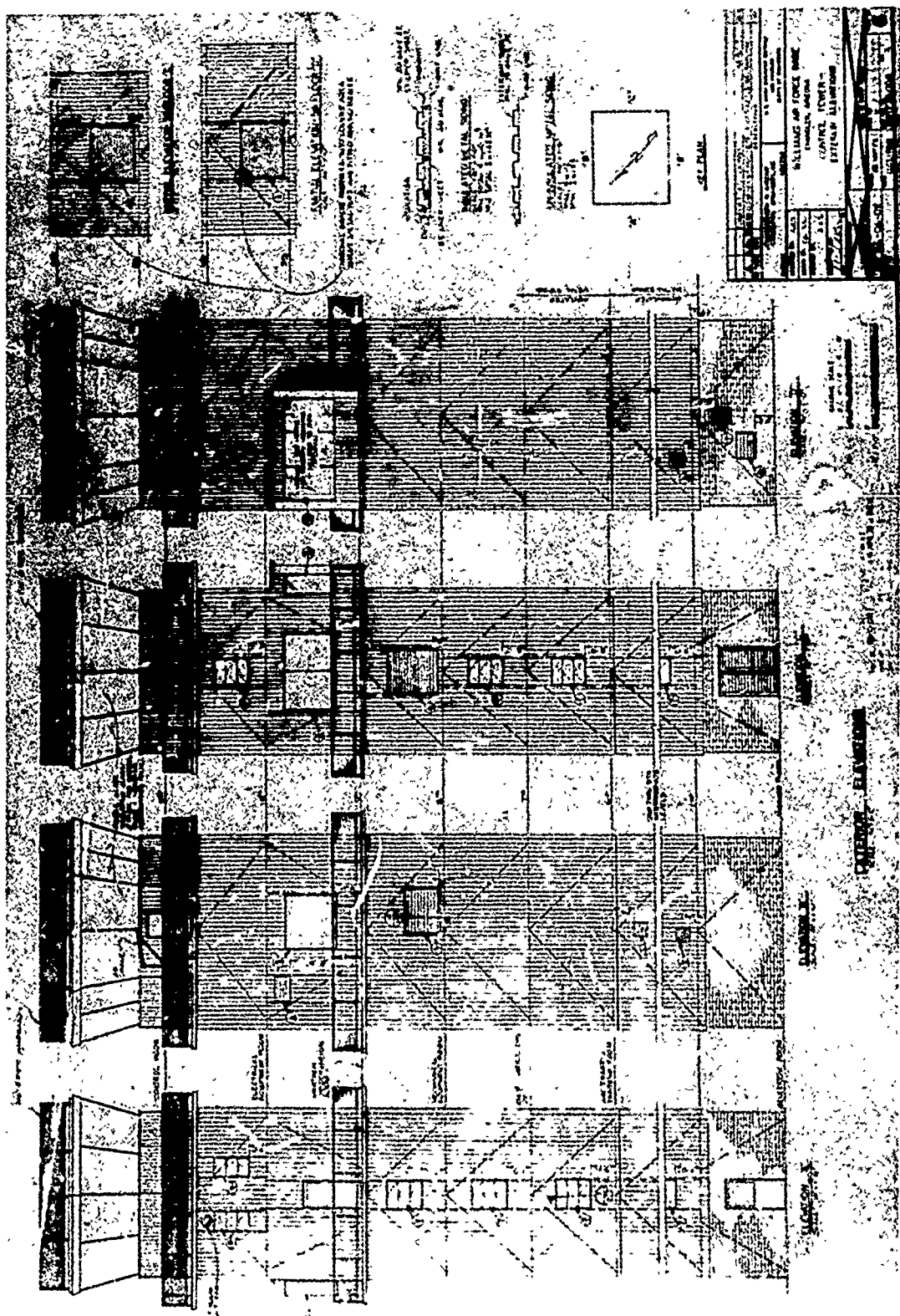


Figure 3. Source data.

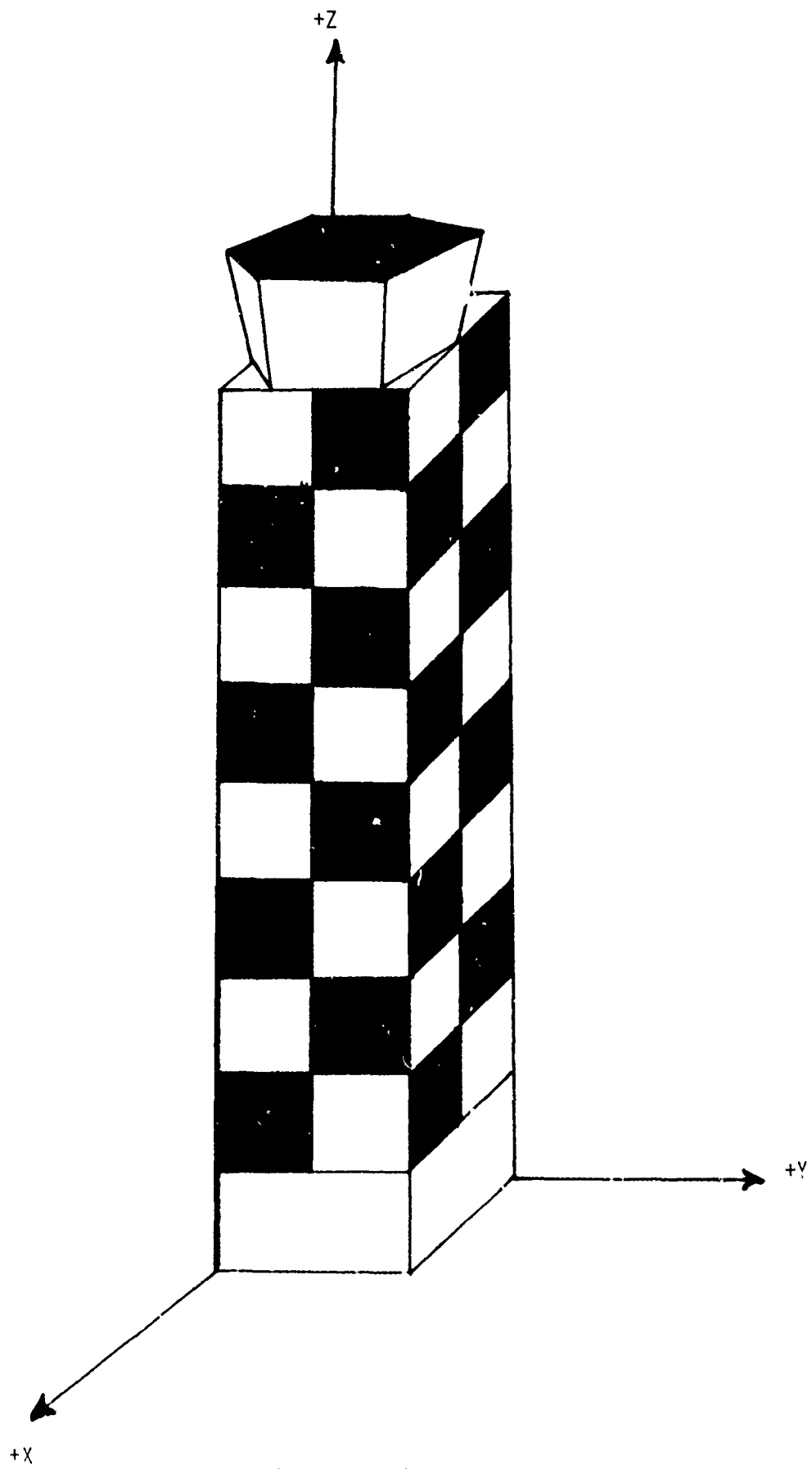
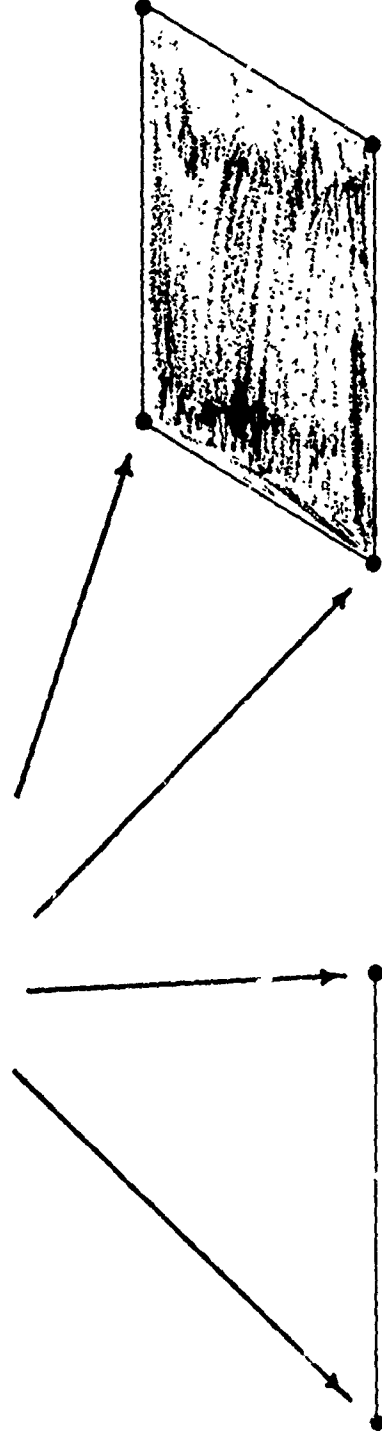


Figure 4. Sketch.

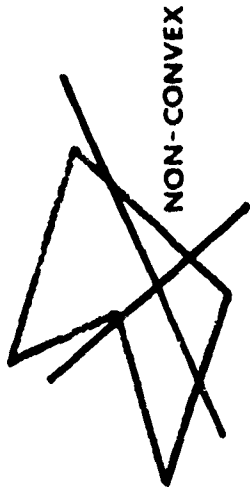
**VERTICES**



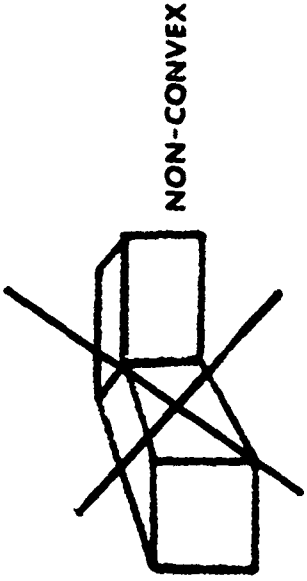
**EDGE**

**planar FACE with  
GRAY SHADE**

*Figure 5. Face.*



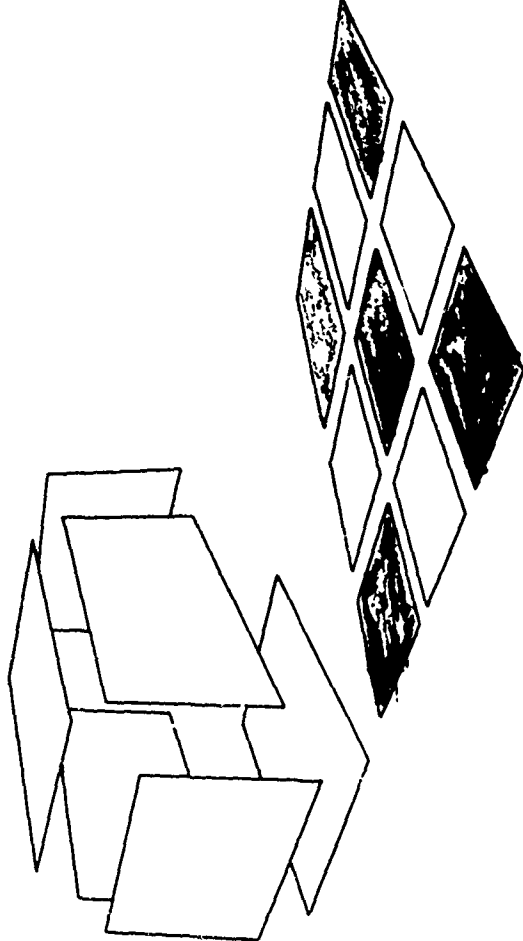
NON-CONVEX



NON-CONVEX

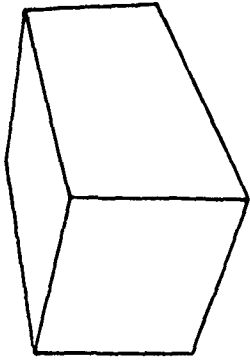
# FACES

CLOSED, CONVEX PLANES



# 3-D OBJECT

A CLOSED, CONVEX POLYHEDRON



# 2-D OBJECT

FACES ALL LYING IN THE SAME PLANE



Figure 6. Objects.

Sets of these objects are combined respectively to form two-dimensional and three-dimensional models (Figure 7).

Collections of these models define an environment (Figure 8).

Basic to the definition of any edge, face, object, or model is the determination of the coordinates of the vertices terminating each edge. Each object, model, and environment has its own reference system. Once the coordinates of the vertices of an object have been determined in its reference system (Figure 9) the modeler can by specifying a scaling, rotation, and translation factor: scale, rotate, and locate an object in the model's reference system. In a similar manner models are located and oriented in the environment.

All of the preceding information is collected as numerical data on special coding forms (Figure 10) which are used by the keypunch operators in preparing the computer input cards. The information on these cards is then read into the computer by the card reader-punch and validated by the offline software programs. Error messages are relayed by means of the teletype and lineprinter, and valid data is stored as libraries on magnetic tape. The final environment is stored on the two fixed head discs.

### Definitions

EDGE – A straight line segment defined by two vertices.

FACE – A closed convex planar polygon.

GRAY SHADE – A uniform monochrome CRT brightness assigned to a face.

OBJECT (2-D) – A set of nonoverlapping coplanar faces.

OBJECT (3-D) – A set of faces forming a closed convex polyhedron.

MODEL (2-D) – A set of 2-D objects.

MODEL (3-D) – A set of nonintersecting 3-D objects.

ENVIRONMENT – A collection of models.

CRITICAL DIMENSION – The maximum linear extent of a model.

LEVEL OF DETAIL – Each feature of the environment is modeled in three levels of detail (Figure 11) with LOD1 the most complex and LOD3 the least complex. In real time the system then selects for each feature to be displayed the appropriate LOD of its representative models consistent with the pilot's viewpoint. Use of this technique results in the elimination from processing those edges, faces, and objects too small to be perceived.

### MODEL TYPES

#### TYPE I

.2-D – Those models whose critical dimension is  $\leq 1$  nautical mile.

.3-D – Those models whose critical dimension is  $\leq 400$  feet.

#### TYPE II

.2-D – Those models whose critical dimension is  $> 1$  nautical mile but  $\leq 120$  nautical miles.

.3-D – Those models whose critical dimension is  $> 400$  feet but  $\leq 7.2$  nautical miles.

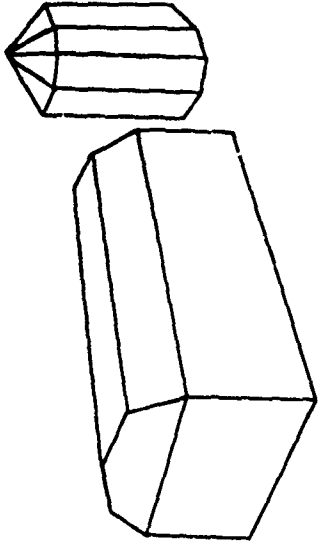
### Constraints

EDGE – From any one viewpoint there can be a maximum of 2,000 potentially visible display edges plus a display boundary and overload reserve of 500 edges.

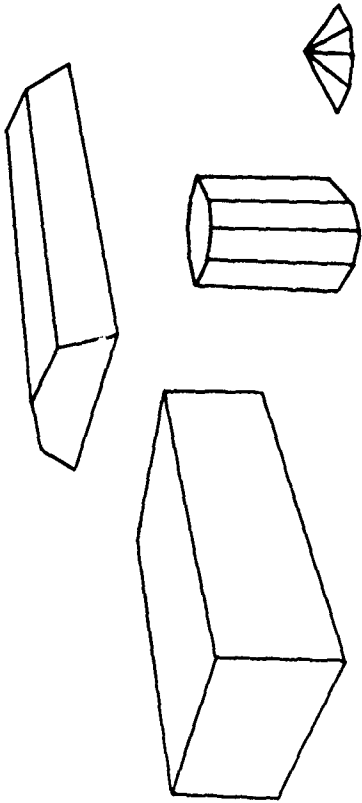
#### OBJECT

.2-D – Each object can have at most 32 edges and/or 16 convex faces lying in the same plane.

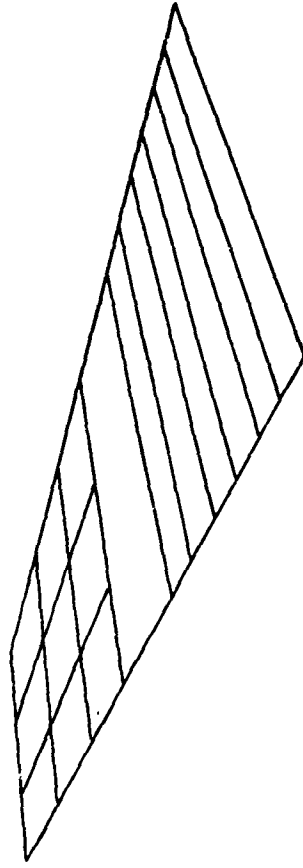
.3-D – Each object must be a closed convex polyhedron and have at most 32 edges and/or 16 faces.



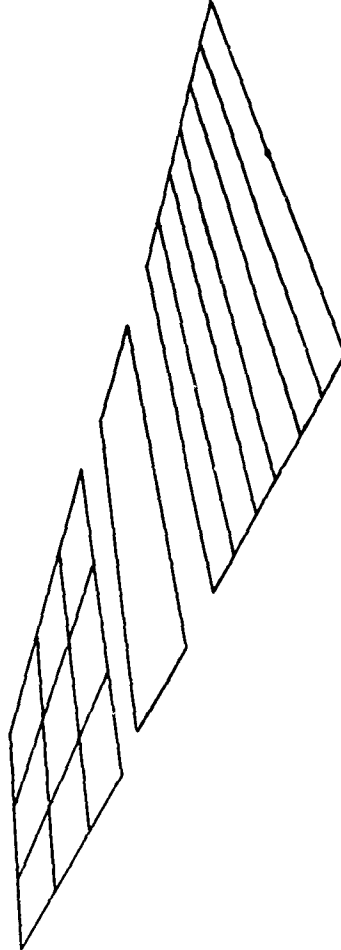
### 3-D MODEL



### 3-D OBJECTS

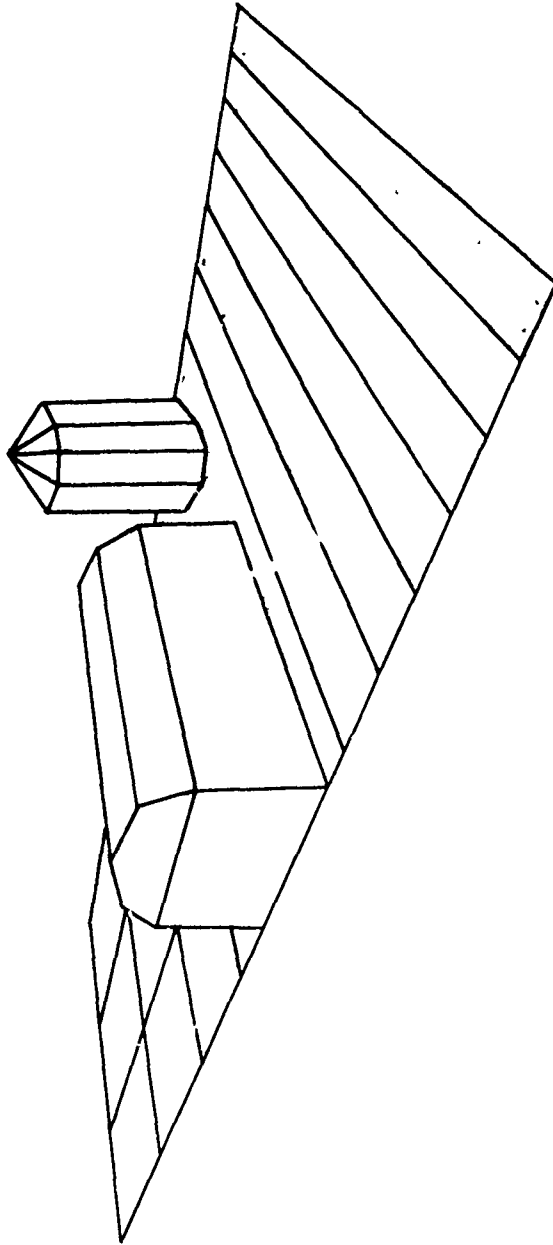


### 2-D MODEL



### 2-D OBJECTS

Figure 7. Models.



# ENVIRONMENT

ENTIRE SET OF MODELS  
AVAILABLE FOR DISPLAY

*Figure 8. Environment.*

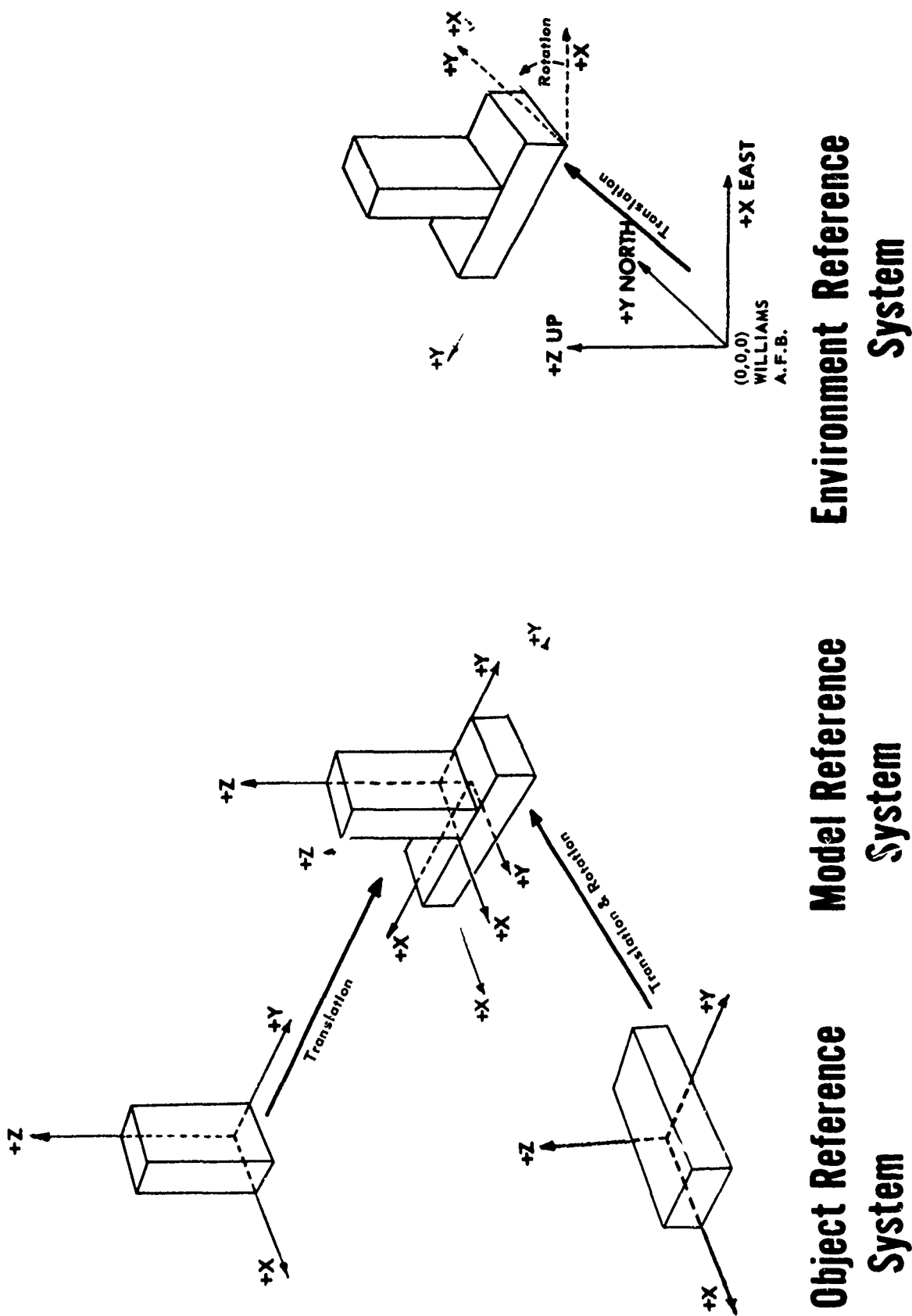


Figure 9. Reference Syst.ms.

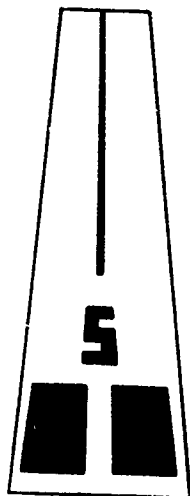


**LEVEL 3**



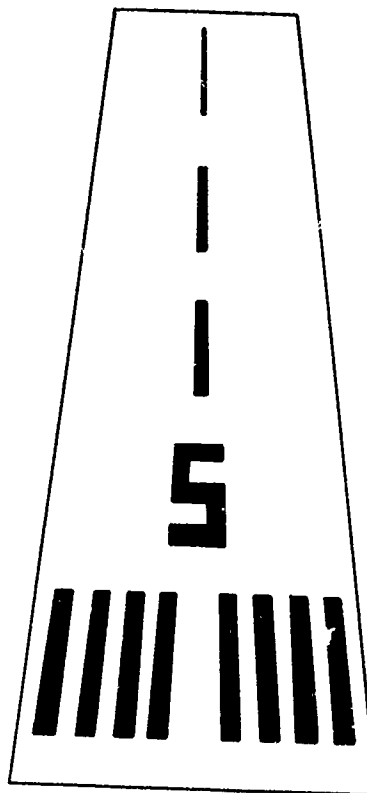
**12 Edges**

**LEVEL 2**



**28 Edges**

**LEVEL 1**



**60 Edges**

*Figure 11. Level of detail.*

Each object utilizing curved surface shading can have a maximum of four vertices per visible face with three vertices being preferable.

#### MODEL

.2-D – Each model can have at most 30 objects.

.3-D – Each model can have at most 15 objects.

.T-37 – The moving model is made up of partitions (3-D models) and can have a total of 100 objects.

#### MODEL TYPES

.TYPE I – In any of the 36nm wide strips running north-south in the environment there can be at most 400 models of this type.

– In any 36nm square there can be at most 200 models of this type.

.TYPE II – In any 200nm wide strip running north-south across the environment there can be at most 400 models of this type.

– In any 200nm square there can be at most 200 models of this type.

VIEW – From any point within the environment there can be:

.within range of view, at most:

– 512 objects

– 200 models

. within field of view, at most:

– 2,000 potentially visible edges plus a display boundary and overload reserve of 500 edges.

– 256 objects

– 200 models

– 30 directional light objects

– 30 blinking light objects

ENVIRONMENT – The total environment, a 1,250nm square area, can contain at most:

– 5,000 models

– 40,000 objects

– 300,000 edges

#### Construction of a Sample Environment

Once the source data is collected and preliminary sketches made the modeler is then ready to define the features in a form expected by the computer software.

To illustrate this process an example has been chosen to include as many of the available options as possible, but does not necessarily present the optimal method of modeling the proposed features.

Assume the features to be modeled include a building with a directional blinking light alongside a textured field as shown in Figure 12.

The modeler begins by creating a library of objects to be used in constructing the models and hence the environment. The textured field, a 2-D surface feature, can be constructed with two objects, one overlaying the other as shown in Figure 13.

Note that the field has been given dimensions of three feet on a side. It will be scaled to the appropriate size when the model is constructed. The first task is to determine the coordinates of the vertices of each edge in the objects reference system as shown in Figure 14.

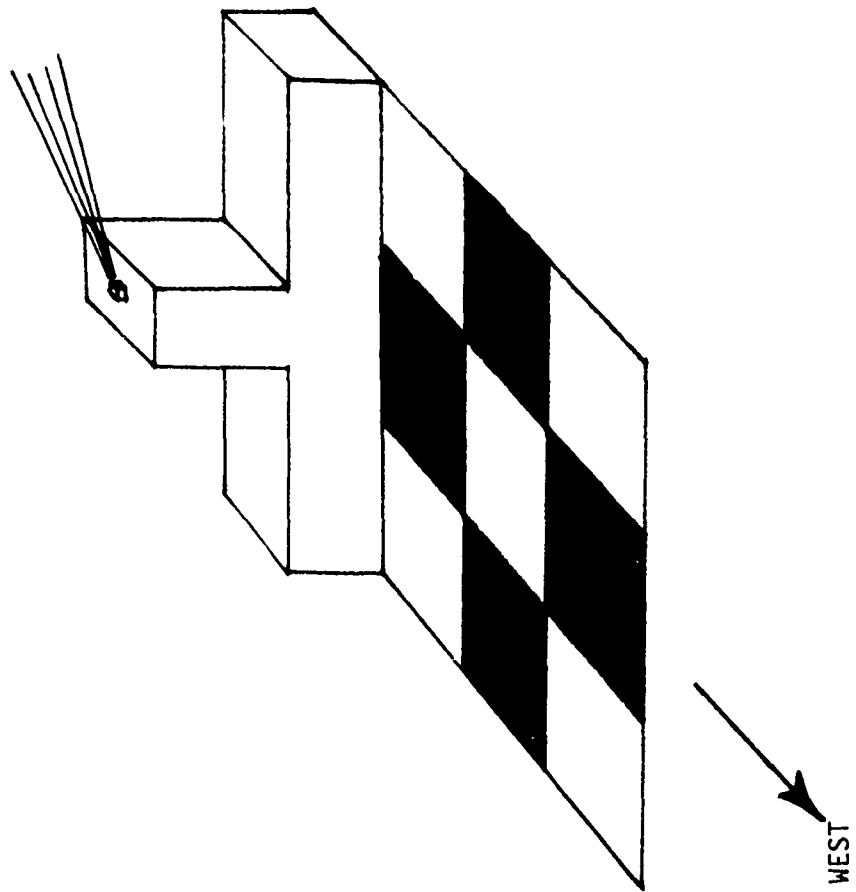


Figure 12. Sample environment.

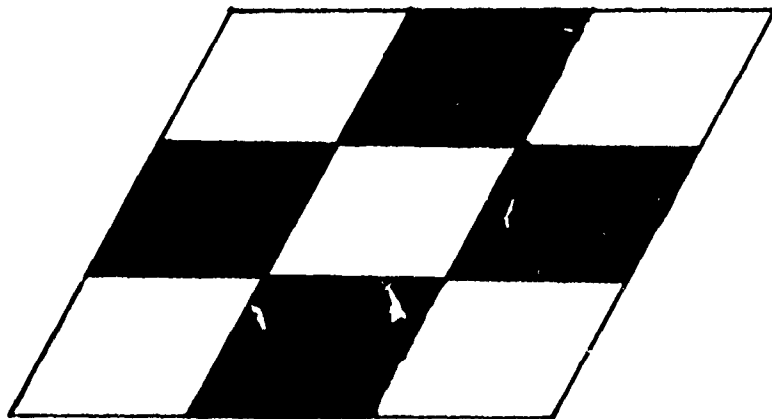
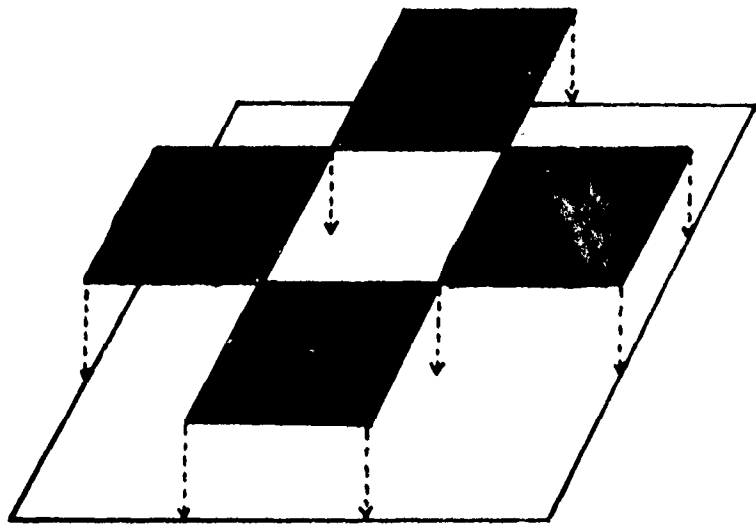


Figure 13. Textured field.

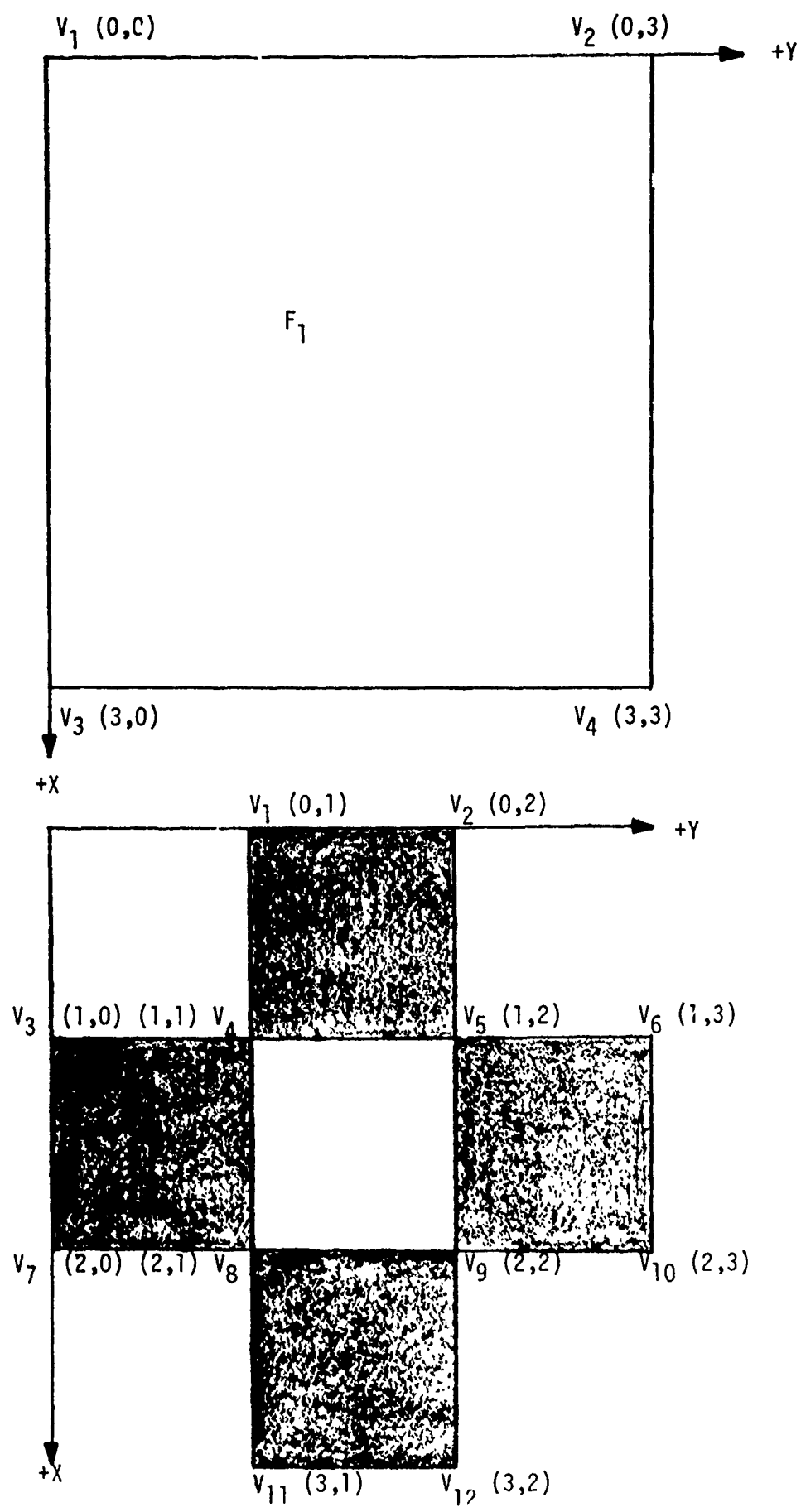


Figure 14. Vertex coordinates of textured field objects.

Having made such a determination, the coding form for the object and vertex cards can then be completed.

Each line of this form represents one 80 column computer card. The gray shaded, boxed areas are for the modeler's record keeping purpose. The first three lines are for the different object header cards: 3-D object, surface object, and 3-D light, respectively.

The three foot square shall be designated as SQR in columns 3 through 6 on this form (Figure 15). This unique alpha-numeric data set number will be carried through on all the related object vertex cards. Next, the second line (S in column 1) is completed with the number of vertices in columns 7-8, and the number of faces in columns 9-10 all fields being right justified. The remaining columns are left blank not being pertinent to this object, and will be explained later. The coordinates of the four vertices of the object are entered in the first four vertex (V in column 1) rows. Columns 7-8 indicate the relative vertex number followed by the X, Y, and Z coordinates in feet unless a 1 is entered in columns 35, 48, or 61 indicating the related coordinate is in nautical miles (6,080 ft.).

The coding form for the face cards of this object is completed next (Figure 16). Enter SQR in columns 3-6 which is carried on all the face cards identified by an F in column 1. Columns 8-9 identify the object's relative face number, 11-12 the gray shade (a number from 0-black to 63-white), 14-15 the number of vertices in the face, and the remaining columns in pairs designate the relative vertex numbers composing the face in clockwise viewing order.

The checkered pattern (CHEK) which will be located over SQR is illustrative of what is called a disjoint surface object indicated by entering a 1 in column 14. A 2-D object is disjoint if it is not convex, and is handled in a special way by the offline software. If a surface is a light, a 1 would be entered in column 15. The remaining vertex and face cards are done similar to that of the preceding object (Figures 17 and 18).

To model the building only one object is needed a one-foot cube (Figure 19), which can be scaled to the appropriate sizes to construct the building. Since CUBE is a 3-D object, fill out the first line on the form (O in column 1) with the appropriate information. If a 1 is entered in column 11 curved surface shading will be applied to the object by the online system causing the object to appear as having curved surfaces. The 1 in column 12 indicates that the object's gray shade will be faded online toward that of the background as a function of range. A 1 entered in column 13 causes the face gray shades to be modified to correspond to the true shading which would occur with a given sun incidence angle. A comparison among an object designated as having curved surface shading, the same object with sun illumination, and the same object with neither can be seen from left to right in Figure 20.

The remaining vertex and face cards are filled in as before and shown in Figures 21 and 22.

The directional/blinking light (Figure 23) requires a 3-D light object header card (L in column one) as shown in Figure 24. The completion of this form is similar to that done for CUBE except for columns 16-57. Entering a 1 in column 16 causes the light to be dimmed in addition to being faded, which is done at half the rate for a light as for an ordinary object. If a light is not dimmed it will be faded until it disappears from view when its perspective image subtends less than one element on the display. If the light is dimmed, a dimming range (columns 17-18) and an extinguishing range (columns 19-20) must be designated. The dimming range specified for a light will cause that light to appear as a two element by two raster line image on the display at that specified range regardless of what its projected image would be. It will remain at that size and be dimmed, in addition to being faded, from that point until it is extinguished at the specified extinguishing range. The range available for dimming and extinguishing are stated in Table 1. For example, entering a 2 for the dimming range causes the light object to go to a 2 x 2 image on the screen at the range at which a five-foot square of cube perpendicular to the viewpoint appears as a 2 x 2 on the display. Entering a 3 for the extinguishing range causes the light object to be completely dimmed from view as a 2 x 2 at that range which a real light 10-foot on a side becomes indistinguishable.

Entering a 1 in column 22 indicates the light object is blinking and requires the specification of an ON, OFF, and DELAY cycle, i.e., multiples of the frame times of 1/30 second. Cycles ON are designated in columns 27-31, OFF 40-44, and DELAY 53-57. Use of the DELAY cycles enables the modeler to vary or sequence the blinking rate of a number of light objects occurring within one model.







# FACE CARDS

AGS 1259

**CHEK**

Data Set

F# G S

#V Vertices in Clockwise Viewing Order

#	F	G	S	#V	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
1	1	0		4	1	2	5	4																													
2	1	0		4	3	4	8	7																													
3	1	0		4	5	6	10	9																													
4	1	0		4	8	9	12	11																													
5	1	1		1																																	
6	1	1		1																																	
7	1	1		1																																	
8	1	1		1																																	
9	1	1		1																																	
10	1	1		1																																	
11	1	1		1																																	
12	1	1		1																																	
13	1	1		1																																	
14	1	1		1																																	
15	1	1		1																																	
16	1	1		1																																	

Figure 18. Face coding form for CHEK.

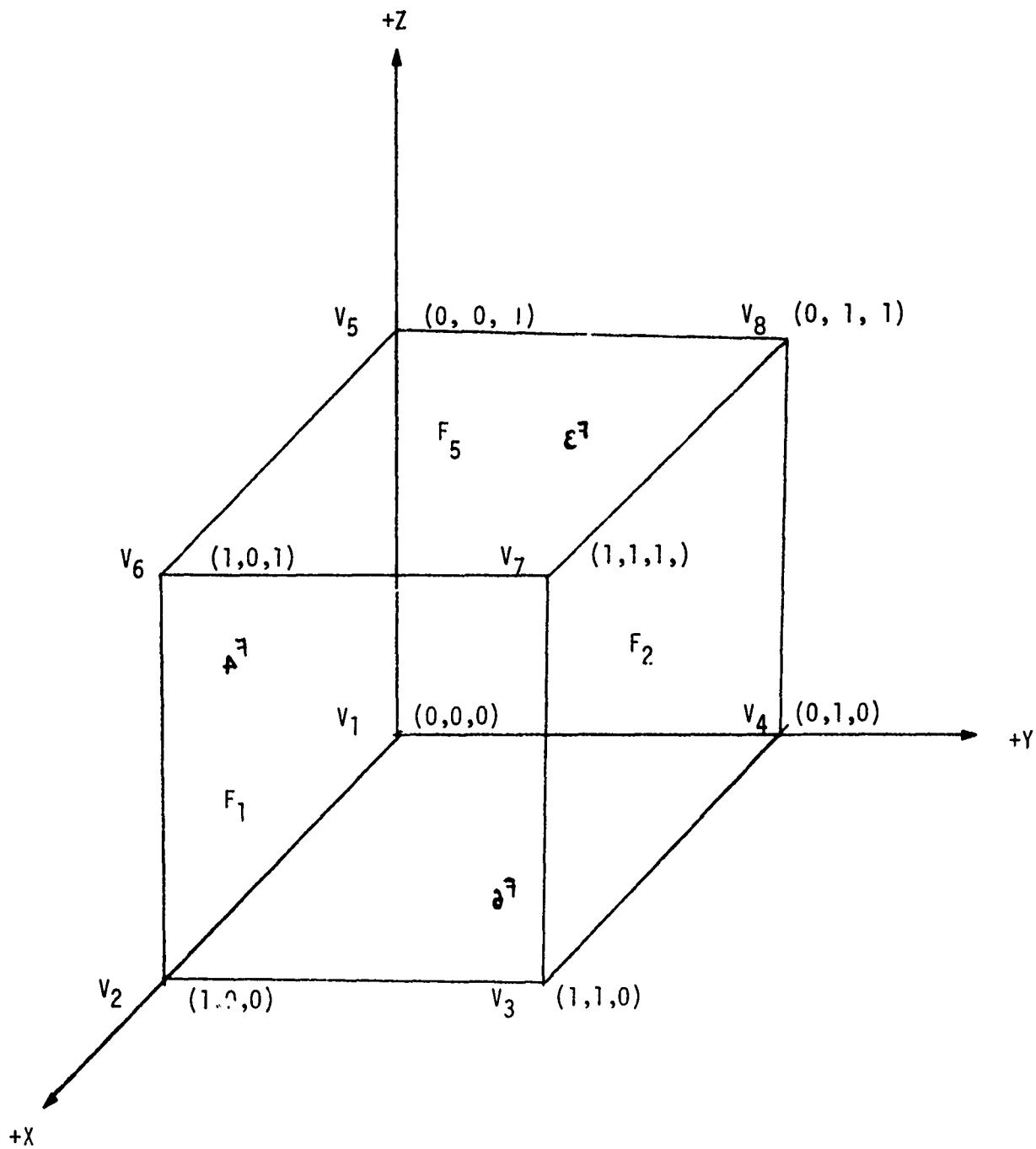


Figure 19. One foot cube.



Figure 20. Sun illumination and curved surface shading.

# OBJECT & VERTEX CARDS

Data Set No.  
**CUBE**

Revision   

Object Description

**1 FT. CUBE**

No. of Edges

**12**

Date

**9-1-74**

Initials

**WJH**

3-D  
Obj

#V	#F	Sh	Fd	Sun
<u>  8  </u>	<u>  6  </u>	<u>  </u>	<u>  1  </u>	<u>  1  </u>
7 8	9 10	11	12	13

Surface

#V	#F	Sh.	Dj.	Lt.	Dm.	D.Pg.	E.Rg.	Dr.	Bk.	(1-1023)	(1-1023)	DELAY
<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>
7 8	9 10	11	14	15	16	17 18	19 20	21	22	27	40	53

3-D  
Light

#V	#F	Fd.	Dm.	D.Rg.	E.Rg.	Dr.	Bk.	Cycles	ON	OFF	DELAY
<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>
7 8	9 10	12	16	17 18	19 20	21	22	27	40	53	

Bound  
Pl

Horizontal Field of Vision	(1-90)	(0-360) Azimuth	Vertical Field of Vision	(1-90)	Elev. Angle
<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>
29 31	31 33	31 33	55 57	55 57	55 57

V

	Miles						Miles						Miles				
7 8	23	X	31	34	35	36	Y	44	47	48	49	Z	57	61	61		
<u>  1  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  2  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  3  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  4  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  5  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  6  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  7  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  8  </u>	<u>  </u>	<u>  0  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  1  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u>  9  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 10  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 11  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 12  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 13  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 14  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 15  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 16  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 17  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 18  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 19  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 20  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 21  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 22  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 23  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 24  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 25  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 26  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 27  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 28  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 29  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 30  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 31  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		
<u> 32  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>	<u>  </u>		

Figure 21. Object-Vertex coding form for CUBE.

# FACE CARDS

**CUBE** Data Set  
 # V Vertices in Clockwise Viewing Order

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1.1	2.0	4	6	7	3	2																										
2.1	2.0	4	7	8	4	3																										
3.1	2.0	4	8	5	1	4																										
4.1	2.0	4	5	6	2	1																										
5.1	2.0	4	5	8	7	6																										
6.1	2.0	4	1	2	3	4																										
7.1																																
8.1																																
9.1																																
10.1																																
11.1																																
12.1																																
13.1																																
14.1																																
15.1																																
16.1																																

Figure 22. Face coding form for CUBE.





**Table 1. Dimming/Extinguishing Ranges for Lights**

Enter	For a Light Approximating a Square or Cube with Edge Dimension of:
1	1 foot object
2	5 foot object
3	10 foot object
4	25 foot object
5	50 foot object
6	100 foot object
7	250 foot object
8	15,000 foot object

A 1 appearing in column 21 indicates that the light object is directional, and requires the entry of a bounding planes card (B in column one) as shown in line four of the form. The viewing cone is defined as depicted in Figure 23. The horizontal field of view is entered in columns 29-32, the azimuth in columns 41-45 (with 0° along the +X axis, 90° the -Y axis, etc.), the vertical field of vision in columns 55-58, and the elevation angle in columns 68-71. The definition of these terms is self-evident from the drawing.

The remaining vertex and face cards are the same as those for CUBE (Figures 24 and 25) except the face gray shade for a light must come from the range of values 37-63.

Having constructed a library of objects it is now possible to build models from these objects. Basically there are three different types of model cards (Figure 26); the model header card (MH in columns 1-2), the object locate-rotate (ML in columns 1-2) and the object scaling card (MM in columns 1-2). The model identification, a unique alpha-numeric identifier, is entered in columns 3-6 and the level-of detail of the model in column 7. A 1 in column 8 indicates it is a runway light model.

The model type is entered in column 18, 0 if a 2-D model, 1 if a 3-D model, 2 if a partition of the moving model, or 3 if a one partition moving model. The moving model in ASUPT is a T-37 aircraft used for formation flying. The moving model is made up of a number of models which are called partitions.

The model's critical dimension is calculated by the offline software if not specified in columns 21-27. This value is used in selecting the LOD of the model displayed, and may be adjusted to affect this selection process.

The data set number entered in columns 28-31 of the ML and MM cards is that of the referenced object. The location of the objects origin in the models reference system is specified on the ML card in the appropriate columns under the X, Y, Z headings as shown on the form with a 1 entered in columns 43, 55, or 67, respectively, if any of these are in nautical miles rather than feet. The rotation factor counter-clockwise about the appropriate axis is entered in the remaining columns as shown. For the MM card, the scaling factor for the object in X, Y, and Z is entered in columns 32-42, 44-54, and 56-66, respectively. Figures 27, 28, 29, and 30 illustrate the two models, and textured field and building with directional light, along with their respective coding forms.

The final step is to place and orient these models in the environment. Assume the environment is construed as shown in Figure 31.

One environment card (E in column 1) is required for each LOD of each model (Figures 32 and 33).

The model ID is entered in columns 2-5 with the LOD in column 6. If a 1 is entered in column 7 the X, Y, Z location coordinates which follow are in nautical miles rather than feet. The rotation of a model is entirely in the X-Y plane i.e., counter clockwise about the Z-axis (columns 46 - 52).

A 1 entered in the designated column (Table 2) indicates the following:

# FACE CARDS

Data Set  
F# G S #V Vertices in Clockwise Viewing Order

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
1	45	4	6	7	3	3	3																										
2	45	4	7	8	4	3																											
3	45	4	8	5	1	4																											
4	45	4	5	6	2	1																											
5	45	4	5	8	7	6																											
6	45	4	1	2	3	4																											
7																																	
8																																	
9																																	
10																																	
11																																	
12																																	
13																																	
14																																	
15																																	
16																																	

Figure 25. Face Coding form for BLNK.



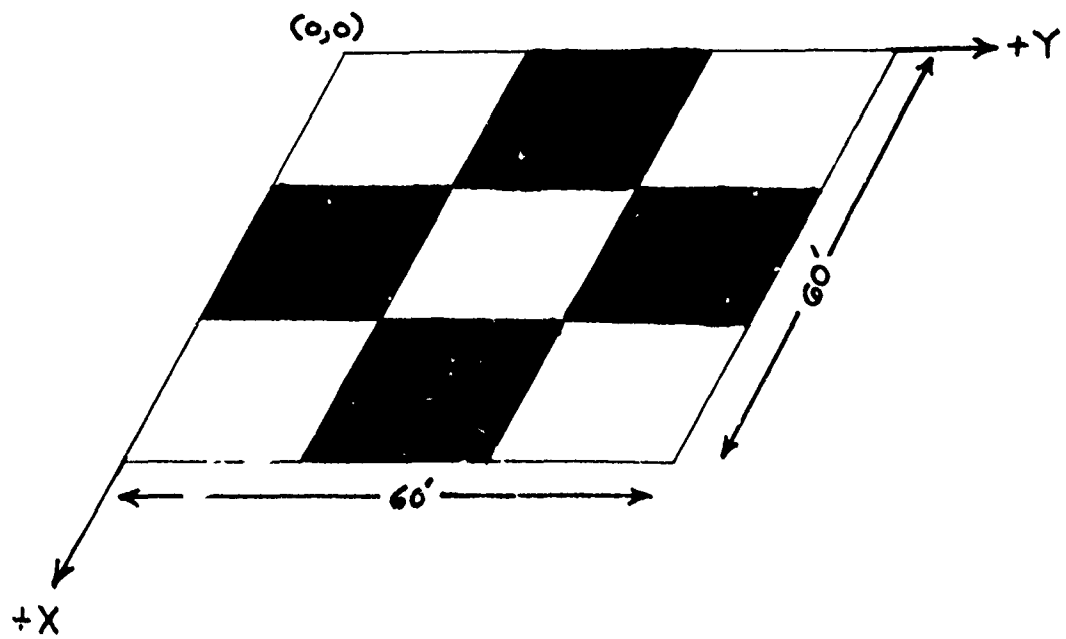
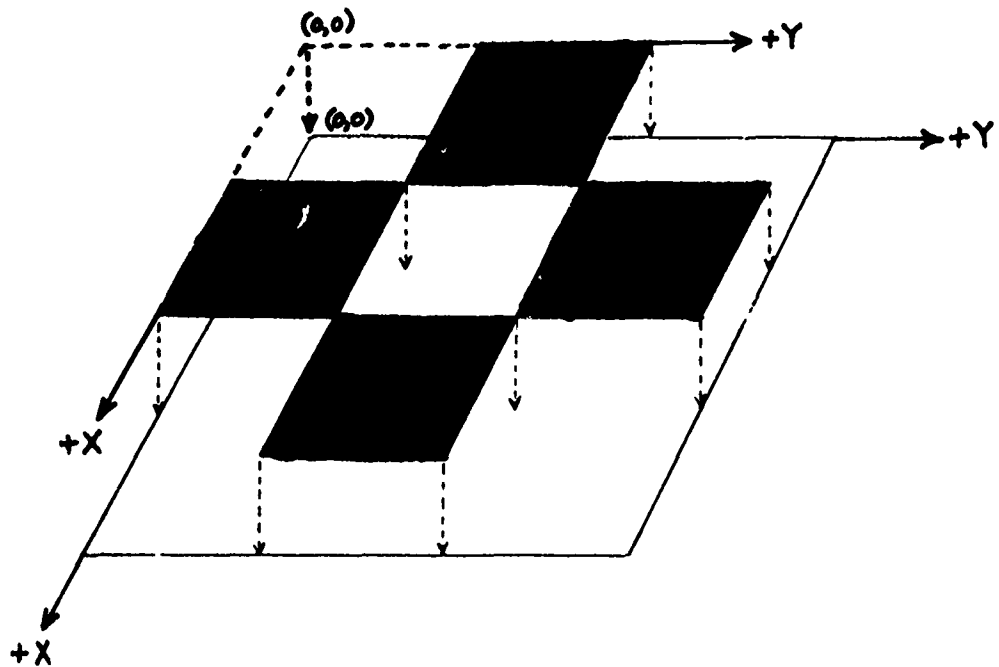


Figure 27. Textured field model.



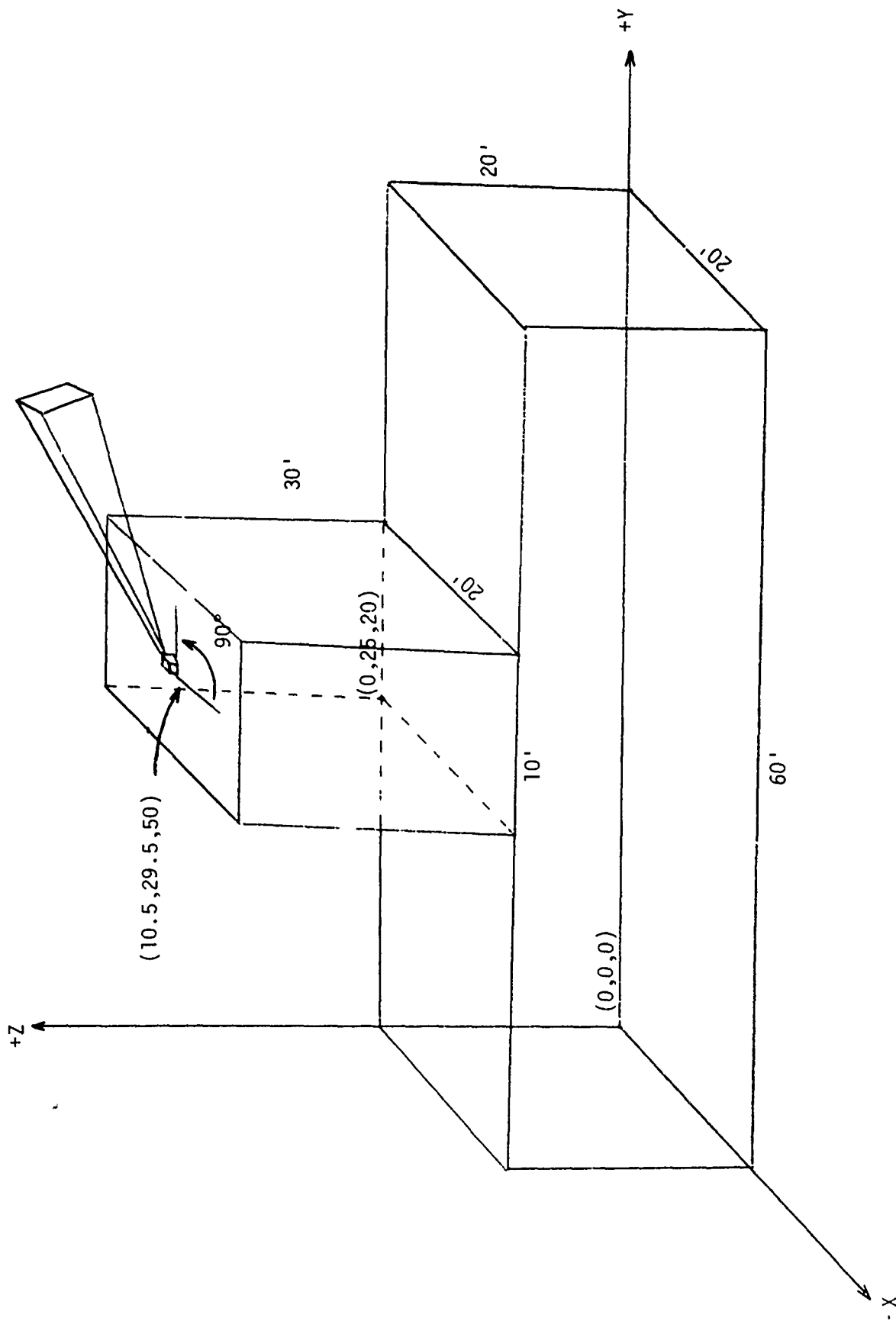


Figure 29. Building model.



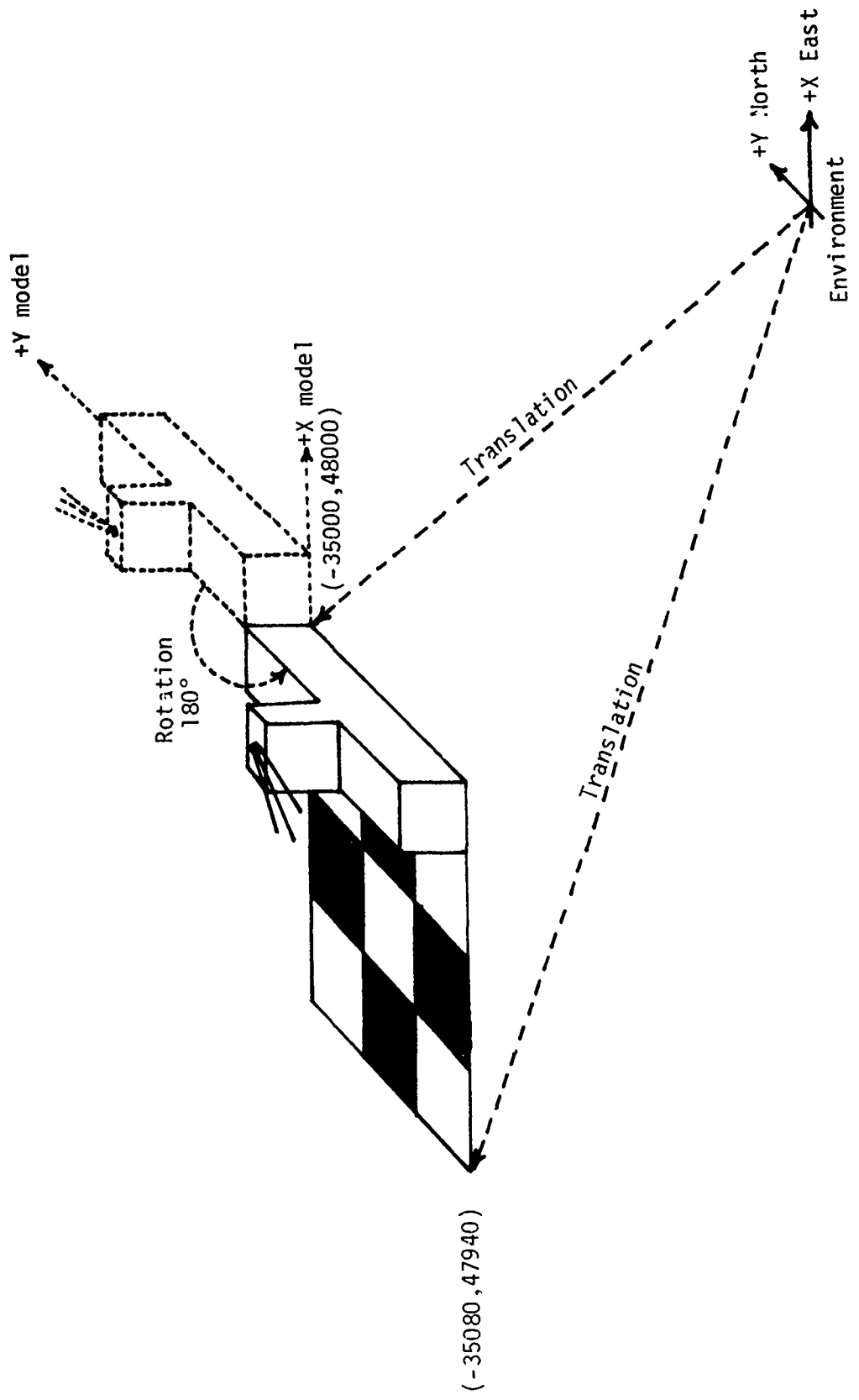


Figure 31. The environment.

## ENVIRONMENT CARDS

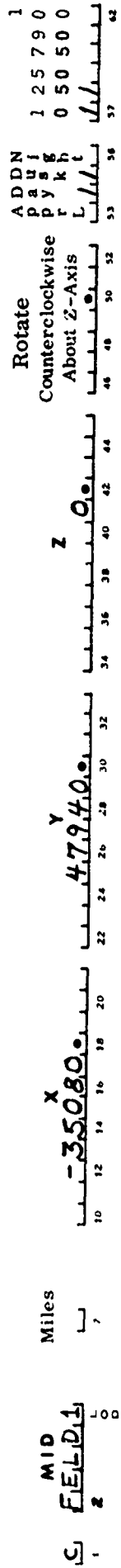


Figure 32. Field environment coding form.

## ENVIRONMENT CARDS

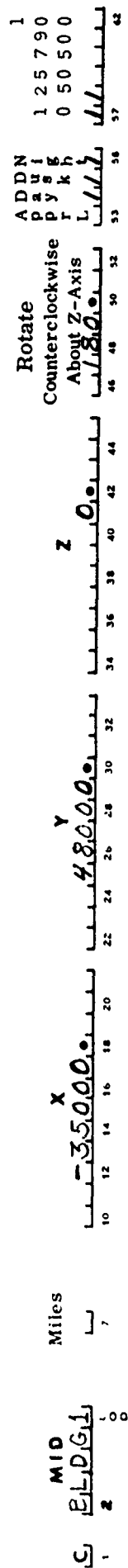


Figure 33. Building environment coding form.

**Table 2. Environment Types and Percentage Categories**

Column	Indicates
53	model is a strobe light
54	model is in the day environment
55	model is in the dusk environment
56	model is in the night environment
57	model is in the 10% category
58	model is in the 25% category
59	model is in the 50% category
60	model is in the 75% category
61	model is in the 90% category
62	model is in the 100% category

The percentage categories are used to share the processing capability of the system when two cockpits are being flown simultaneously.

The example environment has now been completed, however, a few cards have yet to be explained. The organization of the card decks is explained in detail later.

#### Miscellaneous Input

*Normals Cards.* In order to use the normals cards (Figure 34) one must understand the rationale for them. When an object calls for curved surface shading calculations are made to determine the normals to each vertex of that object being the average of the face normals of all faces containing that vertex. If two or more objects *within* a model contain the same vertex the average of the face normals of those faces containing that vertex of *both* objects are used in calculating the vertex normal.

A gray shade is assigned to each vertex. The vertex normals used in the curved surface shading algorithm are analogous to the face normals used in the sun-illumination calculation (curved surface shading utilizes sun-illumination). An incremental change in gray shade is accomplished between the vertices of the object causing the edges to disappear from view giving the effect of a curved surface.

The need for the normals cards arises when two models abutt, for curved surface shading is done on a model basis. Therefore, when two abutting objects of two different models share the same vertex, the vertex normal for that vertex in each of the objects is different. Figure 35 demonstrates the effect that would occur. In case A we have 14 objects to the left and right of the center object. If these are combined so that the left 14 objects constitute one model, the center object and 14 objects to its right form the second model, and apply curved surface shading, then the effect obtained is that shown in case B when the desired effective is that of case D. If the center object is halved creating two 15 object models, the resulting effect is that of case C.

Obviously, a means is needed of specifying the vertex normals for the vertices shared by two or more abutting models, or any case in which it is desirable to obtain an effect different than that which occurs with the normal curved surface shading process. The normals cards enable this to be done.

To illustrate the completion of the normals card form suppose the moving model is being constructed, and the fuselage is bisected for the purpose of joining two partitions (i.e., models) as shown in Figure 36.

Normals cards are needed for all vertices common to these two partitions, however, this discussion covers only the vertex that all four objects share; i.e., objects U and V of partition B, and objects W and X of partition C. The exterior faces of each of these objects has been triangularized as recommended when using curved surface shading. The purpose is to specify the face normals averaged to calculate the vertex normal for  $V_1$  of object U,  $V_3$  of object V,  $V_5$  of object W, and  $V_7$  of object X. In each case the desired effect is to have the vertex normal perpendicular to the diagram pointing out of the page. The object is to eliminate the abutting face normals from use in the vertex normal calculation, and use only the necessary exterior faces.

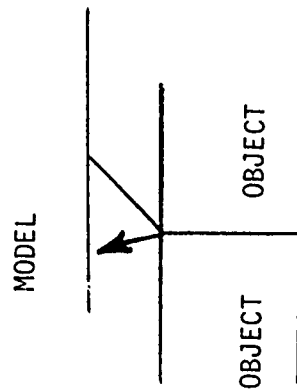
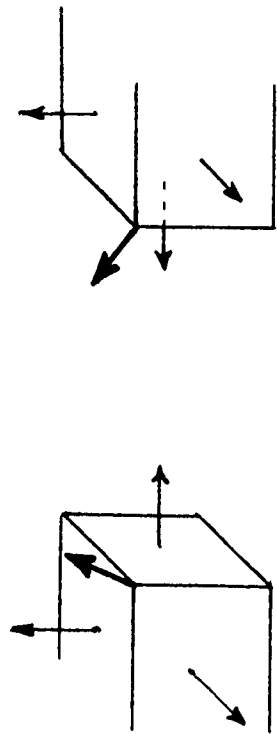
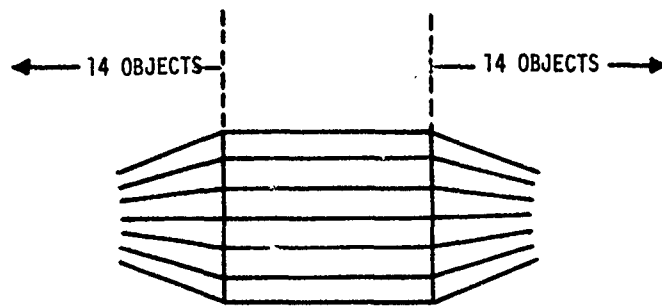
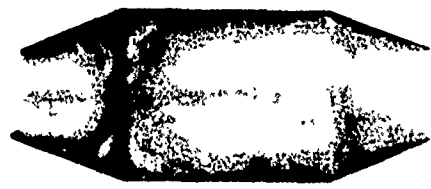


Figure 34. Vertex normals.



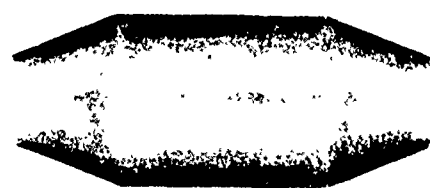
A



B



C



D

Figure 35. Abutting models with curved surface shading.

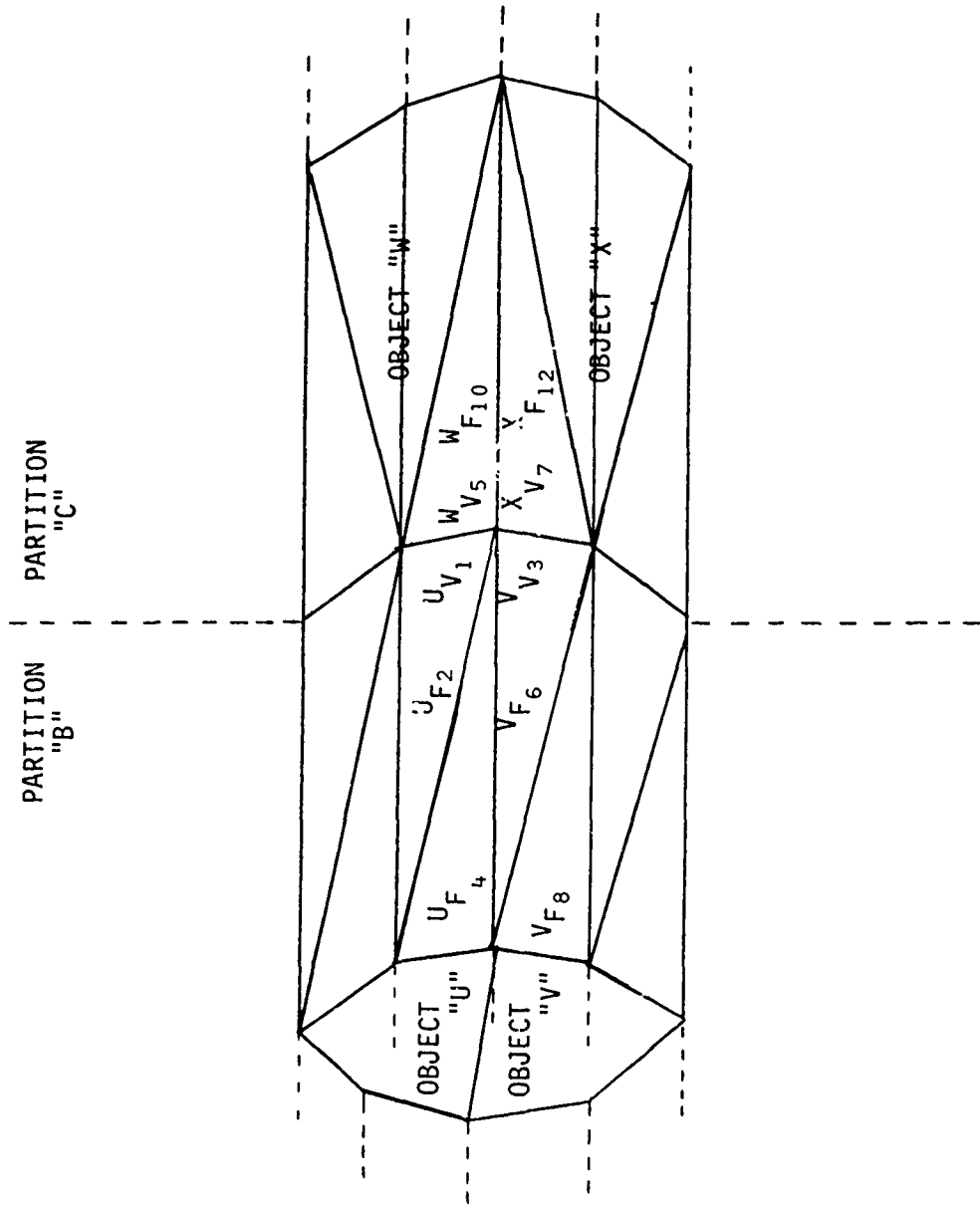


Figure 36. Partitions.

To begin, consider partition B (Figure 37). The model ID is entered in columns 3-6 and the LOD in column 7. Considering  $V_1$  of object U specify which face normals of the objects in this partition (B) shall be used to calculate  $U_{v_1}$ 's vertex normal. Two faces would suffice. Either of faces two and four of object U with either of faces six and eight of object V. On the form indicate the vertex for which a normal is calculated by entering its relative number in columns 8-9, and the object to which it belongs in columns 10-13. Enter the object data set number (columns 14-17) of the object containing those face normals which are to be averaged, and the face numbers associated with these normals in the remaining pairs of columns. This must be done for each vertex of each object within each partition. Completion of the forms for the given example may be observed in Figures 37 and 38.

**Partition Planes Cards** (Figure 39). As mentioned earlier the moving model is in actuality composed of a number of models called partitions. In order to establish online priority among the partitions it is necessary to define separation planes or partition planes which isolate these partitions from one another, and specifically to pick a set of planes (more than one plane may separate two partitions) which satisfies the conditions of the offline listability algorithm. In order for the listability algorithm to be satisfied one of the following two conditions must be met

1. Of the three combinations of pairs in any triplet of partitions, the same separation plane must be used to separate these partitions in at least two of the pairs.
2. There exists only one mandatory separation plane for each and every pair.

Consider the example shown in Figure 40 showing three partitions (1, 2, 3) and four partition planes (A, B, C, D). Table 3 is then constructed. Obviously, this example does not satisfy either of the conditions of listability, however, were either plane A or plane B not defined then condition two would be met.

**Table 3. Non-Listable Partition Set**

Partition Pairs	Planes Separating Partitions
1-2	C
1-3	A B
2-3	D

Table 4 is constructed from the case shown in Figure 41. This example satisfies condition one of listability.

**Table 4. Listable Partition Set**

Partition Pairs	Planes Separating Partitions
1-2	B
1-3	A C
2-3	B

Once the table has been set up as shown one plane must be selected to separate each pair (i.e., select one plane for each row) so that either of the two conditions for listability are met for the whole table. In the second example either B, A, B or B, C, B, may be chosen.

The third example, Figure 42, has six partitions (1-6) and 7 partition planes (A-G). It is left as an exercise, however, a solution appears in Appendix A. Assume the illustration to be a topdown view of a 3-D feature. From Table 4, it is immediately observed that if a listable set of separation planes is to be found then condition 1 of the listability algorithm must be met.

To demonstrate the completion of the partition planes cards, consider the example depicted in Figure 43. In this case three partitions AAAA, BBBB, CCCC (having relative partition numbers 01, 02, 03, respectively, assigned according to the alpha-numeric sequence of the partition IDs) are separated by planes I and II. Table 5 is set up as follows and a plane is chosen to separate each pair of partitions in such a way as to satisfy the conditions for listability.





PARTITION CARD (True Side)																																																																																			
X-COORD			Y-COORD			Z-COORD			RELATIVE PARTITIONS ON TRUE SIDE																																																																										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

PARTITION CARD (False Side)																																																																																			
X-COORD			Y-COORD			Z-COORD			RELATIVE PARTITIONS ON FALSE SIDE																																																																										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

PARTITION CARD																																																																																			
X-COORD			Y-COORD			Z-COORD																																																																													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

Figure 39. Partitions planes card format.

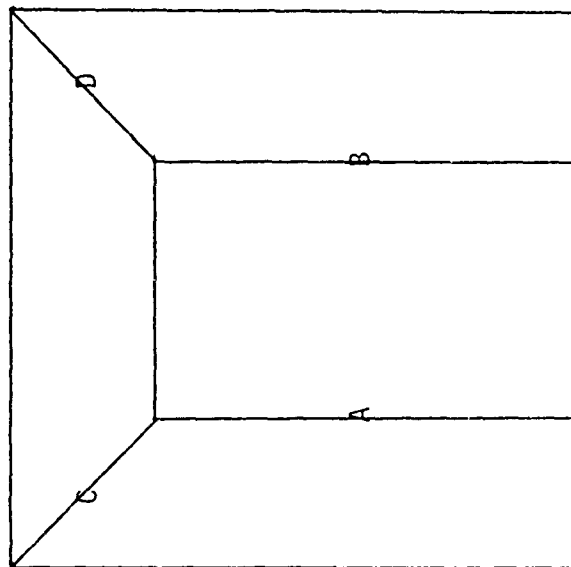
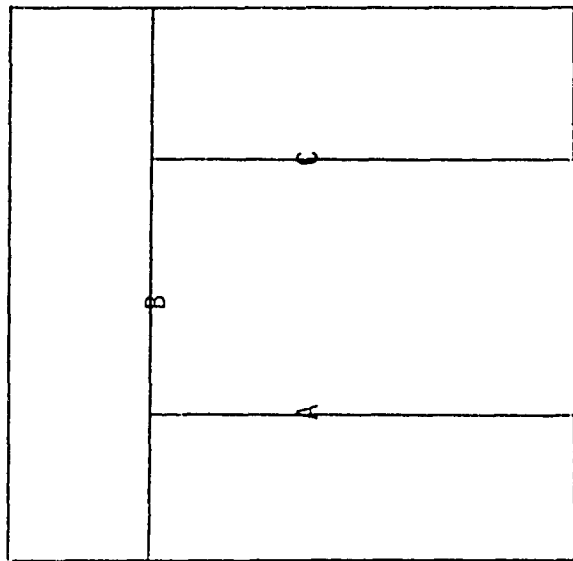
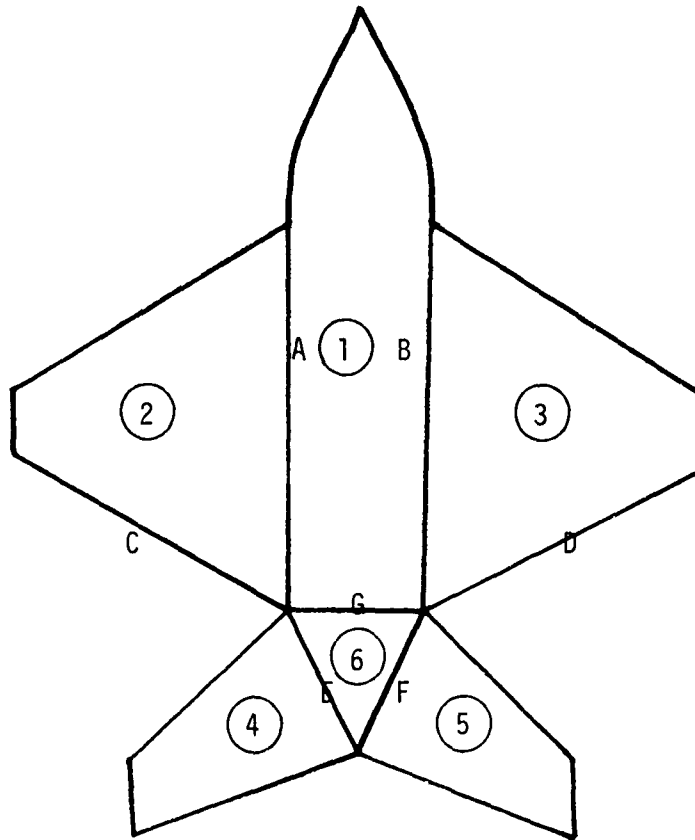


Figure 40.  $N_c, n$ -distable partition set (top view).



*Figure 41. Listable partition set (top view).*



PARTITION PAIRS

- 1 - 2
- 1 - 3
- 1 - 4
- 1 - 5
- 1 - 6
- 2 - 3
- 2 - 4
- 2 - 5
- 2 - 6
- 3 - 4
- 3 - 5
- 3 - 6
- 4 - 5
- 4 - 6
- 5 - 6

PLANES SEPARATING PAIRS

A						
	B					
		C		E		G
			D		F	G
						G
A	B					
		C				G
A			D		F	G
A						G
	B			E		G
			D			G
	B					G
				E	F	
				E	F	
					F	

Figure 12 Listable partition exercise

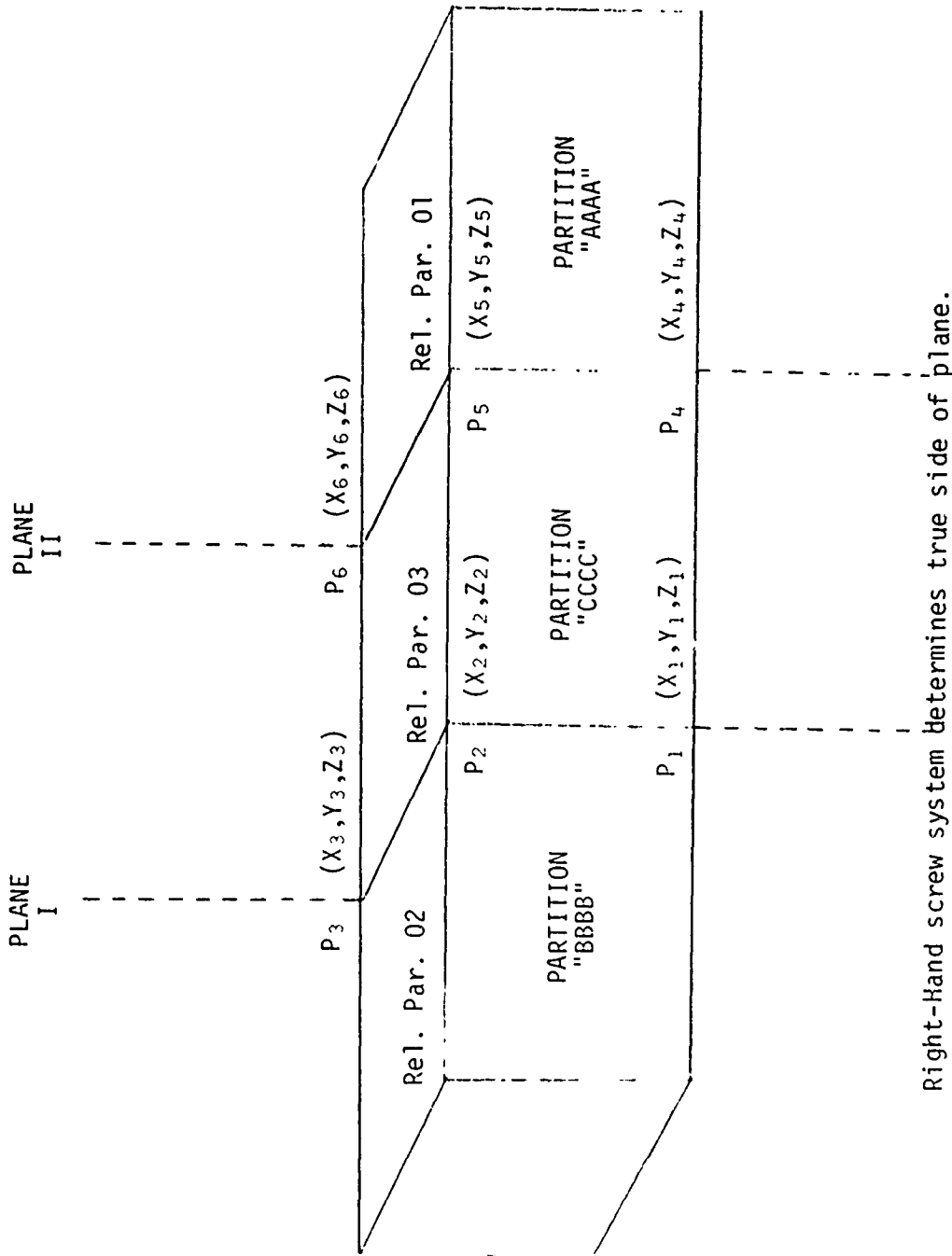


Figure 43. Three partitions.

**Table 5. Partition Pairs and Planes**

Partition Pairs	Planes Separating Partitions*	
01-02	Ⓘ	Ⓙ
01-03		Ⓚ
02-03	Ⓛ	

\*We could also have chosen II, II, I.

The partition planes cards may now be completed, three for each plane. For each plane enter the coordinates of any three vertices defining the plane (one per card, which when taken in order determines the true-false side of the plane according to the right-hand screw system) and the relative partitions on the true and false side according to our table. The completed form for the two planes is shown in Figure 44 and the entries can be referenced to Table 5 and Figure 43. The first two columns of each card are the card identifiers.

*Miscellaneous Input Cards* (Figure 45). End of File Card. This card has 2, 3, 4, and 5 multipunched in column 1.

**Object Delete Card.** This card is used to delete an object from the object library. It has a D in column 1 and the data set number of the object to be deleted in columns 3-6.

**Model Delete Card.** This card is used to delete a model from the model library. It has a D in column 1, the model ID in columns 3-6, and the LOD in column 7.

**Expanded Model Library Card.** This card is used to give an existing model in the model library another name, so that it may be used at an additional location in the environment. Entries on this card include the existing model ID and LOD, and the new model ID and LOD as shown in Figure 45.

**Airport Data Card.** This card is used to input elevation data for up to 15 airports in the environment, so that the surface plane elevation may be adjusted online by interpolating between adjacent elevation data points. A 0 or 1 is entered in column 1, depending on whether the coordinates entered are in feet or nautical miles, followed by the X, Y, and Z coordinates of the 12 points to be entered for each airport determined as shown in Figure 46.

### Source Input Structure

Figures 47 through 50 present a complete detailed account of the card deck sequence as expected by the offline computer software programs.

### Data Libraries

Once the preceding computer card input has been processed by the off-line validation system software the information is then stored as libraries on magnetic tapes. Sets of these tapes shall then constitute the object, model, and environment libraries (Figure 51).

Up to 600 objects can be stored on each object library. Each library consists of two magnetic tapes. The new tape consists of all object sets on the old tape, plus the object data sets added on the last update, less the data sets deleted on the update.

Each model library can have a maximum of approximately 360 models. Each of these libraries also has two tapes of similar construction to that of the object libraries.

The environment library is a series of tapes each being a merge of the previous tape and the new input from the environment card deck. Up to 350 models can be merged at a time to create a new tape in the series. Once the final merge has been accomplished, a load environment tape is created so that the disc may be restored in a more efficient manner.

PLANE I

PARTITION CARD (True Side)										PARTITION CARD (False Side)																																																																									
11 X-COORD X <sub>1</sub>					Y-COORD Y <sub>1</sub>					Z-COORD Z <sub>1</sub>					RELATIVE PARTITIONS ON TRUE SIDE 02																																																																				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

12 X-COORD X <sub>2</sub>										Y-COORD Y <sub>2</sub>					Z-COORD Z <sub>2</sub>					RELATIVE PARTITIONS ON FALSE SIDE 0103																																																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

13 X-COORD X <sub>3</sub>										Y-COORD Y <sub>3</sub>					Z-COORD Z <sub>3</sub>					RELATIVE PARTITIONS ON TRUE SIDE																																																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

PLANE II

PARTITION CARD (True Side)										PARTITION CARD (False Side)																																																																									
11 X-COORD X <sub>4</sub>					Y-COORD Y <sub>4</sub>					Z-COORD Z <sub>4</sub>					RELATIVE PARTITIONS ON TRUE SIDE 03																																																																				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

12 X-COORD X <sub>5</sub>										Y-COORD Y <sub>5</sub>					Z-COORD Z <sub>5</sub>					RELATIVE PARTITIONS ON FALSE SIDE																																																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

13 X-COORD X <sub>6</sub>										Y-COORD Y <sub>6</sub>					Z-COORD Z <sub>6</sub>					RELATIVE PARTITIONS ON TRUE SIDE																																																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84

Figure 44. Completed partition planes card format.

END OF FILE

\* - multi-punch 2, 3, 4, 5 in column 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

OBJECT DELETE CARD

Data Set No.																																																																																																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00

MODEL DELETE CARD

Mod. ID.																																																																																																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00

EXPAND MODEL LIBRARY CARD

Existing Mod. ID.		NEW Mod. ID.																																																																																																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00

AIRPORT DATA CARD

X-COORD		Y-COORD		Z-COORD																																																																																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00

Col 1 enter 0 if in feet  
1 if in miles

Figure 45. Miscellaneous input cards format.

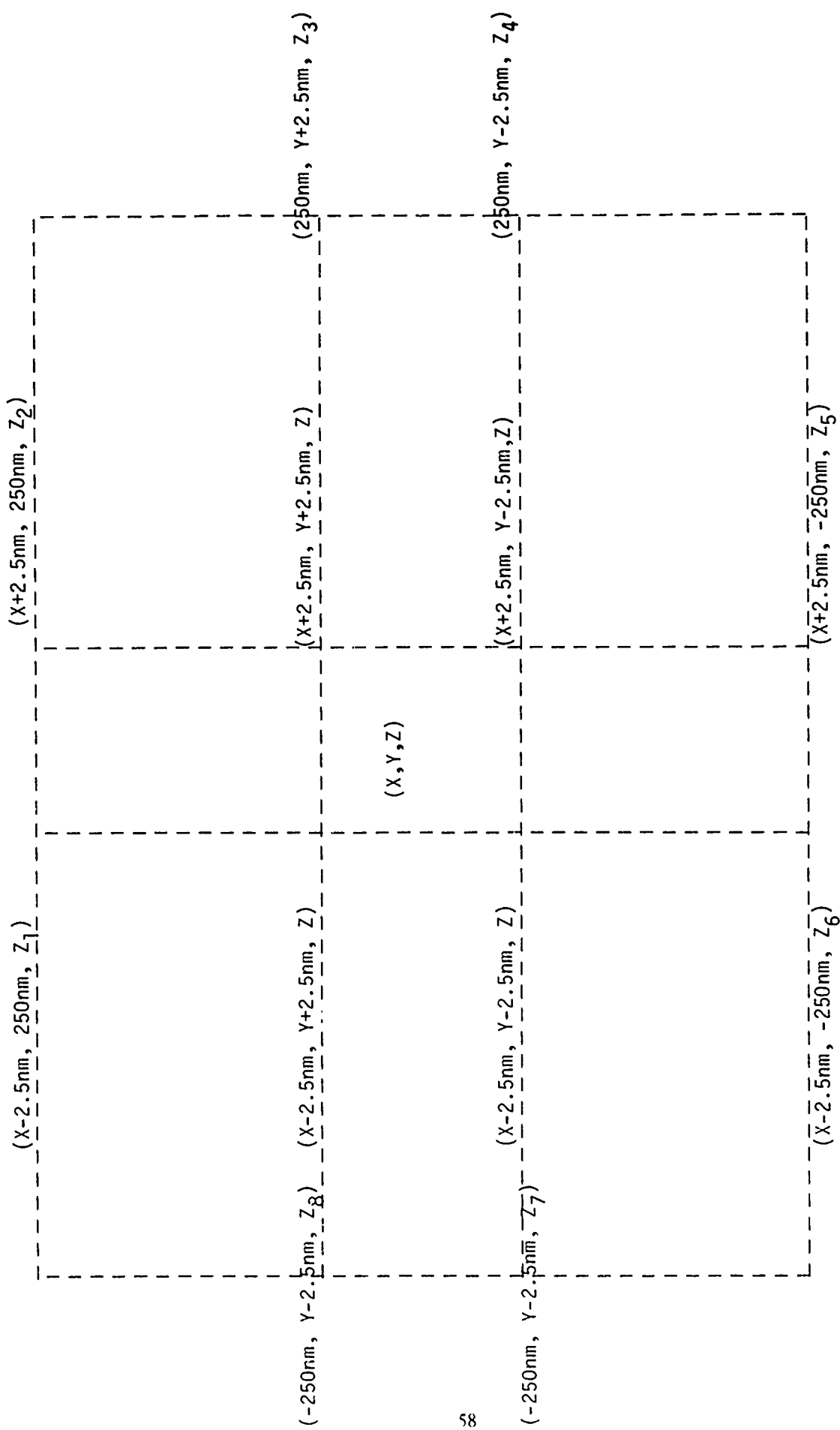


Figure 46. Airport elevation data points.

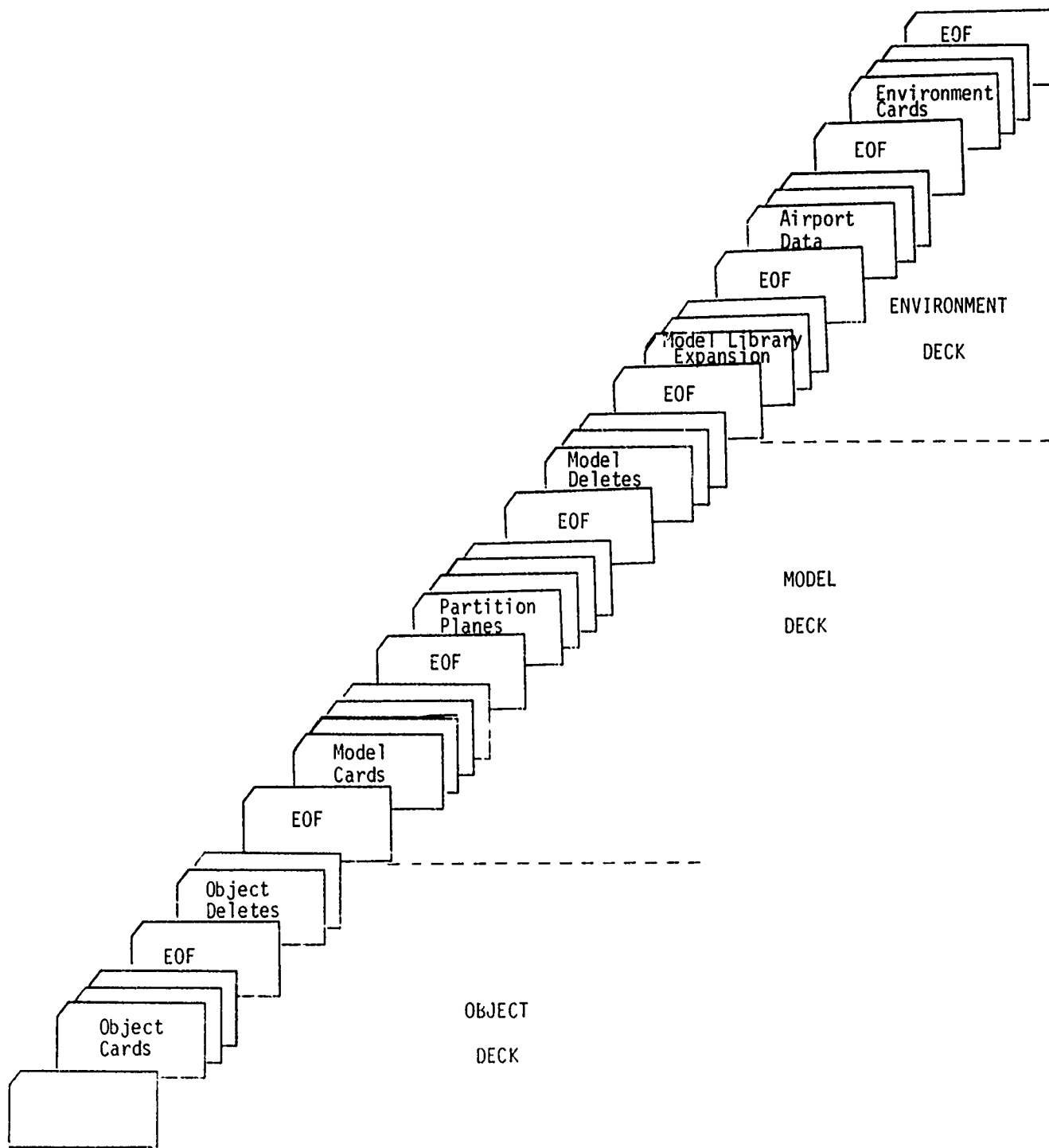


Figure 47 Card deck input order.





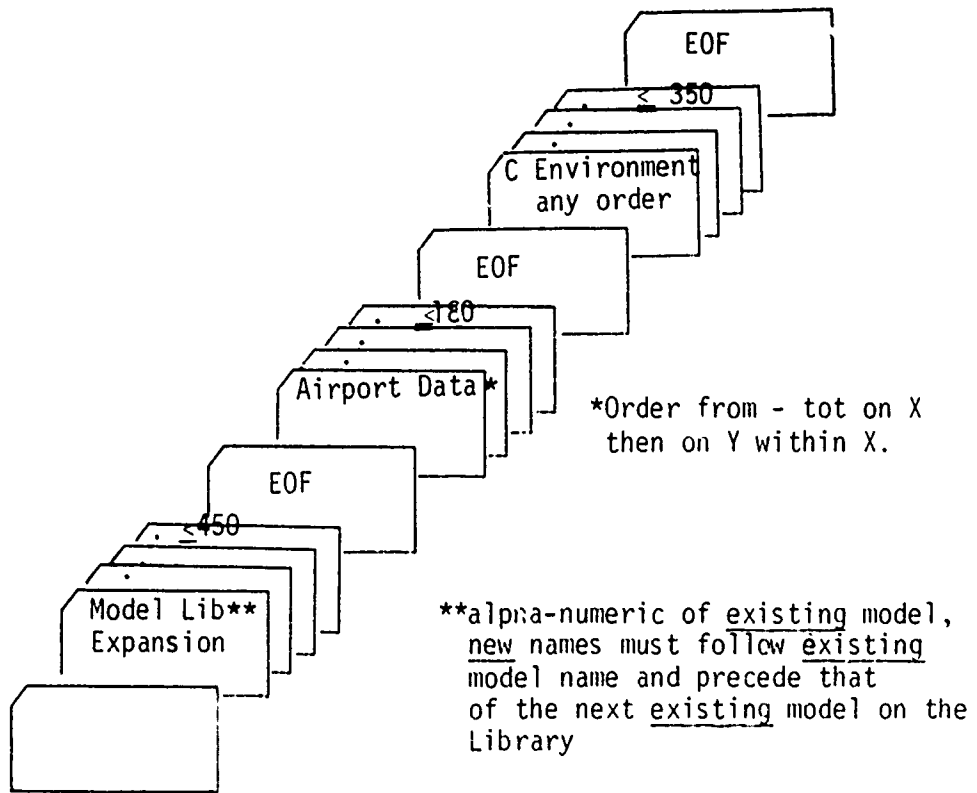


Figure 50. Environment card deck.

MAGNETIC TAPE LIBRARIES

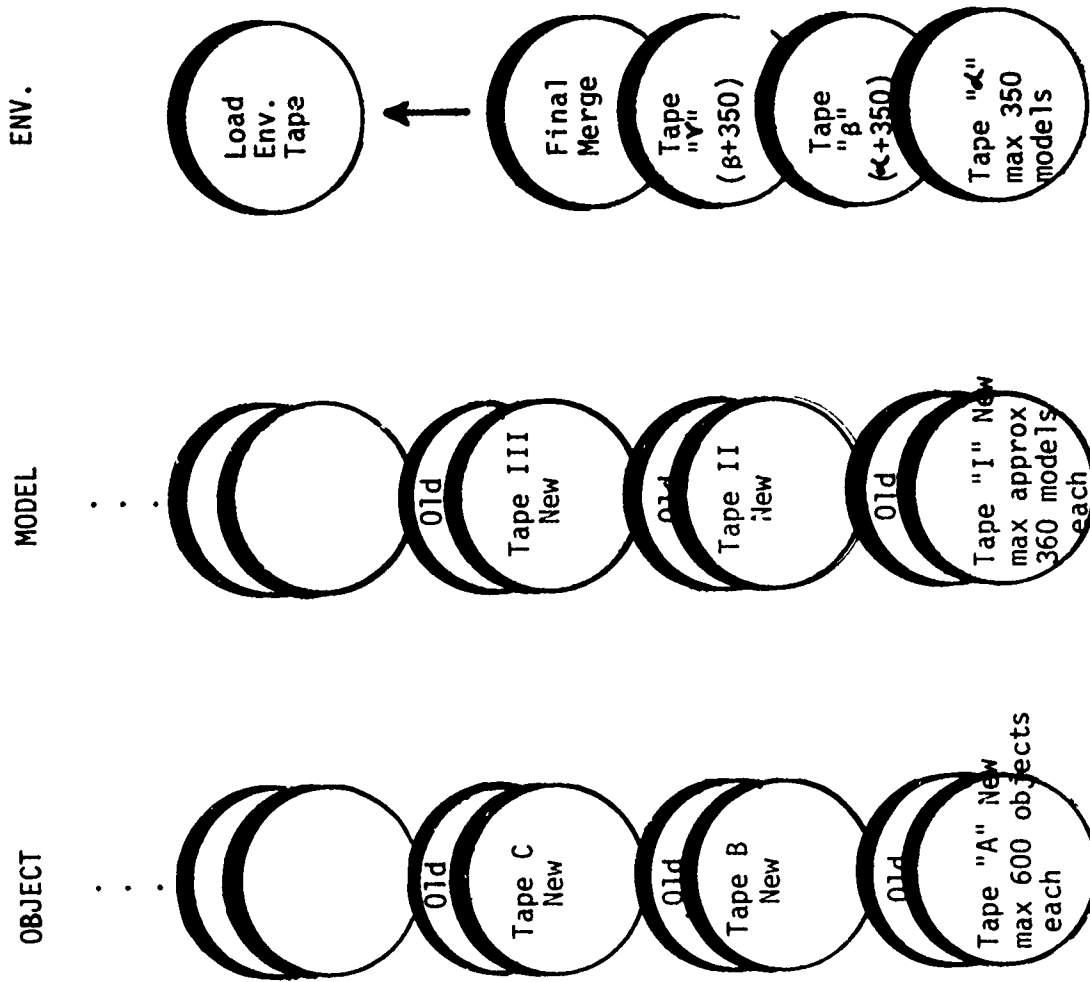
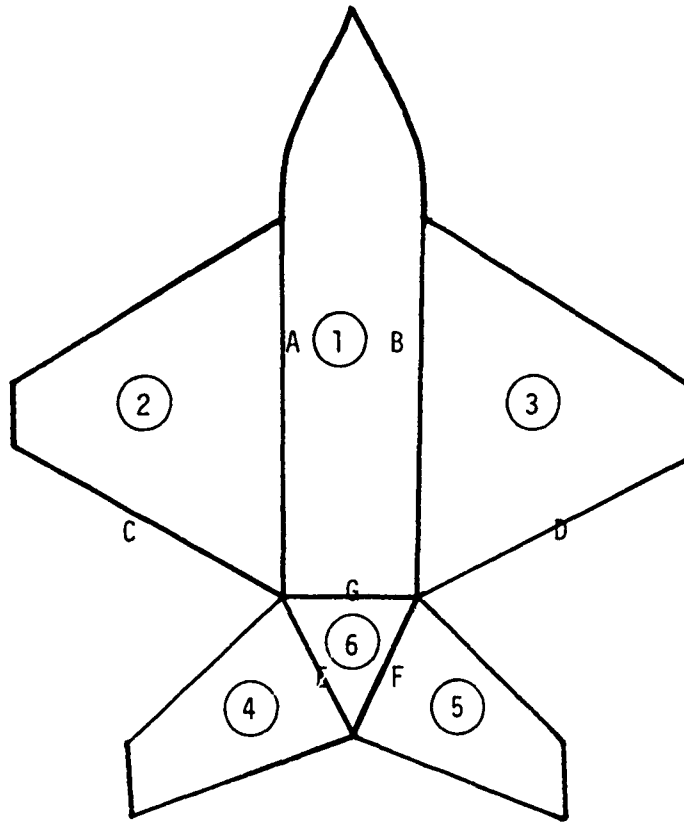


Figure 51. Magnetic tape libraries.

APPENDIX A. A SOLUTION TO THE LISTABILITY/PARTITION PLANES EXERCISE



\*

PARTITION PAIRS

- 1 - 2
- 1 - 3
- 1 - 4
- 1 - 5
- 1 - 6
- 2 - 3
- 2 - 4
- 2 - 5
- 2 - 6
- 3 - 4
- 3 - 5
- 3 - 6
- 4 - 5
- 4 - 6
- 5 - 6

PLANES SEPARATING PAIRS

(A)						
	(B)					
		C		E		(G)
			D		F	(G)
						(G)
(A)	B					(G)
		C				(G)
A			D		F	(G)
A						(G)
	B			E		(G)
			D			(G)
	B					(G)
				(E)	F	
				(E)		
					(F)	

\*A discontinuous circle surrounding a number of planes for a partition pair indicates any one of them may be chosen.

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