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IMPROVED SCENE GENERATOR CAPABILITY

FINAL REPORT

28 OCTOBER 1977

CONTRACT NO. NAS 9-14010

Prepared for

NASA, LYNDON B. JOHNSON SPACE CENTER HOUSTON, TEXAS

DEC 1977 RECEIVED

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ABSTRACT

This is the Final Report submitted in accordance with the provisions of Contract NAS 9-14010, Improved Scene Generator Capability.

This program includes the designing, manufacturing, testing and installation of Electronic Scene Generation equipment. This equipment is a complete, integrated system containing all functions necessary for:

- Model preparation and generation
- Image computation and scene generation
- Collision detection and reporting

This report summarizes the delivered equipment and software and describes the system capability.

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LIST OF ILLUSTRATIONS

1.0 TASK DESCRIPTION

The purpose of Contract NAS 9-14010 is to provide NASA-JSC with a high quality and extremely versatile Electronic Scene Generation System. The intended use of the system is to provide the capability for visual simulation of space craft involved in space maneuvers with other objects and earth landing exercises. Some important capabilities of the system include:

- A modeling system to implement new models--including a large digitizing tablet facility for data entry and modeling programs.

- A collision detection facility to allow the simulation of impenetrable objects and provide data for constraining object motion accordingly.

- An electronic scene generator having:

  a. Surface smoothing to simulate rounded or complex shaped objects.

  b. Directional illumination computation to realistically simulate the sun.

  c. Anti-aliasing and edge smoothing to improve picture quality.

  d. Hidden surface removal by range priority which eliminates the need for separating planes and allows for correct views of dynamically moving objects (including penetration) from any viewpoint.

e. Flexible control structures to allow the scene generation system to be interfaced to NASA-JSC simulation computers and control network.

f. The ability to dynamically link or unlink coordinate systems.

g. Variable fields of view (to simulate TV camera zoom).

h. Two separate views with independent viewpoints, fields of view and aspect ratios.

This contract also provides for the generation of two data bases, one representing the Space Shuttle and one of Edwards Air Force Base.

2.0 SYSTEM DESCRIPTION

The NASA Continuous-Tone Image Generation and Collision Detection System is used to simulate moving objects in real time. The system (see Figure 1-1) consists of three DEC PDP-11 computer systems with special-purpose hardware built by Evans & Sutherland. There is a Visual System (VIS) that is capable of generating two separate smooth-shaded color television images of solid objects. There is a Collision Detection System (CDS) that can detect when the simulated objects are in collision with each other, thereby providing a feedback mechanism which may be used to give the impression of solid, impenetrable surfaces. These two systems are independent. Interaction between the two systems is provided by a third system called the HOST. The HOST receives inputs from other computers and input devices and transmits positions and other information to VIS and CDS. In return, VIS generates the images and provides a synchronization signal to tell the HOST when to update the information for VIS and CDS. The HOST may receive information back from the CDS regarding collisions and take appropriate action.

The modeling system (see Figure 2-1) consists of a calligraphic display system, a large digitizing tablet, and modeling software to provide a flexible engineering design and modeling tool. With this system, a user can create models from a wide variety of sources such as road or contour maps, engineering drawings, or mathematical equations. The Evans & Sutherland PICTURE SYSTEM allows the modeler to view and manipulate the models on a calligraphic display. The models produced by the modeling system are used as the input to programs which produce the data bases for the Scene Generator and Collision Detection System.

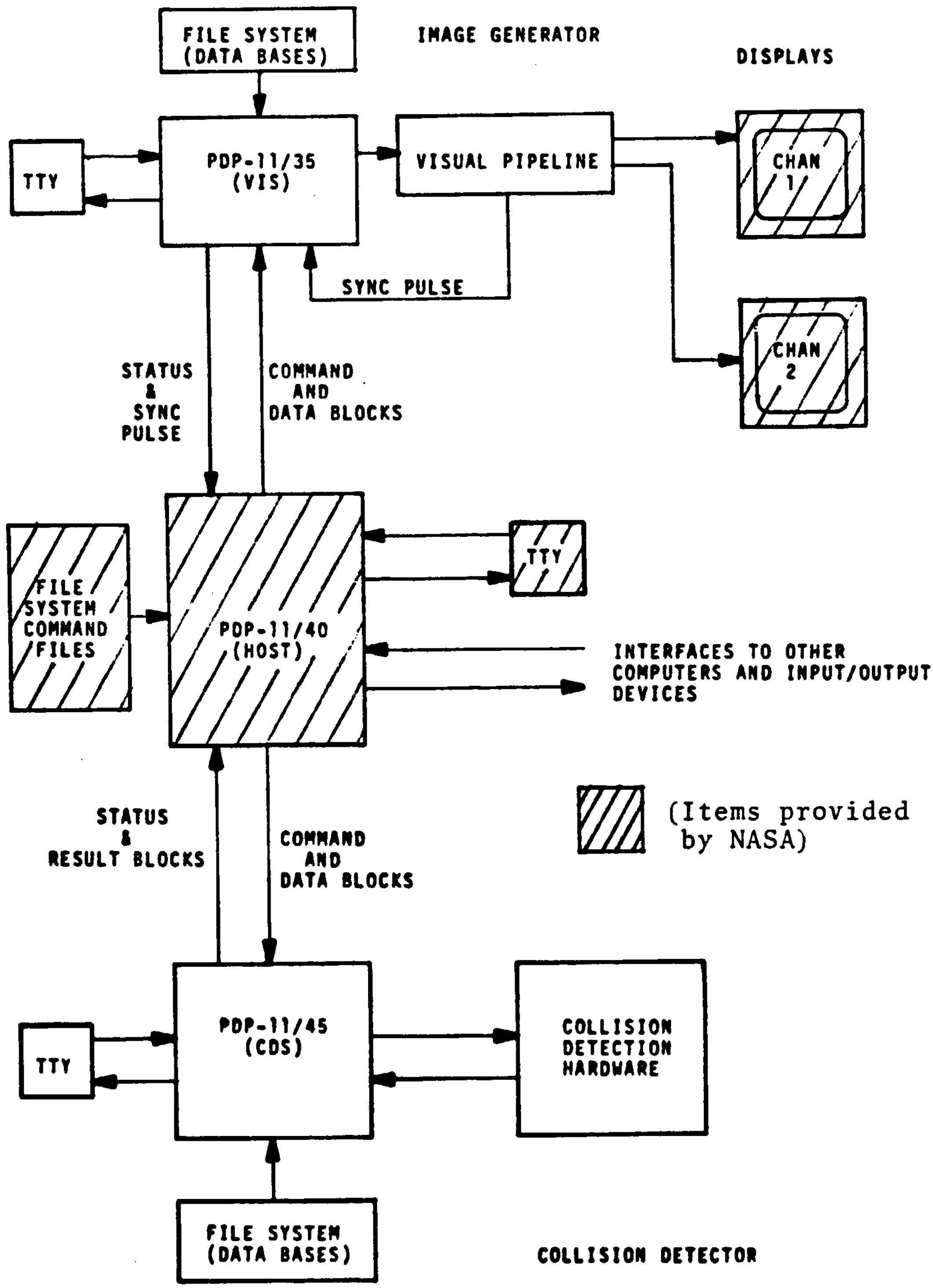

Figure 2-1

NASA-JSC CONTINUOUS-TONE IMAGE GENERATION AND COLLISION DETECTION SYSTEM

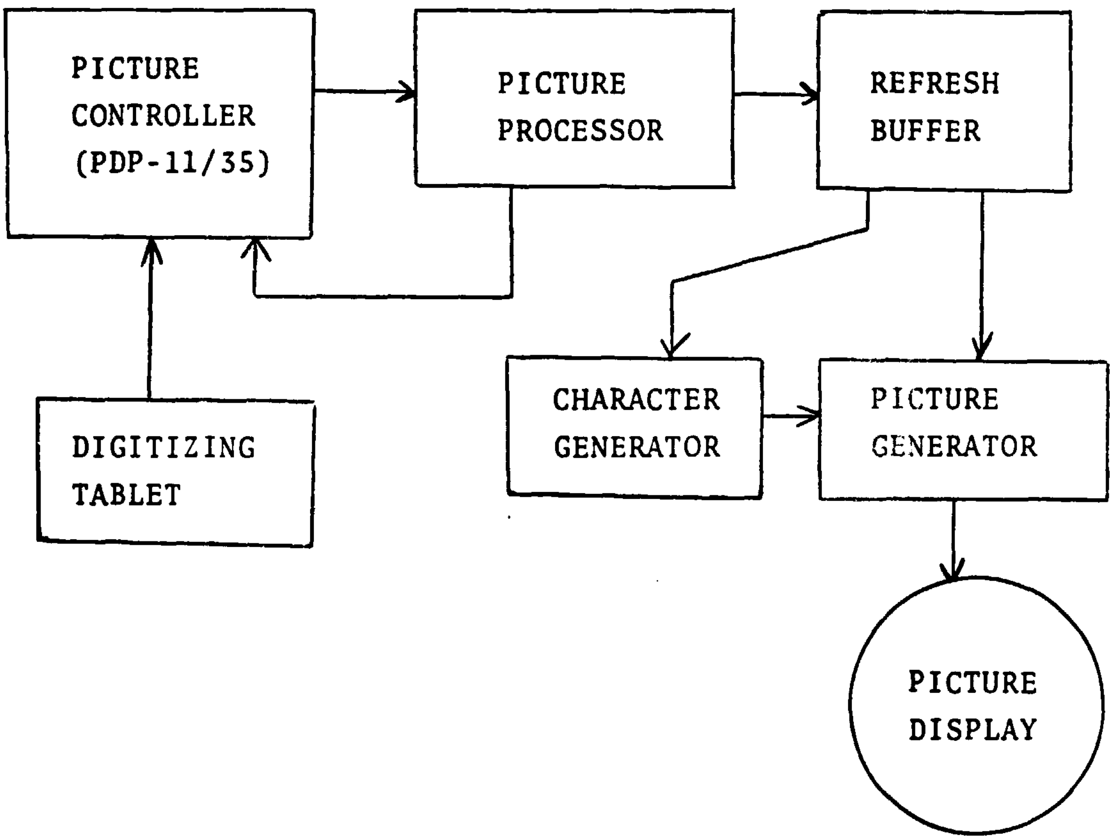

Figure 2-2

BLOCK DIAGRAM OF PICTURE SYSTEM

2.1 VISUAL SYSTEM

Objects to be simulated are described with polygons. A polygon is a surface that is defined by a set of points in three-dimensional space. In general, an object is formed from volumes that are bounded by sets of polygons. A perspective transformation is applied to the polygons to produce a television image from a particular point of view. Hidden surface elimination gives the appearance of having solid objects by shading only those parts of the object which are visible from the viewpoint.

Objects are manipulated using transformation matrices containing rotation and translation information. Some transformations are used once to define a set of objects and others are modified in real time to manipulate objects during the simulation.

Figure 2-3 shows the transformations needed to manipulate the moving parts of the NASA-JSC Space Shuttle model.

The intensity of each polygon is determined by the reflectivity of the model surface, the ambient light, the intensity and angle of the sun vector relative to the polygon surface, plus the effect of landing lights and smooth shading. Both perspective and point lights may be displayed on this system.

The system has two channels. There are separate sun and landing light vectors, ambient light values, fields of view and aspect ratios for each channel. The system capacity for polygons and lights is the sum of the two channels. The entire capacity may be concentrated in a single channel if desired.

The image generation system is comprised of a series of independent processors. There are five principal sections of computation:

1. Visual system controller. This is a Digital Equipment Corporation (DEC) PDP-11/35 general purpose computer. It receives commands and data from the user and the HOST computer and sets up data structures for the hardware to work on.

2. Geometric processing group. This hardware stores and processes the data structures set up by the PDP-11. The simulated objects are transformed into perspective coordinates and sorted according to their Y positions on the screen.

3. Raster conversion and visible surface solution group. The picture information is processed on a scan line and element basis, properly ordered for display. Polygon elements in the scene are processed to resolve priority or hidden surface conditions.

4. Display segment processing and buffer group. Color component and anti-aliasing features are introduced, and the segments are stored in a buffer that contains a complete frame of information for display.

5. Display channel group. The final video output signal is produced for each television channel. The final processing operates in synchronism with the digital element rate.

Table 2-1 summarizes the specifications of the Image Generation System.

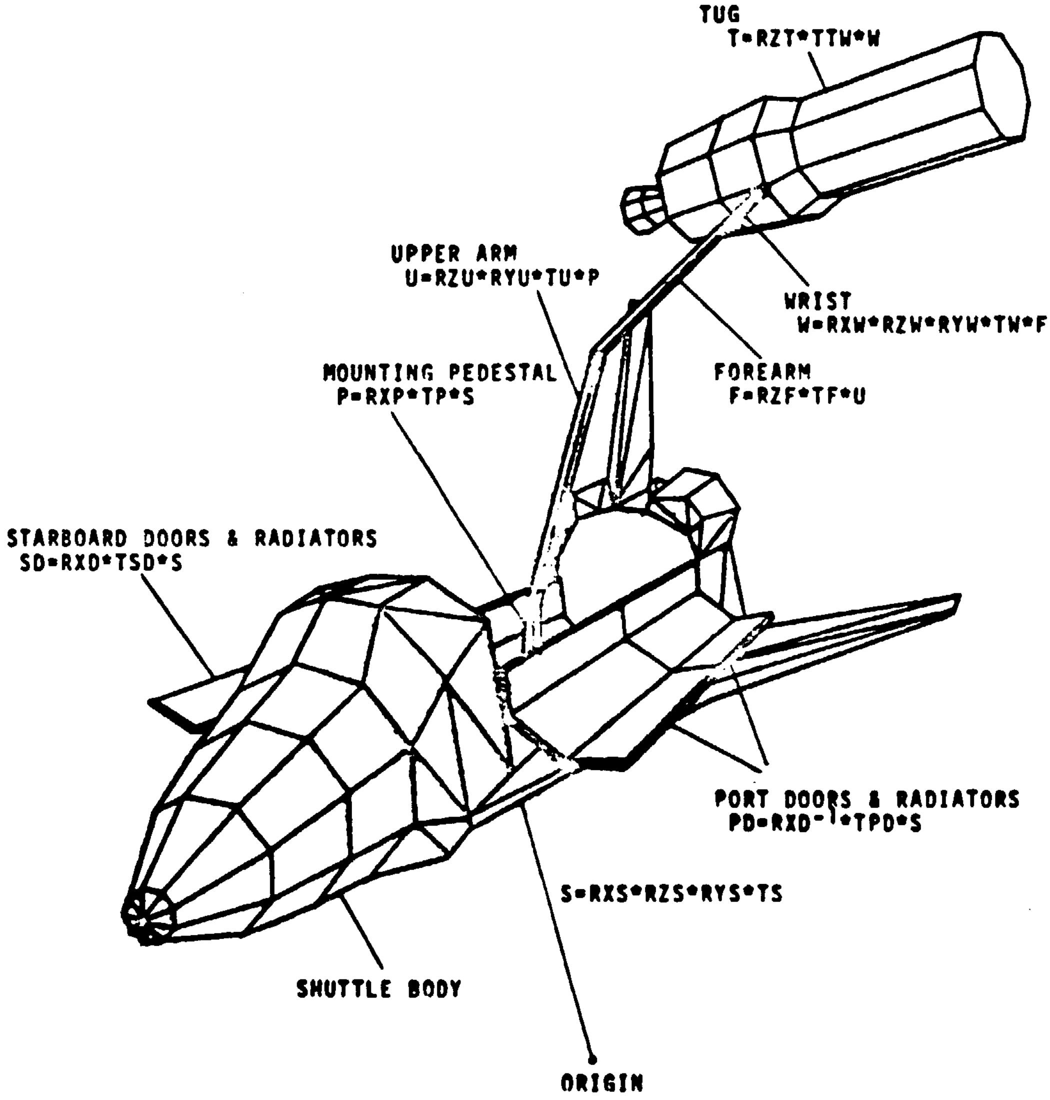

Figure 2-3
MATRIX TRANSFORMATIONS OF SPACE SHUTTLE MODEL

Channels	Two
Capacity	900 total polygons (average of four edges each); 600 front-facing polygons. Capacity may be concentrated in one channel or shared between the two. (Excess hardware capacity and alternate operation modes such as alternate frame update allow the system to operate satisfactorily at considerably higher capacities.)
Overlay Priorities	Normal hidden surface elimination takes place between polygons of the same priority. Polygons may be assigned set priorities if desired. Eight levels of priority are provided.
Shading Modes	Flat and smooth shaded. Intensity is normally directionally dependent.
Colors	There are 256 composite colors available at any time. The incremental amount of red, green and blue of each composite color may be changed dynamically.
Light Sources	Movable sun vector, landing lights (intensity is a function of the distance from the eye-point) and ambient intensity.
Intensity Range	Twelve bits.
Model Resolution	Twenty-four bits for each of three dimensions.
Field of View	25° to 65°.
Frame Rate	25 Hz.
Field Rate	50 Hz.
Line Standard	625 lines.
Anti-aliasing	Diagonal edge smoothing to diminish raster effects.

Table 2-1

VISUAL SYSTEM SPECIFICATIONS

2.2 COLLISION DETECTION SYSTEM

The Collision Detection System (CDS) is used to detect when simulated objects are in collision with each other. In general, these will be the same objects moving in the same manner as those being displayed on the Visual System. The collision detection process is not concerned with lights, colors or shading modes and is completely independent of the viewpoint.

The CDS is an extremely important feature of simulations involving complex environments and dynamic interactions such as the Space Shuttle with a Remote Manipulator Arm. The collision information from the CDS not only allows the simulation of solid, impenetrable objects but also facilitates simulation of docking, deployment and acquisition of payloads, and shuttle landings.

The collision detection process begins with the transformation of all objects into a reference coordinate system. A collision matrix associated with each object allows the user to specify which collisions are of interest. A system of telescoping arms and joints has collisions which occur all the time but are usually not of interest to the simulation. During the course of a simulation, this collision matrix may change as objects become attached or separated.

The result of the collision detection is a collision mask indicating the objects in collision and a point within the volume of collision. This information is sent to the HOST computer for appropriate action. The HOST computer may alter the simulation, modify the motion of the objects, or simply log the collision for later reference.

The Collision Detection System consists of three units:

1. A PDP-11/45 general purpose computer dedicated to controlling the collision processing.

2. Vector Processing Unit (VPU).

3. Surface Clipping Unit (SCU).

The VPU and SCU are special purpose hardware devices built by Evans & Sutherland. The VPU stores the collision model and transforms the polygon into reference coordinates. The Surface Clipping Unit calculates the collision volumes.

Table 2-2 summarizes the CDS specifications.

Capacity	400 polygons, with an average of four edges each.
Model Resolution	Twenty-four bits for each of three dimensions.
Coordinate Systems	Eight independent systems.
Collision Results	Sixteen identifiable objects. Objects of interest and collisions of interest specified dynamically. Location of collision in space.

Table 2-2

COLLISION DETECTION SYSTEM SPECIFICATIONS

2.3 MODELING SYSTEM

The modeling system combines a general purpose graphics display system, a large digitizing tablet, and a group of modeling programs to facilitate the generation of data bases for continuous-tone image generation.

Some of the modeling programs enable the user to digitize large geographic areas from road maps and contour maps. Other programs help the user digitize objects from the same plan view and elevation drawings that engineers use. The user has programs to model roads and rivers, buildings, and mountains. In addition, there is a surfaces-of-revolution program to model objects that are symmetrical about a radial axis such as storage tanks, jet engine housings, and rocket ship hulls.

Because the modeling system includes specialized tools like the roads program, some digitizing problems are simplified. However, the user is not limited to modeling objects that fit into the category of one of the specialized tools because the modeling system also provides a general capability. The user may custom build one of a kind objects, with the aid of the tablet and the general purpose digitizing program ZEUS.JOY.

The graphics display system can present dynamic, true perspective pictures of three-dimensional objects. The objects can be smoothly rotated, translated and changed in scale in real time. Individual sub-objects can assume independent or compound motion.

In addition to generating models for the visual scene generator and CDS, the graphics system can be utilized for engineering design tasks. Cockpit layout, space allocation, instrument panel layout, piping system design and control diagrams are but a few possibilities.

Table 2-3 summarizes the PICTURE SYSTEM specifications.

PICTURE CONTROLLER	DEC PDP-11/35
Dimension modes	Two-dimensional, three-dimensional or homogeneous
Coordinate specification	Absolute or relative
Drawing modes	Move, draw, dot or character
PICTURE PROCESSOR	Translation, rotation, scaling, clipping, perspective, viewpoint mapping, zooming, hit test and memory write back
CHARACTER GENERATOR	
Character set	96 character extended ASCII
Capacity	1725 characters
PICTURE GENERATOR AND DISPLAY	
Line modes	Solid, Blink, Dash
Intensity	256 levels, depth-cueing
Display capacity (at 30 frames/ sec.)	o 11500 connected 1/2" lines o 1625 connected 10" lines o 6650 dots 1/4" apart o 1725 characters 0.14" high
DISPLAY	Calligraphic
Spot size	0.020 inch
Addressable location	4096 X 4096
Endpoint matching	.020 inch
CRT size	21" rectangular

Table 2-3

PICTURE SYSTEM SPECIFICATIONS

3.0 CONCLUSIONS

The combination of features that comprise this system makes it uniquely suited for visually simulating the Space Shuttle and its interaction with the Manipular Arm and other objects. The command and data structures allow for dynamically linking and unlinking many objects and coordinate systems. The hidden surface solution by range priority allows for correct views of dynamically moving objects from any viewpoint. Objects may penetrate each other to simulate docking situations or telescoping arms. Smooth shading, anti-aliasing and edge smoothing techniques help provide a high quality picture. The Collision Detection System allows for simulation of impenetrable objects and docking maneuvers. The modeling system allows the user to quickly produce new data bases for desired simulations.

4.0 SAMPLE ENVIRONMENTS

Figures 4-1 through 4-5 illustrate representative views which are produced by the equipment data bases delivered under this contract, NAS 9-14010.

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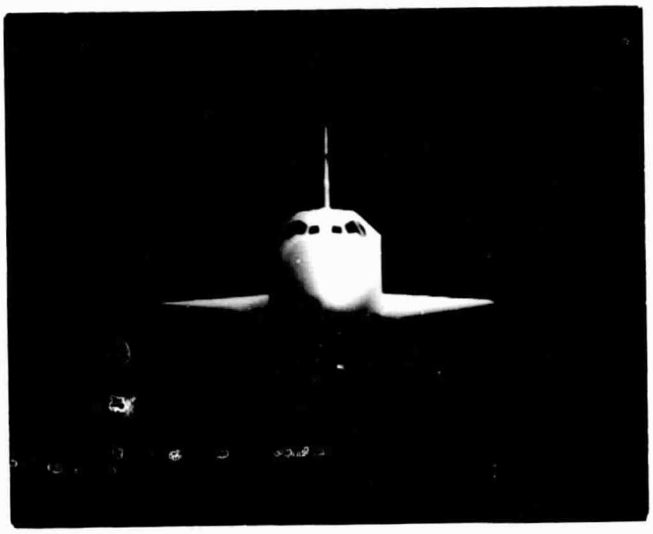

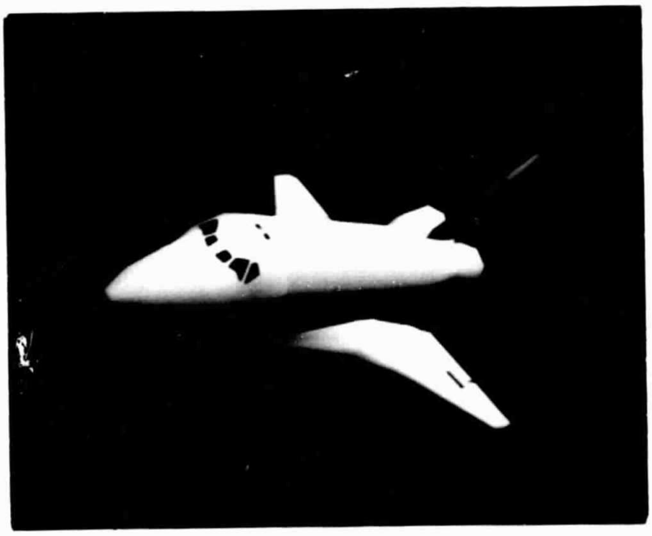

Figure 4-1. These views of the Space Shuttle illustrate the use of smooth shading to enhance its rounded appearance.

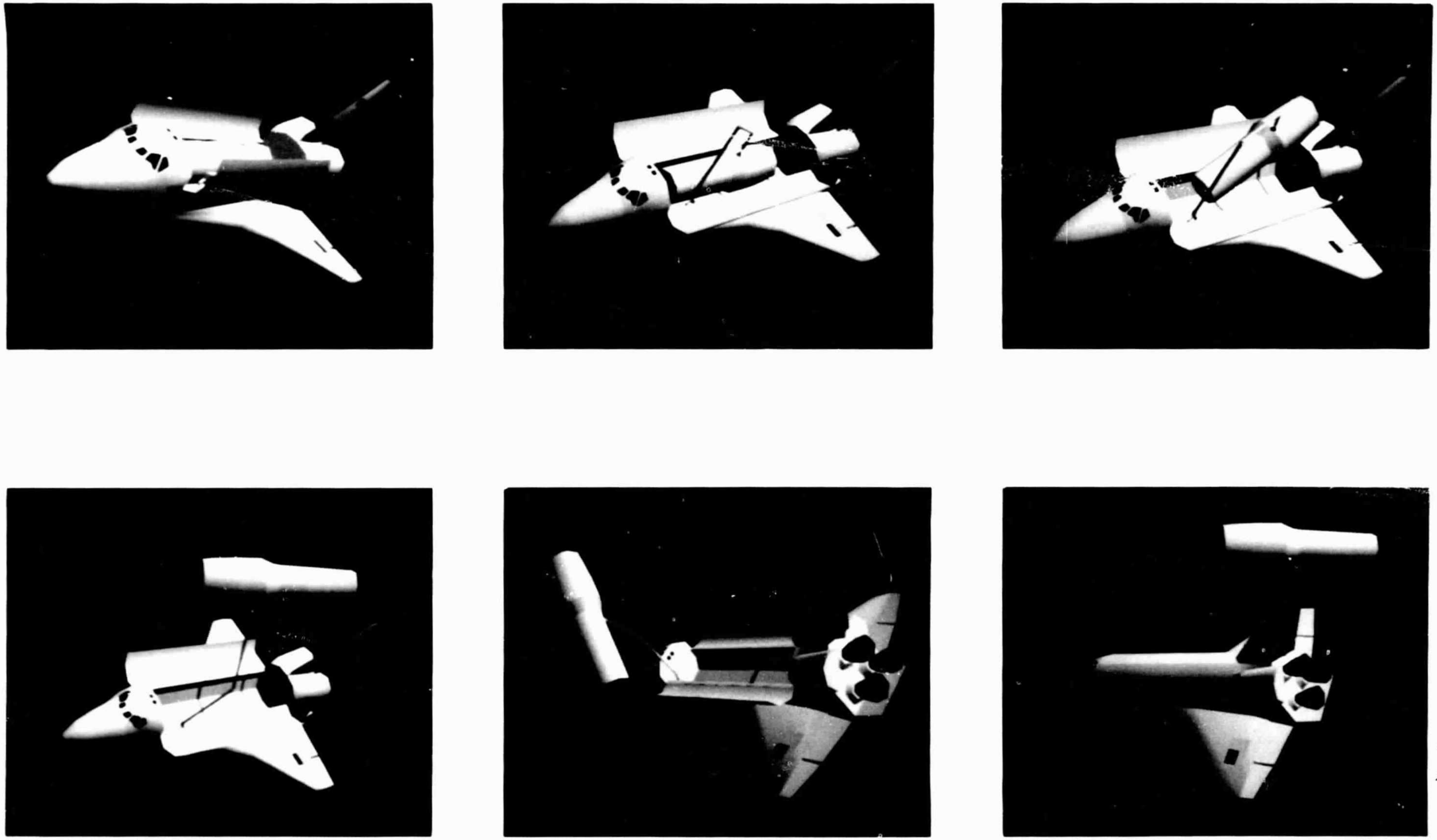

Figure 4-2. This sequence of photographs is taken from one of the acceptance test scenarios. It illustrates the use of the Manipular Arm to remove a payload from the cargo bay.

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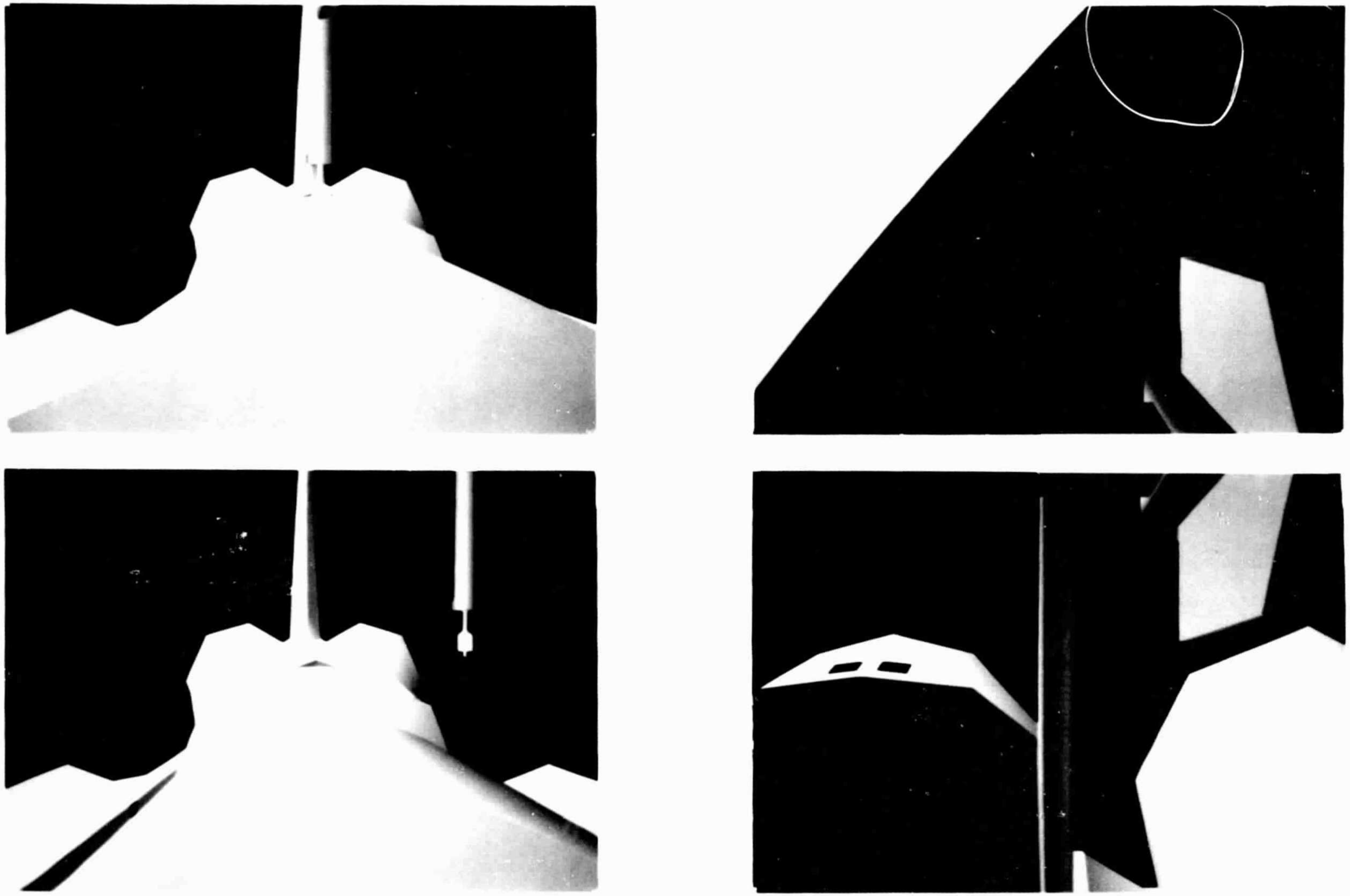

Figure 4-3. The two channels of the Scene Generator may be used simultaneously to view the same situation from two viewpoints. The photographs on the left are what an astronaut might see out the back window of the Space Shuttle. The photographs on the right are the views from a T.V. camera mounted near the end of the Manipular Arm.

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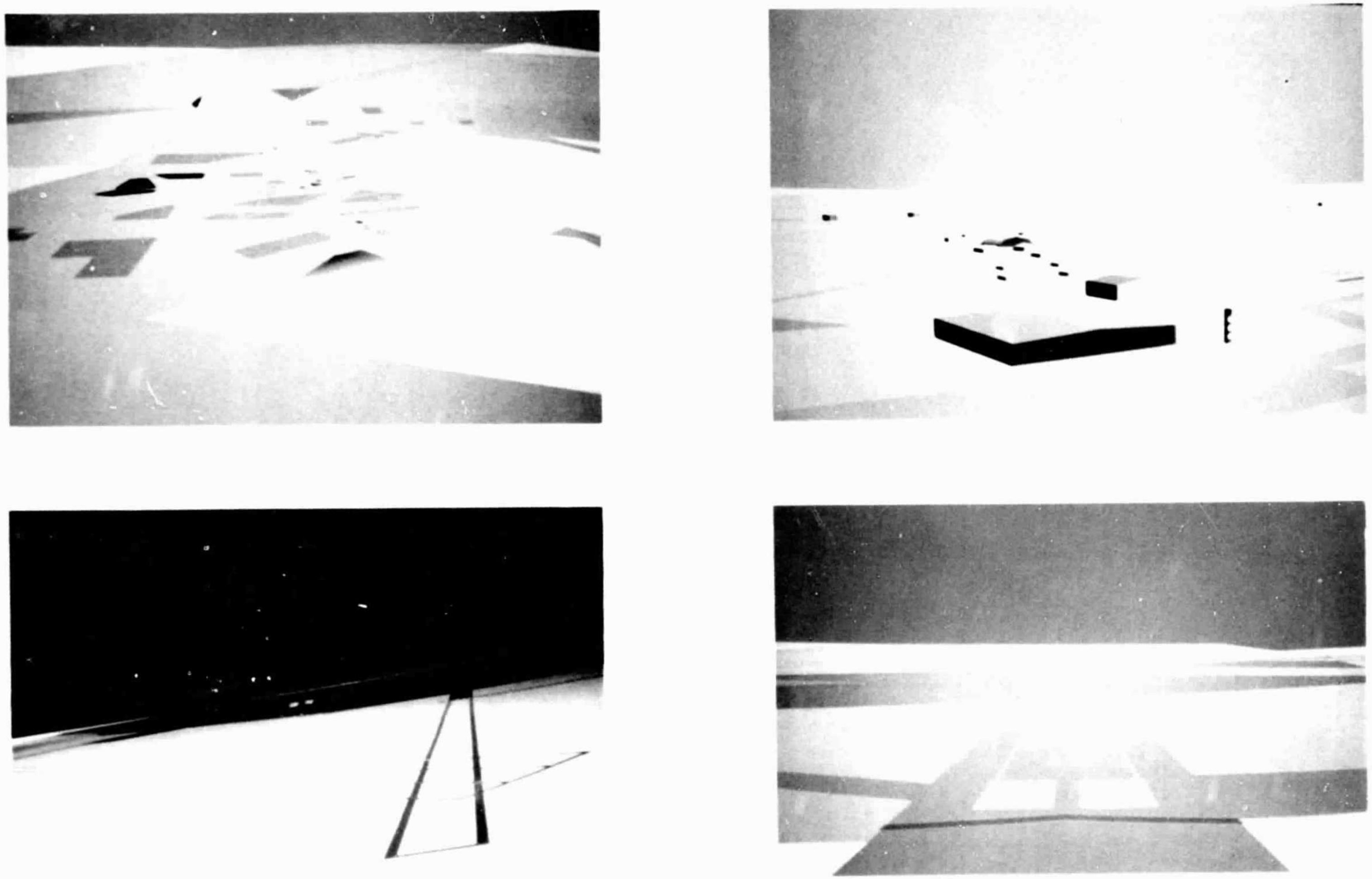

Figure 4-4. These photographs show a small portion of a data base representing Edwards Air Force Base in California. This data base allows Space Shuttle landing simulation over an area of approximately 7000 square miles.

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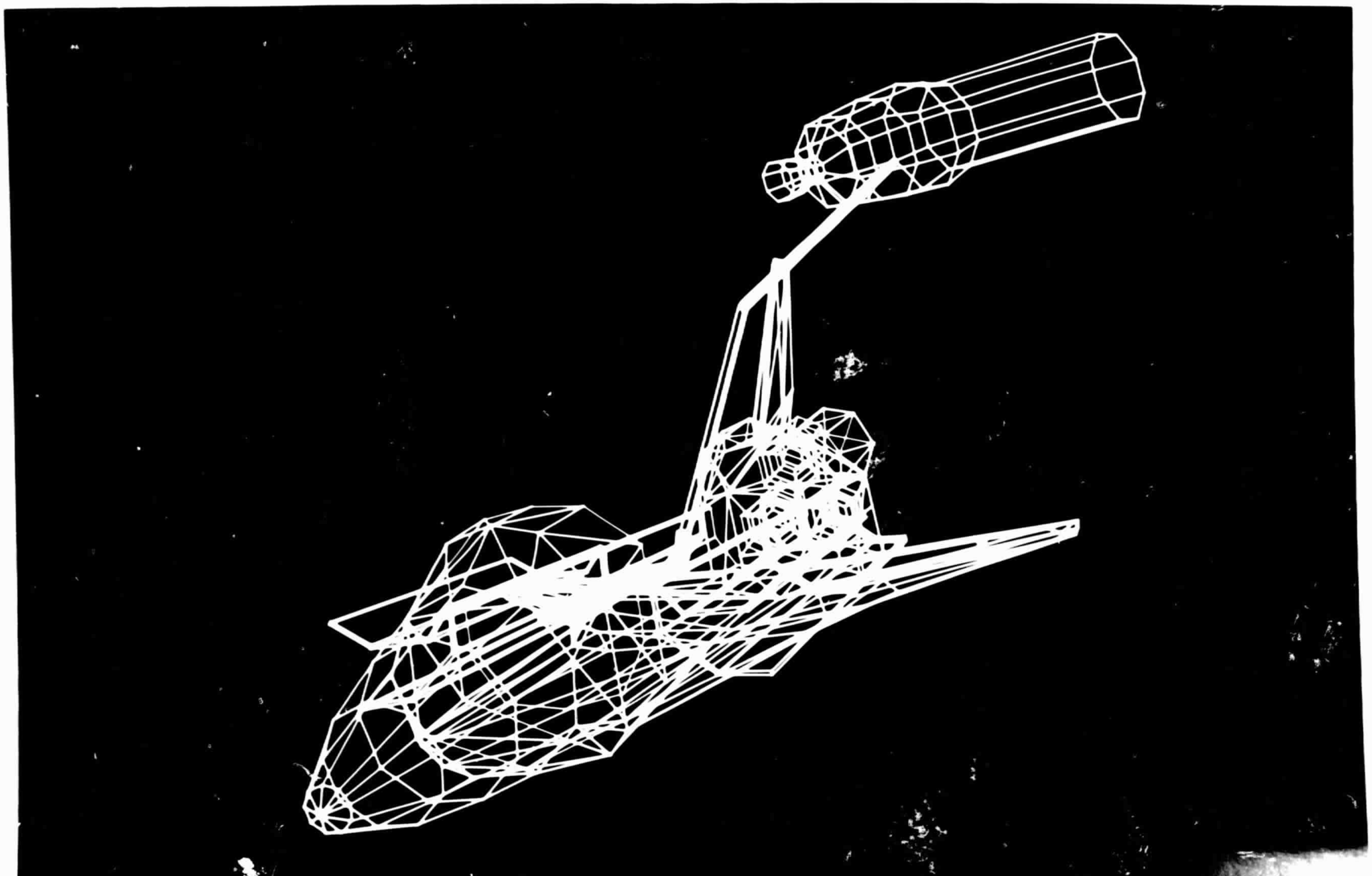

Figure 4-5. The Modeling System combines an efficient set of modeling tools and a powerful language to give the user graphic feedback about the modeling progress. This photograph of the PICTURE SYSTEM screen shows one stage in the development of the Space Shuttle data base.