THE SHUTTLE MISSION SIMULATOR VISUAL IMAGERY

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Abstract

Shuttle Mission Simulator visual imagery at the NASA Johnson Space Center is described. SMS visual imagery includes low earth orbit, six landing sites, landing aids systems, the Orbiter payload bay, stars and miscellaneous objects. Visual imagery of early space shuttle mission payloads in the SMS is described. Two current visual simulation problems are discussed.

Mission Simulators at the NASA Johnson Space Center

The primary NASA Johnson Space Center simulators used for flight crew training have been the mission simulators. They are also interfaced with the Mission Control Center for joint flight crew/ flight controller training. During a flight new contingency procedures are sometimes developed or verified in the mission simulators. A high degree of fidelity or realism is built into the simulator crew stations interior appearance and in the operation of instruments and controls.

Previously mission simulators utilized several different image generation techniques. These usually pushed the state-of-the-art in visual simulation. Stars were generated using "starballs" (ball bearings imbedded in a non-reflective sphere). Films were used to generate earth and lunar imagery in the Command Module Simulator, for example. Landing models viewed by television were used in the Lunar Module Simulator and in the Orbiter Aero-flight Simulator. Space vehicles seen during rendezvous maneuvers were simulated using models viewed by television except one Gemini Mission Simulator equipped with electronic generation of the Agena vehicle.

The continued use of starballs, films, and models was determined inadequate to meet space shuttle payload simulation requirements. Computer image generation technology sufficiently matured in time to be available for the SMS (Shuttle Mission Simulator). In fact, the SMS uses the Singer Company's first commercial DIG (Digital Image Generation) systems.

The Shuttle Mission Simulator

The SMS is being developed into a four simulator complex. The FBS (Fixed Base Simulator) is configured like the Orbiter including a simplified mid-deck. Landing and launch motion cues are provided in training using the MBS (Motion Base Simulator). The MBS currently has only the forward portion of the flight deck. The aft portion will be added in a separate crew station scheduled in September 1982. The GNS (Guidance and Navigation Simulator) went into limited operation in May 1982. It will serve as the primary SMS hardware and and software development facility. Training in the SLS (Spacelab Simulator) is scheduled to begin March 1983.

The SMS uses four DIG systems. Each DIG generates three simultaneous scenes. Two systems are dedicated to generating color imagery for the six forward window visual displays of the FBS and MBS, respectively. Any four adjacent windows may be used simultaneously since two forward windows use the same view. A third DIG generates up to three black and white views for the Orbiter's CCTV (Closed Circuit Television) system. The CCTV has two crew station monitors, capable of showing split screen views of two cameras. The Mission Control Center may select and command a separate camera if the flight crew is not commanding it. The fourth DIG generates three views for the two aft and two overhead windows. One view is shared by a pair of windows selected by the SMS operator.

Earth Imagery

The earth was modeled as a polyhedron composed of 1620 equilateral triangles with sides averaging 460 nautical miles. Surgace features were modeled with 3000 additional polygons or faces (19,000 face boundaries). Face boundaries are the sides (edges) of faces (polygons). It has sufficient coastline detail to recognize large land areas but not small isolated islands, except for a few were detail was enhanced. Large cyclonic cloud features were modeled as well. Most of these were placed over the oceans where no other scene detail exists to visually indicate the direction of the Orbiter's motion. This color earth imagery is displayed only in the forward window DIG systems. Figure 1 shows a PAM (Payload Assist Module) spacecraft deployed over Ireland and Great Britain. Norway, Sweden, Denmark, Netherlands, and Belgium appear in the background.

The earth is modeled simply as a circular disc in the aft and CCTV DIG systems. Twenty-seven hexagonally-shaped cloud formations are modeled on the earth in a square array. They enable perception of spacecraft attitude motion when the earth fills the window or CCTV view. The clouds are fixed. Thus, cloud motion due to spacecraft movement along the orbital track is not shown. The clouds were modeled to show proper perspective when viewed from 150 nautical miles altitude. This gives the earth disc an illusion of having a sperical shape. Two earth discs are available. A bright version of the earth is used during daytime. A darker version is substituted when the Orbiter crosses the day-night terminator.

FIGURE 1. PAM Over Great Britain

Imagery of Space Shuttle Landing Sites

Edwards AFB, California.

Edwards, the landing site for STS-1, 2 and planned for STS-4 was the first approach and landing area modeled. It is also the most detailed, using over 11,000 face boundaries. This and other landing models lie on top of the earth model and are modeled in color. They are used for Orbiter altitudes under 150,000 feet. A 190-by-276 mile area scene was modeled two dimensionally, except for seven hills south of Rogers dry lake modeled in 3D (3 dimensions). Hindsight impressions are that a smaller Edwards approach and landing area with more 3D mountains might appear more realistic.

Any one of several lakebed or concrete runways may be used for a space shuttle landing. Landing skid marks are modeled on the primary runways to provide height cues. For the same reason, a few vehicles are placed near the runways. The concrete runway was modeled with 3D distance markers showing how many thousand feet remain to the end of the runway.

Kennedy Space Center, Florida.

The KSC (Kennedy Space Center) launch and landing area modeled Florida from the Keys to St. Augustine. It is high-detailed containing 8800 face boundaries. The launch tower was modeled to provide visual motion cues from just before liftoff through tower clearance.

The KSC runway was designed for Orbiter landings following the test phase of the Space Shuttle Program or following a RTLS (Return to Launch Site) abort. It is amply long and wide having the same dimensions of 300 feet by 15,000 feet as the main concrete runway at Edwards, AFB. Figure 2 shows KSC runway 15 from 20,000 feet altitude.

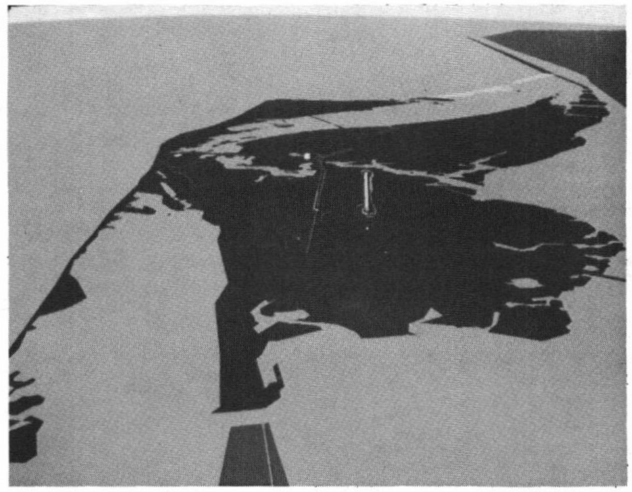

FIGURE 2. Kennedy Space Center, Florida

Northrup Strip, New Mexico.

Northrup Strip, an alkali flat lying just west of White Sands, is similar in appearance to Rogers dry lake at Edwards AFB. It serves as a contingency landing site for use when the lakebed at Edwards is wet, as it was on STS-3, and for practice landings in the STA (Shuttle Training Aircraft) since it is closer to Houston. Figure 3 shows Northrup Strip runway 17, a simulated STS-3 perspective from 3000 feet altitude. The mountains are in close proximity to Northrup, hence were modeled 3D. Northrup modeling required 3700 face boundaries.

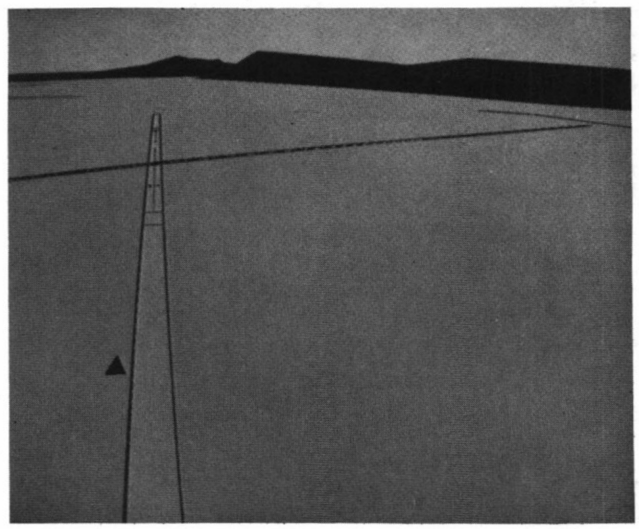

FIGURE 3. Northrup Strip, New Mexico

This and other contingency landing sites have much smaller areas modeled than Edwards or KSC. Sufficient detail is included for recongition and orientation. A high level of detail is expended in the runway areas. These scenes are inexpensive. Typically the modeling requires two man-months plus one-half month software development and checkout.

Rota Naval Station, Spain.

Rota was available as a late launch abort contingency landing site for the first three space shuttle flights, which had 38-to-40.6 degree orbit inclinations. Lower orbit inclination flights pass further south and would need to land in Africa. In Figure 4, showing an approach to Rota runway 10, it is apparent that the scene outside of the airport area is fairly low-detailed. There were 1600 face boundaries used to model Rota.

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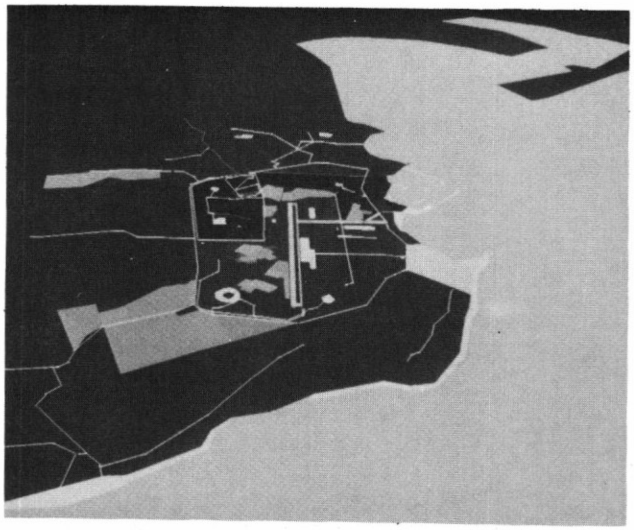

FIGURE 4. Rota Naval Station, Spain

Kadena AFB, Okinawa

The Kadena contingency landing site was modeled with 1700 face boundaries. Figure 5 shows an overview of Okinawa. Kadena runway 5L is seen from 64,000 feet altitude. The clarity of the scene is due to the absence of haze. Computer generated image landing systems now available have realistic-appearing visibility attenuation due to haze. The SMS has limited haze generation capability separate from the DIG.

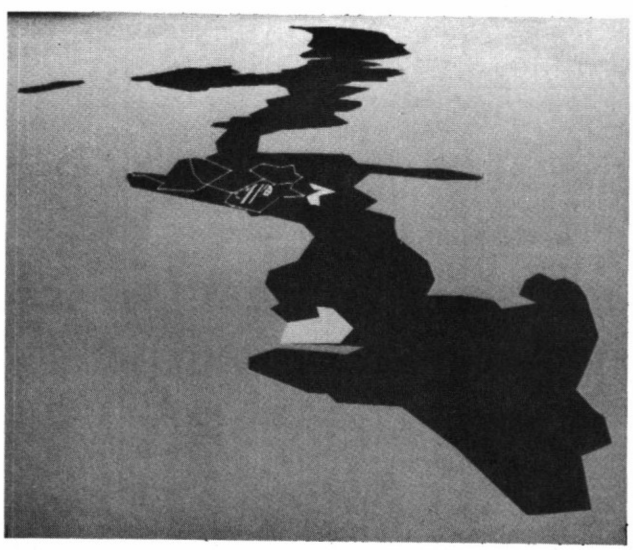

FIGURE 5. Kadena Air Force Base, Okinawa

Hickam AFB/Honolulu International Airport

This contingency landing site uses the 12000 x 200 feet runway constructed off Oahu for jumbo jet landings at Honolulu International airport. Runway 26L is seen in Figure 6. Pearl Harbor lies in the background, with the island of Kawai in the distance. Figure 7 shows a closer view of runway 8R. The white background is Honolulu. The island of Molokai lies in the distance. Mountains on the major islands are 3D requiring more detail than usual. 3500 face boundaries were used.

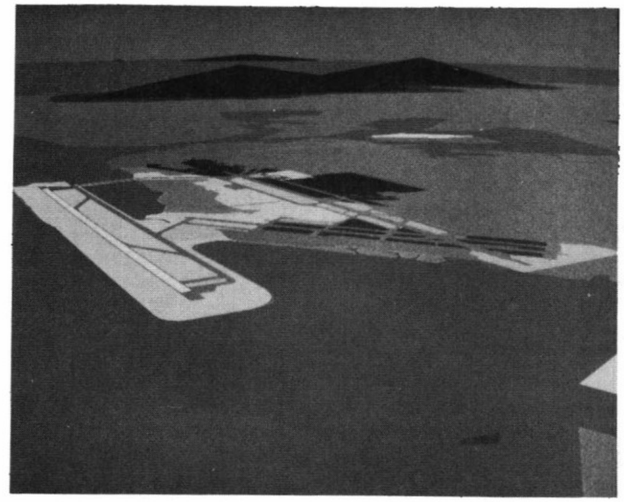

FIGURE 6. Hickam Air Force Base/Honolulu International Airport

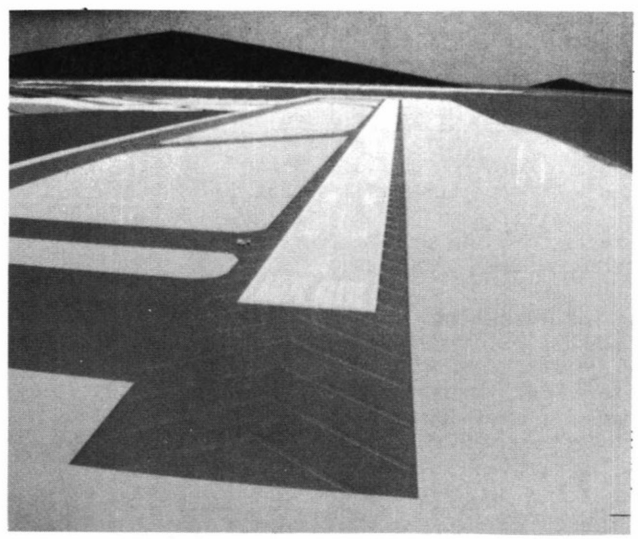

FIGURE 7. Honolulu International Airport Runway 8R

Dakar, Senegal

Dakar was selected as a late launch abort contingency landing site for flights having easterly launches (28.5 degrees orbit inclination). Dakar, on the African coast, is the next contingency site to be modeled for the SMS.

Other contingency sites are planned. High inclination orbits, like the 57 degrees planned for Spacelab missions, would need a launch abort landing site in Northern Europe. If a tailored scene is not desired or available, it is possible to substitute one of the existing landing sites for the desired one. The scene is rotated to align a runway to the proper heading or azimuth. For example, a Rota runway might be used for a landing at Dakar prior to the time Dakar is modeled.

Precision Approach Path Indicators

The Space Shuttle Program utilizes a backup visual landing aid system call PAPI (Precision Approach Path Indicators). Four sets of white over red lights are installed on the ground at the outer glide slope aim point located 7500 feet short of the runway threshold. They provide an out-the-window indication of the outer glide slope flight path angle within one degree accuracy for a nominal 19 degree glide slope. The PAPI's show 4 white lights for over 22 degrees and one red/three whites for 22-20 degrees. The desired pattern of two reds/two whites indicate 19 $\pm$ one degree. Three reds/ one white show 18 -16 degrees, and four reds indicate under 16 degrees. PAPI's are utilized down to 1750 feet altitude where the preflare pitchup maneuver is performed. The preflare reduces the Orbiter's flight path angle to 1.5 degrees on the inner glide slope. PAPI systems are installed at the Kennedy Space Center, Edwards AFB, and White Sands landing sites.

Separations between the lights of 25 or 40 feet posed a resolution problem for SMS PAPI light simulation. SMS light separations were increased to 62-1/2 feet to enable recognition of the PAPI light pattern at/above 15,000 feet altitude. Figure 8 shows a 3700 feet altitude view of Edwards AFB lakebed runway 23, used for the STS-1 and 2 landings. Two reds and two white PAPI lights are seen below the black steep glide slope aim point triangle. PAPI simulation first introduced for STS-4 flight crew training has received good crew acceptance.

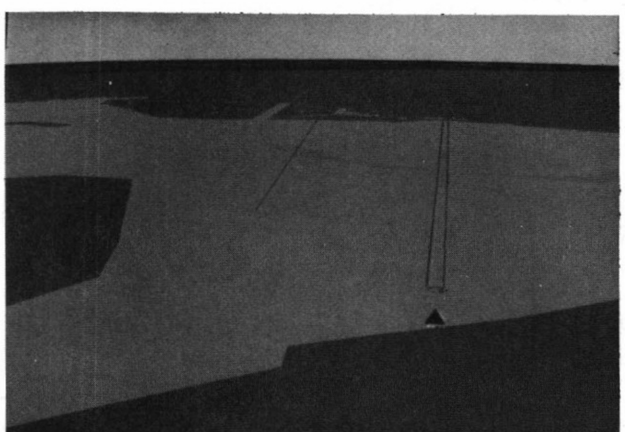

FIGURE 8. PAPI Lights on Rogers Dry Lake Edwards Air Force Base, California

Space Shuttle Payload Imagery

The SMS aft and overhead windows and CCTV system are primarily designed for payload operations training. The payload bay interior and Orbiter tail structure are properly shaped but without much added detail. The payload bay doors and radiators and their motions are simulated. The four payload bay CCTV cameras and the motions of their pan-tilt units are simulated. Either one or two RMS (Remote Manipulator System) arms are simulated if present. Each arm has an elbow camera with pan-tilt motions and a wrist camera.

Payloads designed for deployment by the RMS require an RMS payload grapple fixture. The grapple fixture has a probe or stem that the RMS end effector grapples. The probe is supported by three symmetrically arranged cams. A grapple fixture target having its own stem is displaced eleven inches from the grapple fixture probe. The target and its stem are viewed by the RMS wrist camera in properly aligning the RMS with the grapple probe. Failure of this wrist camera during the STS-3 flight contributed to the elimination of the IECM deployment task. Grapple fixtures are modeled in the SMS with 288 visual and 192 occlusion object face boundaries each. (The need for occlusion objects will now be explained.)

Space shuttle visual payload simulation is unique in that 48 or more moving objects may be present in the payload scene. These include:

7 Port RMS arm segments
7 Starboard RMS arm segments
5 Movable CCTV cameras
5 Camera pan/tilt units
8 Payload bay lights (ON-OFF-DIM)
2 Payload bay doors
2 Payload bay radiator panels
4 Deployable payload spacecraft
8 Spacecraft sunshield objects
48

With so many moving objects a combination hardware/software approach was chosen to determine which objects are in front of or occlude other objects. Occlusion objects having simple rectangular geometry (boxes) are modeled to enclose the visual objects. Occlusion object priorities are then determined by special occlusion processor DIG hardware operating with a general purpose computer programmed to solve occlusion priority algorithms.

Figure 9 depicts the STS-2 OSTA-1 (NASA Office of Space and Terrestial Applications) payload. OSTA-1 was modeled with 1180 visual and 768 occlusion face boundaries. The DFI (Development Flight Instrumentation) payload is shown in the rear of the payload bay. STS-1 carried only the DFI modeled with 192 visual and 96 occlusion face boundaries.

Figure 10 shows the fixed payload objects simulated for STS-3 training: the OSS-1 (NASA Office of Space Sciences) payload and the DFI. Moving objects are absent from this view. These include the payload bay doors and radiators, RMS, cameras, the PDP (Plasma Diagnostics Package) and the IECM

(Induced Environmental Contamination Monitor). The payload REM's (Release Engage Mechanisms) may be recognized by the V-shaped guides on two sides used in berthing the PDP and the IECM.

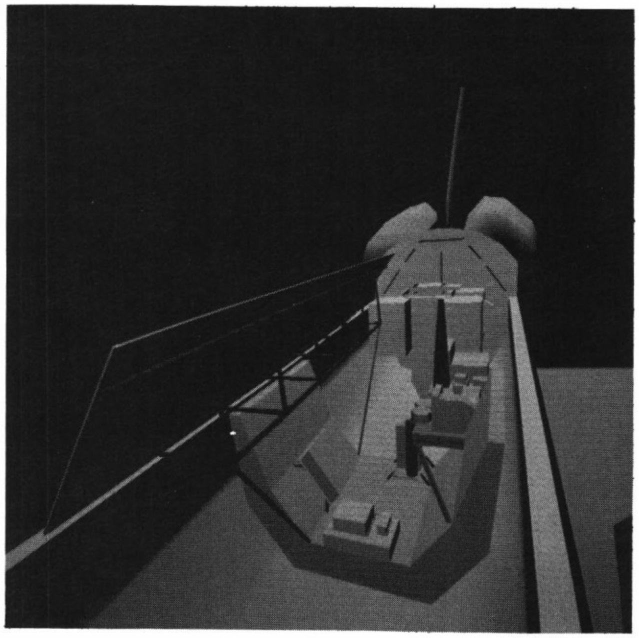

FIGURE 9. STS-2 OSTA-1 and DFI Payloads

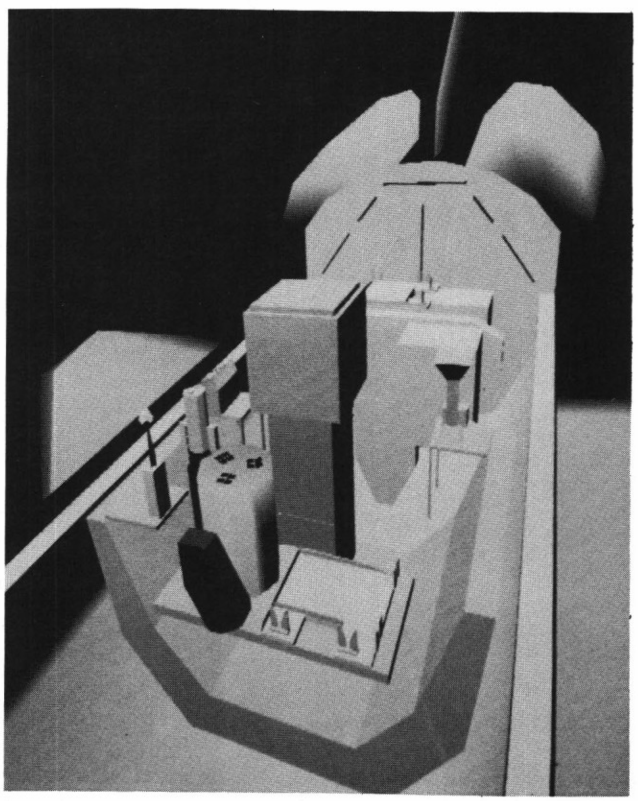

FIGURE 10. STS-3 OSS-1 and DFI Payloads

The STS-3 payload modeling alone required 3168 visual face boundaries. This detailed imagery brought the CCTV DIG hardware past its limit of 256 image edge intersections per scanline when two detailed payload scenes were selected on the CCTV monitors. The aft DIG with a 512 intersection limit has no such problem. To reduce the number of intersections slightly the Orbiter exterior normally not seen was eliminating saving 519 visual and 192 occlusion object face boundaries. The old version was retained, however, and was used again for nose tile inspection procedures checkout in the SMS during the STS-3 flight. The data below summarizes the CCTV/aft DIG face boundaries used for STS-3 simulation:

	Visual	Occlusion	Total
Stars (overhead windows only	1079	0	1079
Sun, Moon, Earth	489	0	489
Simplified Orbiter exterior (complex 1075)	220	144	364
Payload bay, bulkheads, and 7 lights	176	720	896
Payload bay doors and radiator panels	488	1632	2120
RMS (one arm)	544	720	1264
5 cameras/pan tilt units (344 each)	520	1200	1720
STS-3 OSS-1 payload	2188	912	3100
STS-3 DFI, REM/IECM payloads	980	864	1844
Total number of face boundaries	6684	6192	12876

A PAM (Payload Assist Module) spacecraft is planned for boosting a payload into a high altitude orbit. Figure 11 shows an aft view of two PAM D spacecraft modeled in the SMS with three DFI containers shown in the foreground. The horizon sensors of the PAM's are protected in the payload bay by sunshields. The sunshields have been retracted to deploy the aft PAM. The PAM's are spin-stabilized then ejected by springs. Potentially, four PAM D's may be deployed on a single flight.

The PAM's are modeled with a "generic" payload that uses the allotted payload volume. Thus, only one PAM model is needed. Each PAM D, including sunshields, require 1425 face boundaries (27 visual objects modeled with 561 face boundaries and 36 occlusion object boxes modeled with 864 face boundaries).

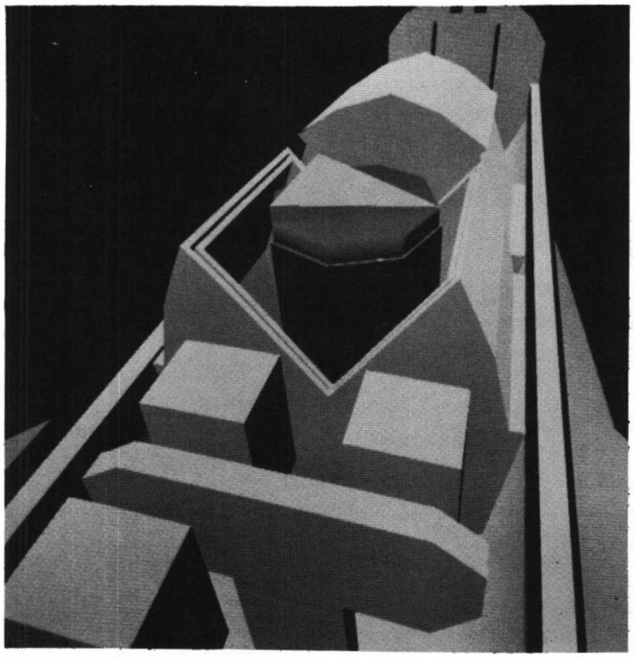

FIGURE 11. DFI and 2 PAM D's
(Sunshields closed on one)

Stars and Miscellaneous Objects

Stars

The DIG generates 1079 stars, enabling recognition of any constellation. Stars are displayed in the forward and overhead window displays where navigational star sightings are performed. Stars are not needed in the aft windows or in the CCTV system.

RCS Jet Firings

Dim orange-colored plumes from four forward RCS (Reaction Control Subsystem) up and side firing jets on the Orbiter's nose are visible at nighttime. These primary RCS jet plumes were modeled with orange triangles or cones to give visual confirmation of nighttime attitude control jet firings. The jet plumes are normally positioned out of the field-of-view of the forward windows. While a jet is firing, its plume image is repositioned into the appropriate windows. This simulation was first implemented for STS-5 training.

SRB Separation Flash

The orange-colored flash from the SRB (Solid Rocket Booster) separation motor-firing covers the front windows. This gives visual confirmation of the SRB separation event which occurs typically two minutes five seconds after liftoff from the launch pad. (The actual SRB's are not seen from the spacecraft windows.) This simulation is handled like RCS jet firings; that is, an orange object is positioned to cover all of the front windows while the SRB separation motors are firing.

Sun, Moon, and Earth

The sun, moon and earth are treated as special two-dimensional miscellaneous objects in the CCTV and the aft windows. Although these objects move, they need not be counted among the 48+ moving objects allowed in the payload bay. This advantage results from the fact that their occlusion priority never changes; that is, payload objects always may occlude the earth. The earth is always closer than the moon and may occlude it. The moon always may occlude the sun, and the sun may always be in front of stars.

Likewise, in the forward window DIG systems the sun, moon, RCS jet plumes, and the SRB flash are treated uniquely as miscellaneous objects. These special moving objects are not counted among any two moving objects (such as the external fuel tank or deployable payloads) allowed to be simultaneously displayed in the forward windows.

Two Current Visual Simulation Problems

Daytime Lighting in SMS Crew Stations

The Orbiter receives a lot of sunlight through its ten windows. Stars are not visible in daytime. Thus, navigational star sightings are not possible until the crewman's eyes have had time to dark adapt after sundown. The SMS crew stations, however, have a relatively dark environment day or night, as have all the previous spaceflight mission simulators at the NASA JSC. This dark environment is due to the inability of the visual displays to provide real-world daytime illumination levels through the windows. Thus, in the SMS eyes can remain relatively dark adapted and stars may be seen/navigational star sightings performed even in daytime.

The first approach to the problem of the sun in the windows was to call attention to the fact that the sun was present. The size of the sun was increased from 1/2 degree diameter to a 35 degree diameter sunglare model. It washed out stars in its proximity but could not, of course, provide bright solar illumination into the crew station. Realistic sunshine through the windows is difficult, and not considered feasible for the SMS, but a simple solution is being investigated: auxillary lights in the crew station which are automatically turned on whenever the Orbiter is in sunshine.

Partly-Cloudy Landing Site Conditions

Partly-cloudy skies usually are present at the Kennedy Space Center, the primary landing site for ongoing operational space shuttle flights. Clouds may obscure visual approach and landing cues. The SMS presently has no partly-cloudy sky capability. Either a clear sky or a solid overcast sky may be simulated. Height and thickness of a cloud deck may be selected by the SMS operator.

Modeling individual clouds is time-consuming and requires much scene detail that otherwise could be used for landing scene ground features. Hence, there is a reluctance to expend much image generating capacity for clouds.

A solution under investigation is to model identically shaped cloud cells arranged in a regular pattern, somewhat like stratocumulus clouds. Initial study quickly verified that because of the relatively shallow viewing angles used (19 degrees glide slope) the number of cloud cells needed for a given amount of ground feature obscuration may be greatly reduced by using thicker clouds.

Identically shaped and regularly spaced clouds minimize false training cues from unique cloud shapes and patterns. Several versions of the clouds may be needed to prevent the trainee from quickly learning where to expect to see a given ground feature in relation to the fixed cloud pattern. Moving cloud patterns, if feasible, would eliminate this problem.

Only one cloud need be modeled, which is replicated at all other cloud cell positions. Cloud cells which conceivably may be flown through have to be modeled inside and out. Normally only the outside surface of a cloud or any 3D object needs to be modeled. But unless the cloud surface is modeled to appear from the inside, the cloud simply disappears when one flies into it.

Generation of New Visual Imagery

New imagery is generated through use of a digitizing table. The table may be connected to any of five Interdata 8/32 computers operating offline from the SMS. An associated TV monitor displays the scene as it is being built up by the modeler. The constructed scenes may be checked out with the use of a flight control panel operating with the DIG offline from the SMS. (See Figure 12.)

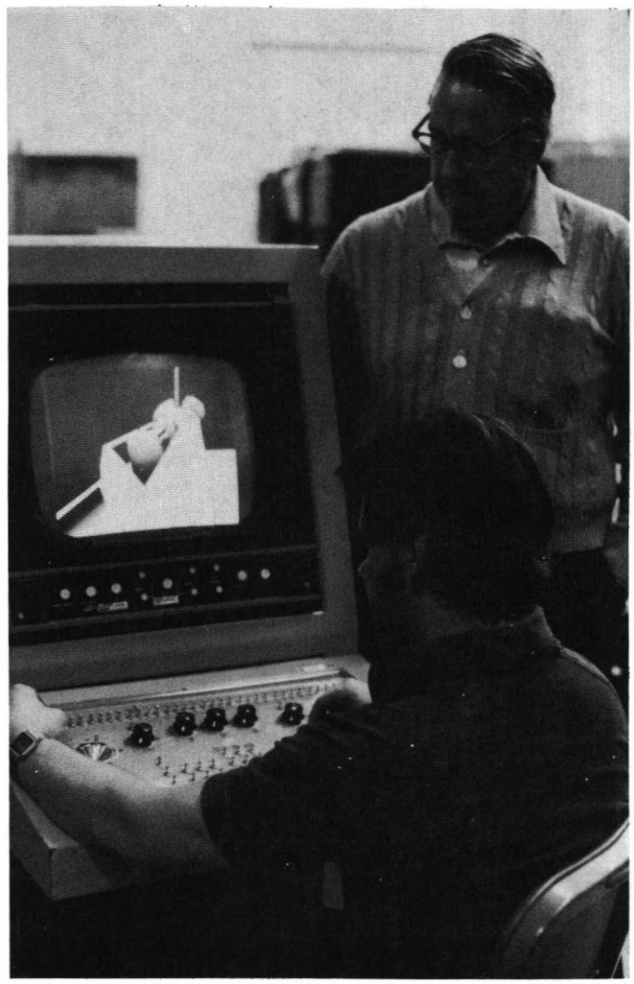

FIGURE 12. Checkout of SMS Visual Imagery

Conclusions

Computer generated visual imagery has proved to be a versatile image generation method adequate to meet current SMS visual simulation requirements. Important visual scenes have been quickly and efficiently created for the earth, landing sites, payloads, and other visual phenomena/objects that heretofore would have been impossible to adequately simulate. Continuing work on current problems and the application of the continuing development in computer image generation technology shows promise of providing an ever more realistic appearing visual environment in the Shuttle Mission Simulator and other simulators.