Visual Observations Over Oceans

R. D. Terry[a]

ABSTRACT

During the Apollo-Soyuz Test Project mission, visual observations of ocean features were successfully performed by the Apollo crewmen. Although three of the four ocean observation targets were cloud covered during the mission, observations of one scheduled target and of many targets of opportunity clearly demonstrated that astronauts could be trained to become excellent ocean observers. Previous space (but nonobservational) experience was found to be unimportant when compared with premission briefings and aircraft flyover exercises. Although the low spacecraft altitude (approximately 220 km) was excellent for Earth observations, the high relative velocity hampered target acquisition and created brief observational times of 5 to 20 seconds. The duration of the 9-day mission was insufficient to demonstrate any marked improvement in the "learning curve" of the crew.

Important factors in locating, identifying, describing, and photographing ocean features from space were (1) the presence or absence of sunglint, (2) water color, (3) clouds, (4) spacecraft altitude, (5) spacecraft attitude, (6) photographic equipment, (7) window fogging, (8) dual tasks, and (9) description as opposed to photography.

On the basis of crew comments and the findings of this author, the following recommendations can be made for Earth observations on Space Shuttle missions.

1. Flyover exercises must include observations and photography of both temperate and tropical/subtropical waters.
2. Sunglint must be included during some observations of ocean features.
3. Imaging remote sensors should be used together with conventional photographic systems to document visual observations.
4. Greater consideration must be given to scheduling Earth observation targets likely to be obscured by clouds.
5. An annotated photographic compilation of ocean features can be used as a training aid before the mission and as a reference book during space flight.

INTRODUCTION

The purposes of this specific investigation were (1) to evaluate the visual observation capabilities of spacecraft crews during a short-duration (9 day), low-altitude (220 km) orbital flight, (2) to contrast these capabilities with the capabilities developed during the 84-day Skylab 4 mission, and (3) to develop training techniques for making ocean observations and acquiring oceanographic data during orbital missions of the Space Shuttle and Spacelab vehicles. (Scientific results of oceanographic investigations are reported elsewhere in this volume.)

To achieve these purposes, observations and photographs of various ocean features were obtained during the Apollo-Soyuz Test Project (ASTP) as part of the Earth Observations and Photography Experiment. The simultaneous acquisition of ground-truth data by research vessels was also scheduled. Analyses of all these data helped answer the following questions.

1. What is the configuration of the "learning curve" for useful visual observations of the oceans

---

[a] Richard Terry & Associates/Environmental Science & Services, San Clemente, California.

by astronauts?

2. How do premission briefings contribute to observer performance as compared with previous space-flight experience?

3. What constraints are imposed upon visual observations by low-altitude, short-duration missions?

4. Is previous space (nonobservational) experience useful?

During the ASTP mission planning, four primary ocean targets were selected for observations and photography. These were the approaches to the English Channel and the Strait of Gibraltar, the Tasman Sea (off Australia), and the Kermadec Sea (off New Zealand). Many other visual observations of ocean features were planned in various parts of the world. However, this study will not include detailed analyses of the ocean targets, largely because other research, independent of this study, is being performed (ref. 1), and because this study is primarily concerned only with the answers to the four questions listed previously.

SOURCE MATERIALS

Visual Observation Comments

Visual observation comments made by the astronauts during ASTP are derived from the following NASA Lyndon B. Johnson Space Center (JSC) ASTP internal sources: (1) Technical Air-to-Ground Voice Transcription (JSC-09815), (2) Onboard Voice Transcription (JSC-09966), (3) onboard science tapes, (4) Visual Observations Debriefing (JSC-09920), and (5) Technical Crew Debriefing (JSC-09823). These five sources were compiled into a single document by El-Baz (ref. 2).

Photographs

A total of 2670 35-mm and 70-mm color photographs was taken during ASTP. Video-tape recordings were also made that included brief views of the ocean; however, these tapes were not examined as part of this study.

When 70-mm film was depleted, the crew used 35-mm film for Earth photography. Unfortunately, the 35-mm film was designated for indoor photography and was unsuitable for other purposes. Although color photographs on 35-mm film show clouds and gross features, subtle changes in ocean color and texture are undetectable.

Table I lists all ASTP photographs of the four targets established for ocean observations and concurrent surface investigations. Not all the photographs included in table I show the actual targets; they are listed because they are photographs taken near the targets. All photographs taken during ASTP are listed in the "Index to Onboard Photography," a JSC internal document prepared by Richard W. Underwood, and in NASA publication number TM 58218.

Ground-Truth Investigations

Ground-truth data were obtained during ASTP in four target areas. These are described in the following paragraphs.

Spanish Bight/Strait of Gibraltar

Ships and aircraft of the U.S. Navy acquired oceanographic data in the Spanish Bight/Strait of Gibraltar area. Included were P-3A *Orion* antisubmarine warfare (ASW) aircraft flying from the Azores. Air expendable bathythermograph (AXBT) instruments were dropped by these aircraft on July 19, 20, and 21, 1975. The oceanographic research vessel U.S.N.S. *Kane* obtained temperature/depth data along a northeasterly track toward the Spanish coast on July 21 and 22. The aircraft carrier U.S.S. *Kennedy* acquired Defense Meteorological Satellite Program (DMSP) imagery (visible and infrared) of the target on July 20. This imagery was sent to the U.S. Navy Weather Facility DMSP van, North Island, San Diego, California, for enhancement (ref. 1).

Tasman Sea

In the Tasman Sea, the Royal Australian Navy ship H.M.A.S. *Bombard* was stationed in the middle of one of the most intense warm-water eddies ever surveyed. The ANZUS eddy had a diameter of approximately 250 km and was nearly circular.

The *Bombard* was in the eddy, observing cloud and sea conditions, while making current speed and direction, temperature/depth, and sound-velocity measurements for 4 days. During the first 2 days, there were clear skies, with a well-developed formation of cumulus clouds over the eddy, and in the center were a dozen Japanese long-line tuna vessels. Unfortunately, a front moved through the area, making it impossible to see the eddy on the day of the ASTP observation. Previous researchers had identified the ANZUS eddy (refs. 3 to 5).

Kermadec Sea

The Royal New Zealand Air Force used P-3A *Orion* aircraft to observe and photograph conditions and to collect oceanographic and meteorological information along a 640-km (345 n. mi.) track extending from East Cape, New Zealand, northeastward toward the Kermadec Islands. The aircraft flew at an altitude of approximately 1500 m (5000 ft) on 3 consecutive days; the second was the day of the ASTP observation. In addition, the New Zealand Navy research vessel R/V *Tui* was in the same area, making a detailed survey of an eddy north of New Zealand. The eddy was identified by changes in sound velocities. On the day of the ASTP observation, oceans to the east of East Cape were obscured by clouds.

Approaches to the English Channel

To cover approaches to the English Channel, the Royal Air Force (RAF) flew *Nimrod* aircraft (converted *Comets*) westerly out of southern Ireland. The RAF dropped AXBT's along a 960-km (520 n. mi.) line. This area was also obscured by clouds during the visual observation experiment.

Scheduling of Events

Before the ASTP mission, a schedule of events, including Earth observations, was carefully planned, and an "ASTP Earth Observations

TABLE I.— ASTP Photographs of Ocean Test Sites

Geographic area	*Revolution*	*Photograph no., AST-*	*Film size, mm*
Spain/Gibraltar	73	27-2366, [a]27-2367, 27-2362 to 27-2365	70
	88	[a]24-1944	70
		11-684 to 11-688	35
Tasman Sea	123	20-1655 to 20-1659	70
Kemadec Sea	17	22-1776 to 22-1778, 1-036 to 1-040	70
	107	7-397 to 7-399	35
Approaches to English Channel	74	30-2541 to 30-2548	70
	119	20-1640 to 20-1644	70
	135	24-1948 to 24-1952	70
		10-599, 10-600	35

[a] Photograph of actual site, based on ASTP maps.

Book" was prepared for the astronauts. Ground-truth investigations were scheduled in accordance with the dates and times assigned for Earth observation passes. Although the spacecraft passed over or near each of the targets several times, additional visual observations were prevented because of scheduling conflicts. The first Earth observation pass was not completed until spacecraft revolution 17, approximately 33 hours after launch. Initially, only one crewmember was assigned to Earth observations during each pass; however, events occurred so quickly that eventually two or all three crewmembers became involved in Earth observations. In this way, it was considerably easier to obtain simultaneous visual observations and photographs.

For the Spanish/Gibraltar target, there were four possible opportunities to make visual observations: revolutions 43, 58, 73, and 88. Visual observation experiments were performed on revolutions 73 and 88, but the most important observation was made during revolution 73, when the site was in sunglint.

With the exception of the first 16 revolutions, there were at least 7 opportunities to observe the approaches to the English Channel (i.e., revolutions 44, 59, 74, 88, 104, 119, and 134). Earth observations were performed during 2 days on revolutions 74 and 134/135, but the areas were cloud covered.

The area of interest off the Australian coast was an eddy in the Tasman Sea near Sydney. Excluding early revolutions, there were only three possible passes (revolutions 108, 123, and 138) over the target; the Earth observation was attempted on revolution 123, but the area was obscured by clouds.

Off East Cape, New Zealand, the two possible revolutions for Earth observations were 17 and 32; one actual observation was made on revolution 17 when the site was cloud covered. The flightpaths of an additional seven or more revolutions passed over the target, at right angles to the flightpath of the P-3A *Orion* aircraft.

During the joint U.S.-U.S.S.R. operation, the Apollo spacecraft was at an altitude of approximately 183 km. After revolution 11, the altitude was increased, averaging approximately 220 km and varying between 165 and 237 km.

BACKGROUND

Since the Gemini flights, when the first ocean pictures were taken, there has been considerable interest in observing and photographing the world's oceans from space. During the early Apollo missions, emphasis was placed on obtaining photographs of ocean features, and some astronauts were briefed in oceanography before the Apollo 7 and 9 missions. However, few ground-truth investigations in support of orbital observations and photography were made before the Skylab 4 mission (refs. 6 and 7). The ASTP mission provided the second significant opportunity to perform visual observations of ocean features together with concurrent ground-truth investigations.

Ocean investigations on ASTP were planned through the efforts of Robert E. Stevenson, Office of Naval Research (ONR), Pasadena Branch Office, and Scientific Liaison Officer at the University of California, San Diego (La Jolla), California. The ocean observation project was directed by ONR in cooperation with the Smithsonian Institution; JSC; the Atlantic, Pacific, and Mediterranean units of the U.S. Navy; the RAF; the Royal Australian Navy; the New Zealand Defense Scientific Establishment; and the Royal New Zealand Air Force. Before and during ASTP, U.S. Navy Comdr. Robert F. Lawson (retired), also of the ONR Pasadena Office, coordinated all of the worldwide international military units gathering oceanographic data. An "Ocean Observations Desk" was set up at the JSC Mission Control Center during the critical days of the mission and was manned 24 hours a day by members of the Earth observations team.

As previously stated, four primary ocean targets were selected for observations and photography during the ASTP mission: the approaches to the English Channel and to the Strait of Gibraltar, the Tasman Sea, and the Kermadec Sea. There were several reasons for choosing these targets. First, they were on opposite sides of the world (antipodal) and large hydrodynamic features caused by the interaction of major ocean currents with landmasses could be examined. These areas had the following features in common: (1) a confluence of a major transoceanic current and a continent, (2) islands influencing the flow of the current, (3) indigenous coastal currents, (4) a coastal ocean modified by dominating winds, and (5) large-scale turbulence resulting partly from the interference of the adjacent landmasses.

There were also the following major differences: (1) mid-latitude waters (Western Europe) compared to subtropical waters (Australia and New Zealand), (2) current flow toward the Equator (Europe) contrasted with flow toward the South Pole (Australia and New Zealand), (3) a small as opposed to a large inland sea (the Irish Sea and the English Channel in contrast with the Tasman Sea), and (4) a current modified by inflow from a major inland sea (Mediterranean) contrasted with a current modified by a large island complex (New Zealand). Furthermore, there is a seasonal difference between the European summer and the Australian winter, but this difference has no effect on the hydrodynamic similarities.

Astronaut observations of ocean areas were also planned for the Pacific Northwest, southern California, the western North Atlantic Ocean, the Caribbean and Mediterranean Seas, the northwest Indian Ocean, the Arabian Sea, the Arabian (Persian) Gulf, and targets of opportunity. In each case, the astronauts were asked to observe, describe, and photograph (1) ocean currents, (2) ocean fronts, (3) internal wave patterns, (4) eddies, and (5) combinations of features believed to exist in each area.

This particular study was focused on evaluating the visual observation capabilities of spacecraft crews during a short-duration, low-altitude orbital flight in contrast with the capabilities developed during the 84-day Skylab 4 mission, and on determining the applicability of the observations to the oceanography requirements of tactical fleet units. It should be strongly emphasized that the primary task of each astronaut was to describe the ocean scene in as much detail as possible, without making more than the most obvious evaluations and interpretations of observed features. In short, the crewman was to be an observer; he was not expected to be an oceanographer or a maritime meteorologist. The ASTP crewmen were given 16 hours of briefings in oceanography before the mission so that each crewmember would be able to recognize pertinent ocean features. Briefings included lectures on fundamentals of ocean current systems, ocean dynamics, air/sea interaction, and the visible sea-surface/marine-atmosphere manifestations of features of interest. (These discussions were conducted by George Maul, Atlantic Oceanographic Laboratory of the National Oceanic and Atmospheric Administration, and Robert E. Stevenson of the ONR.) Furthermore, the crew was involved in flyover exercises off the southern California coast, the Gulf of Mexico, and the eastern coast of the United States. The purpose of the flyovers was to give the crew practical experience in observing from the air features such as upwelling, bow waves, island wakes, internal waves, sediments (off river mouths, plumes, and indicators of water movement), wave refraction, gyres and eddies, scum lines, texture and water color, current boundaries (delineated by water color and/or texture), and sunglint. As a result of the briefings and flyovers, the ASTP crew had more oceanographic training than any other NASA flightcrew. However, only one of the astronauts, the Apollo commander (ACDR), had previous space experience. He had flown on the Gemini VI mission (25 hours 51 minutes), the Gemini IX mission (72 hours 21 minutes), and the Apollo 10 mission (192 hours 3 minutes), for a total of 290 hours 15 minutes, before the 9-day ASTP mission.

IMPORTANCE OF SPACE EXPERIENCE AND THE LEARNING CURVE

Introduction

The primary source of information used to determine the learning curve in making useful visual observations of ocean features was the transcript of astronaut comments made during the ASTP mission (ref. 2). The debriefing transcripts were less important because they did not accurately portray real-time learning. To gain a proper perspective of the learning progress, it seems worthwhile to summarize the astronauts' real-time comments, which can be found in reference 2. The following paragraphs summarize longer comments made by the astronauts during the mission and omit short chats of no value. Specific and relevant comments are quoted; however, certain editorial liberties are used to make the commentaries more understandable.

Visual Observations

Revolution 17: During the first visual observation pass off East Cape, New Zealand, the land area was cloud covered, and there was little to observe in the water to the east, or between North and South Islands. The astronauts were uncertain about whether they were observing plankton, scum, or sea floor. The ACDR called the discolored water "plankton," although the command module pilot (CMP) thought it might be the bottom. However, a few seconds later, the CMP evidently had a different opinion and called it "scum," which could be plankton. Several photographs were taken of the area with the 70- and 35-mm cameras. Thus, NASA photograph AST-22-1777 (fig. 1) shows the coastline and a discoloration in the water. A second photograph, AST-1-037, shows similar features in the water, but the coastline is not visible. The structure of the discoloration is not typical of the sea floor, and it is therefore concluded that the features in the water are due to sediment or plankton. The onboard conversation suggests that possibly the two men were looking at different features at different times, and that the CMP had perhaps initially seen the sea floor and then had later seen the scum or plankton.

During this first visual observation pass, the crew quickly and accurately ascertained the problem inherent in using a color chart inside the spacecraft to determine water color. The color was decidedly different when viewed in shade and in sunlight.

Revolution 19: The ACDR indicated that it was possible to see much more detail at the current 177-km ASTP altitude than at the 225- to 300-km altitudes flown during Gemini missions. He also stated that everything appeared much closer and that everything moved much more quickly past him.

Revolution 39: The docking module pilot (DMP) gave a brief description of sediment plumes off the East African coast and even suggested that there were cold-water gyres spinning off currents.

Revolution 42: The DMP commented about large Bénard cells in the Atlantic Ocean and about the lack of eddies in the Mediterranean Sea: "It's a completely homogeneous surface down there."

Revolution 64: The CMP was looking for eddies in the Coral Sea and ended his Earth observations with the comment that he saw what appeared to be numerous eddies; he correlated cloud rings with eddies in this area and elsewhere in the southwestern Pacific Ocean (fig. 2).

Revolution 72: The DMP was unable to observe the Falkland Current, but he photographed the clouds because "the cloud patterns . . . may have been the current." Then, he added, "If that's typical of Gulf Stream operations, it could be the same down here."

As the spacecraft passed over the Libyan Desert, near Tripoli, the DMP observed: "Coming up on another very hazy area again. Ah, that's because we're right on the coastline." Then, ". . . there's some very light color along the coastline. I think that's probably due to shoals rather than any current flow . . . ." The DMP also mentioned an "unusual cloud pattern, that . . . probably defines a large current . . . ."

Revolution 73: The ACDR tried to locate a current boundary and noted that he could not see wakes around islands, or visible currents off the west coast of Africa.

As the spacecraft approached the observation target near the Spanish coast, the ACDR could see neither internal waves east of Gibraltar nor current boundaries to the west. But as the spacecraft got closer to Spain and the Sun angle changed so that the ocean was in the Sun's glitter, the ACDR recorded: "Oh, now I see these internal waves; there (they) are. All those waves and the boundary off the coastline . . . ." (fig. 3).

The plumes of the Rhône River, emptying into the Mediterranean, were noted but were not further described.

By revolution 74, the crew was seriously complaining about the spacecraft attitude for conducting Earth observations.

Revolution 78: The CMP commented: ". . . it

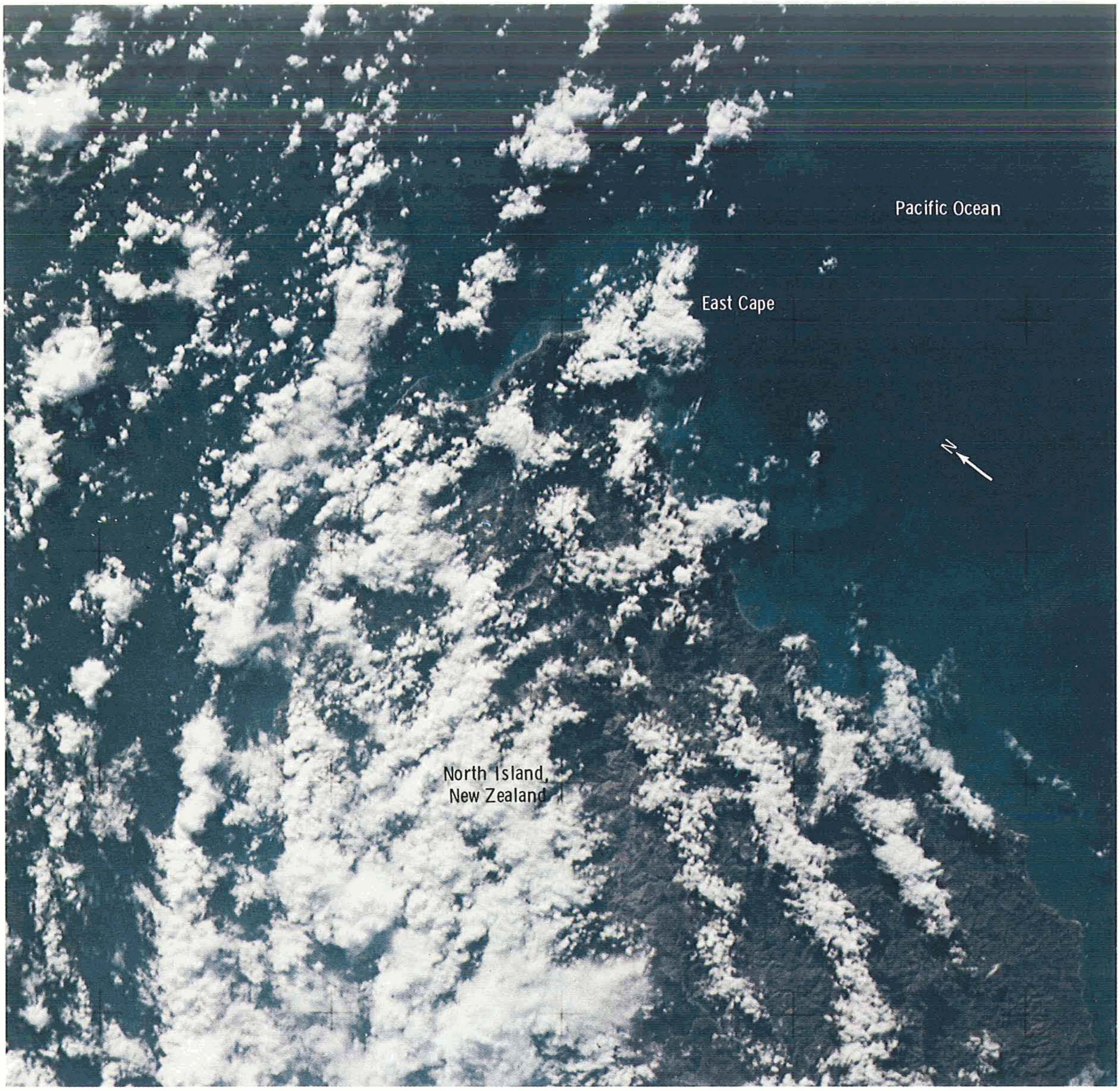

FIGURE 1.—East Cape, New Zealand. Discolored water, possibly caused by plankton or sediment (AST-22-1777).

looks like the Pacific is just full of eddies. Great big eddies . . . we think they are eddies because they are giant cloud-ringed areas that sort of make you think the water there is either hotter or colder than the rest . . . . They're all sizes." Later, the eddies were estimated to be 10 to 15 km in diameter, with some measuring tens of kilometers.

Revolution 79: Off Australia, the ACDR observed "some beautiful internal waves right off the coastline . . . . It's just like off Gibraltar. Certain Sun angles, you couldn't see . . ." (He could see nothing.)

Near the Marshall Islands, the DMP recorded: ". . . I'm passing a very distinctive cloud line laying off across the water which probably marks the

FIGURE 2.—Typical cloud-ring structure in the South Pacific Ocean, identified by the ASTP crew as an ocean eddy (AST-2-111).

FIGURE 3.—Oceanographic features off the Spanish coast. According to R. E. Stevenson, the features observable in this photograph are internal waves; the first sequence marks the boundary of the Huelva Front, and the roughened sea surface marks the straight current shear on the edge of the Tarif eddy. The shear, first seen by the ACDR (Maj. Gen. Thomas Stafford), is now known as the Stafford Shear (AST-27-2367).

edge of a current or an eddy, it's so distinct. However, it's not a convective cloud feature . . . ." The next day, they added to this observation as follows: ". . . there was a line of circles . . . running east-west. And it looked like a line of circles—like a chain . . . . And if you looked at one of those, and you could see them only because of the clouds, and it just made us wonder if maybe that was, perhaps, the boundary of a current . . . (they) must have been 100 to 200 miles long." Thus, cloud patterns were being used to draw major conclusions about ocean features. Unfortunately, the astronauts had little to say about ocean color or sea-surface texture on either side of the cloud lines. Later, when reminded of this, they agreed to look more closely.

Revolution 90/91: The DMP reported a series of small (12 km) eddies off Yucatán, "typical of the other eddies we see." He was unable to observe the Gulf Loop Current in the Gulf of Mexico; there was some cloud cover, "and it doesn't seem to be any particular pattern that would define a current."

Revolution 91: As they passed over the region between Norfolk, Virginia, and Cape Cod, Massachusetts, the DMP commented on muddy rivers, but he observed no gyres. The CMP and the DMP also observed "a cloud flow pattern coming over the tip of (an) island," and suggested, "cloud patterns may give a clue to the current." By revolution 91, after performing many Earth visual observations, the crew had concluded that Earth observation was at least a two-man job, and later they indicated that all three crewmembers were participating.

Revolution 104: The seaward limit of the muddy waters of the Orinoco River was determined on the basis of water-color changes.

Revolution 105/106: While over the New England coast during revolution 105/106, the DMP commented: "We're having trouble telling sunglint from red tide . . . . In addition to this highly important qualifying factor, the crew further decided that in the area where red tide was supposed to occur (i.e., near Boothbay Harbor, Maine), the water color was "obviously sediment . . . . And we're trying to differentiate if it's really a red tide or red sediment." They explained that some of the red coloration was obviously red river sediment because they could trace the same color clearly up the river. Both during the mission and during the debriefings, they refused to state categorically that they had seen red tide, stressing the influence of the reddish color in sunglint and the obviously sediment-laden waters of the river.

Revolution 112: The DMP commented on the enormous sediment plume of the Yangtze River and added: "And I think they showed pretty much how the current flows—rather, the coastal area or the area offshore." He also observed some outstanding internal waves in the Andaman Sea, off Thailand (fig. 4).

Revolution 123: For several days before the observations of ANZUS eddy, the Australian Navy reported that a large cumulus cloud was located directly over the eddy. Shortly before the Earth observation on revolution 123, a front moved through the area, and the ACDR reported that the area was "totally cloud covered." Approximately 320 km (175 n. mi.) east and south of the Hawaiian Islands, the crew observed "countless" eddies (as determined by rings of clouds), and the DMP observed the edge of a current and gyres. The crew also observed a small gyre or eddy with a cloud in the middle, along the edge of a current running east-west: "The cloud banners on both sides and clouds within it look a good deal like a Gulf Stream type of current."

Revolution 124: The CMP noted that, off the east coast of Australia, suspended sediments were always near shore, never extending to, or beyond, the Great Barrier Reef. A distinct island wake and a "boundary" near an island off Australia were noted conclusively by a change in water color. The CMP concluded, "that if I see sediments, I can't describe them too well." Following an earlier request to observe ocean texture where eddies were said to occur (i.e., eddies that were identified solely on the basis of linear or circular clouds), the CMP photographed an eddy in the Pacific Ocean in sunglint and tried to describe its texture as follows: "I see a slight textural change in (the) Sun, but it's so slight I can hardly describe it." He made a further observation that ". . . there were cumulus clouds emanating out of the side and sort of the interior of it . . . ."

By this time in the mission, the crew was ob-

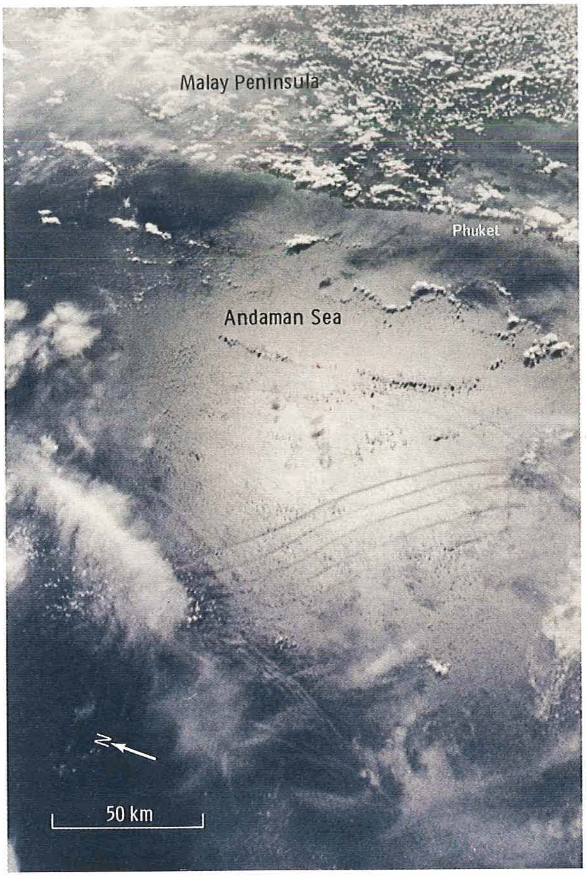

FIGURE 4.—Large internal waves in the Andaman Sea, off Thailand. Also note the linear, ribbonlike cloud patterns parallel to and near the shore. These are frequently considered to be boundaries of currents (AST-7-427).

viously on the "look out" for features observable in sunglint: "Got a picture of an island . . . (with) a lot of sunglint around it . . . you may be able to see some current patterns . . . ." In addition, they were equally observant of the good relationship between linear and circular cloud patterns, and current boundaries. Thus, the CMP said: "Typical, rather linear cloud patterns in the mid-Pacific oriented east-west. I see this quite a bit. Makes you think it might be associated with the water current . . . . These cloud patterns go sometimes for hundreds of miles."

Revolution 134/135: As they crossed the coast of Central America and moved over the Atlantic Ocean, the ACDR observed "a boundary layer," and photographed "internal waves and could even be some big upwellings." Onboard, the CMP inquired about the upwelling, and also agreed that "there is a thing that looks like an upwelling," approximately 30 km (15 n. mi.) offshore.

Later in the same revolution, the ACDR reported: "I just couldn't see a Gulf Stream boundary . . . or the Caribbean Current . . . . There's no differentiation in colors." A few moments later, he said, ". . . boundary right in the Atlantic Ocean . . . we have a boundary of (a) current from light blue to dark . . . ." This observation was made near Bermuda.

All three crewmembers observed the "tremendous sediment plumes" of the Danube Delta. The DMP remarked that the Danube water appeared to be "running right across the Black Sea."

Revolution 135/136: The crew was prepared for observing the Gulf Loop Current and/or internal waves. During revolution 135/136, the ACDR first noticed an eddy in the Gulf of Mexico; then, the DMP said that he thought he saw the Gulf Loop Current, but quickly added that there was a "total change in cloud pattern . . . ." The area off Monterrey, Mexico, was cloud covered, "but there's then a line of clouds that come right up around—almost follows the contour of the coast. I would guess it might very well be the Gulf Loop Current we're looking at. The problem is I can't see it off to the north." The ACDR commented again on the eddy, and he and the DMP then observed the eddies, but did not describe them further. They could see boat wakes off the Mississippi Delta, and they noted the water-color change in the delta area.

Farther up the east coast, suspended sediments, plumes, gyres, and pollution were briefly mentioned during flight over the Potomac River, Chesapeake Bay, and New York Harbor. The crew again attempted to identify red tide in the Boothbay Harbor region, but the DMP had to admit (after several passes) that he was uncertain about seeing red tide such as he had observed off the west coast during a flyover exercise. He also said that he had not seen any oil slicks, "And I think we probably wouldn't, generally, without having some sunglint." A little later, when over the Atlantic Ocean, the DMP added: "You know, (with) the combination of the cloud cover and the

Sun angle, we could have oil all over and we'd never know the difference."

Discussion

From these brief statements made by the crew, it is evident that extreme caution must be exercised in arriving at conclusions about the learning curve, the importance of previous space-flight (but nonobservational) experience, and other related factors. One reason for caution can be shown by the number of words spoken. The complete transcript of visual observation comments amounts to approximately 24 000 words, including technical discussions, air-to-ground transmissions, and so forth. Approximately 7500 words, totaling approximately 50 minutes of conversation, actually deal with visual observations of ocean features. This total averages approximately 17 minutes per crewman, which is quite insignificant. Another reason for caution is that three of the four targets established specifically for simultaneous ground-truth investigations and visual observations were obscured by clouds. This left only one brief visual observation supported with ground-truth data, i.e., the Spanish Bight/Strait of Gibraltar.

After the mission, Stevenson studied the ground-truth data and the visual observations and photographs of the Strait of Gibraltar. He indicated that the Atlantic Ocean west of the strait showed the following oceanographic features: (1) the Portuguese upwelling zone, (2) the Huelva Front, (3) warm surface water over the Spanish shelf, (4) a flow of warm water into the Mediterranean Sea, (5) upwelling off southern Spain with an associated sequence of warm-core eddies, (6) upwelling and turbulent eddies off the Atlantic coast of Morocco, and (7) an irregularly shaped area of warm water seemingly trapped west of Gibraltar.

In the Strait of Gibraltar area, the ACDR observed internal waves and a boundary off the coast of Spain (fig. 3). These features were visible only in the Sun's glitter; therefore, his field of view was significantly restricted. Because of the low altitude and the high groundspeed, the ACDR had only approximately 10 seconds to view the scene in sunglint; nevertheless, he did verify the presence of some of the ocean features that Stevenson (ref. 1) had described in considerable detail. It is important to note that the ASTP crew saw some of the features off Spain they had been trained to look for, and to recognize, during premission briefings and flyover exercises.

As discussed later, there were a number of constraints on good visual observations, but it should be emphasized that sunglint was the most important factor in observing the features off Spain. Although not all ocean features require Sun glitter in order to be visible, the ACDR's experience in observing the ocean features off the Strait of Gibraltar focuses attention on the necessity for pre-space-flight training that includes discussion of sunglint.

An effort was made to determine the learning curves of the ASTP crewmen by studying the changes in the observational capabilities of each crewmember as the mission progressed and by comparing the ACDR's learning curve with the curves for the other crewmembers to determine the importance of previous space experience. To do this, all Earth observation comments made by each crewmember were extracted. These extracts were examined first in a cursory manner for general impressions, then in detail for indications of improved learning. The extracts were also compared in detail for evidence of greater or less ability and/or improved Earth observation proficiency among the entire crew. Special attention was given to comparing the ACDR's learning curve with those of the other two crewmembers. Obvious inherent difficulties in making these comparisons include the following facts: (1) statistically, the data (for three men, during only 9 days) are meager, (2) evaluation may assume that the three men are identical in every respect—an illogical assumption, and (3) the brevity of Earth observation comments may make meaningful conclusions impossible.

During debriefings, the astronauts were asked if they felt more confident as the mission progressed. The CMP responded: "There's a learning curve." The DMP added that during the early part of the mission, the astronauts were "about four times busier than we really expected to be. We felt like we didn't really have time to prepare properly . . . ." With more experience, and with all three men engaged in Earth observations, the DMP thought they obtained reasonably good results.

A combination of factors contributed to the learning curve. These included (1) an increase in crew involvement and cooperation, (2) a change in spacecraft attitude for easier viewing, (3) an improvement in the crew's ability to select the best camera/lens combination, (4) the use of sunglint to observe ocean features, and (5) an improvement in verbal descriptions as the crew learned to recognize features. The visual observation experience led the crew to make specific recommendations for a manned Earth observation ball, or turretlike module, equipped with sighting devices, quick reference navigational aids, and other items, for future space flights that include Earth observations.

Although quantitative evidence is lacking about the learning curve of the ASTP crew with respect to Earth observations, several possible scenarios may illustrate and encompass what is known.

First scenario: An untrained observer asked to look for ocean features off Spain might or might not have visually followed the entire sweep, from when the ocean waters off Spain first became visible in the distance until the ocean features became clear in a vertical view in the Sun's glitter. An untrained observer might have prematurely concluded that nothing was visible in the area because the water appeared uniformly blue in color. Thus, his attention might have wandered, or he might have been distracted for a few seconds, or he might have moved from the observation window. A few seconds would suffice since the scene in the Sun's glitter would last only a few seconds. Clearly, an untrained observer would not have understood air/sea interactions, and probably would not have known the significance of subtle changes in water color and texture. Similarly, the ACDR admitted that, before the ASTP ocean briefings, he was totally unaware of the meaning of the many ocean features that he had seen during previous space flights.

Second scenario: Assume an ASTP crew with more than 16 hours of premission oceanographic briefings and flyovers in which various ocean features were shown and explained. These training exercises demonstrated to the crew the importance of Sun glitter in accentuating certain features. Consequently, the trained observer did not let his eyes wander when a target was coming into view; therefore, when the ocean scene changed in sunglint, he was ready to verify whether the predicted ocean features were indeed present. Throughout ASTP, there were many such targets that tested the ability of the crewmen to recognize chance ocean features and air/sea interactions.

Third scenario: The ACDR had the same amount of Earth observations' training as the other two crewmembers, but he also had considerable space-flight experience. During Earth observations briefings, the ACDR indicated that during other space flights he had seen many of the features that were of interest to oceanographers, but he was unaware of their origin or importance. Thus, before the briefings, the ACDR was almost like the untrained observer depicted in the first scenario. Possibly, the ACDR was the first to recognize and learn about ocean features observed from space during the briefings, although there is no way of proving this advantage. However, it is evident that all members of the ASTP crew learned to recognize ocean features from briefings and flyovers.

Thus, there is no conclusive proof that nonobservational space experience is particularly beneficial. Certainly, the ACDR was the first crewmember to complain seriously about the spacecraft attitude for visual observation. Yet, the DMP, with no space experience, provided some of the longest descriptions of cloud systems. This could mean that the DMP had more experience in meteorology, or simply that he was more verbose.

It is impossible to judge quantitatively the oceanographic and observational abilities of each crewmember, because of the paucity of conversational ocean-feature discussions. Based on the transcripts, it appears that the most important factors are the quantity and quality of the briefings on ocean phenomena and of the flyover exercises. Throughout the 9-day ASTP mission, the astronauts' comments were similar and reflect similar learning from briefings and flyover exercises. For example, each crewmember showed heavy reliance on using circular and linear cloud patterns to identify eddies and current boundaries; yet, they are not known to have seen differences in water color or texture on either side of the clouds to make a perfect cloud/ocean boundary correlation. They had to be asked during the mission to verify changes in water color and texture on either side of the clouds because of their total reliance on clouds to delineate water systems. In other words, during briefings, they had been trained to recognize linear clouds encompassing current boundaries and the circular cloud systems of eddies.

According to Stevenson et al., the Skylab 4 crew began to improve noticeably in Earth observation descriptions after approximately 2 weeks in space (ref. 6). Because of the higher altitude of the Skylab spacecraft, the acquisition/observation time at each target was approximately 40 to 45 seconds, compared with 5 to 20 seconds for ASTP. Longer visual observation times greatly enhanced the crewmen's ability to observe and learn. Another obvious factor was the much longer time spent in space by the Skylab 4 crew—84 days, compared to 9 days for ASTP. These two factors unquestionably had an important role in differences of learning curves for the two missions. The ASTP crew had an extremely short acquisition/observation time, which resulted in brief verbal descriptions; complete crew attention was focused on making the observation and/or photographing the target, and on the need to do this quickly. The short observation times, with one target quickly following another, left the crew little time to view, to study, and to reflect upon—or even to record—their observations or impressions. On the other hand, the Skylab 4 crew had much more time to prepare themselves mentally before and after target acquisition and observation. The importance of time cannot be overemphasized; it represents a major difference between a low-altitude, short-duration mission and one of long duration and high altitude. The evidence is conclusive: the ASTP crewmen were always pressed for time with no time to digest, describe, photograph, or evaluate what was seen.

Conclusions

Responses to the four questions posed in the introduction to this paper are presented in the following paragraphs.

On the basis of the experimental results, it does not appear that previous nonobservational spaceflight experience is as significant as premission briefings and flyovers. The assumption that the ACDR may have learned more rapidly during briefings cannot be proved. The three astronauts appear to have similar Earth observation capabilities, a strong indication that the 16 hours of briefings and the flyover experience were dominant factors in the learning process for performing useful visual observations.

Although it is difficult to depict quantitatively the configuration of the learning curve for useful visual observations of the oceans by the ASTP crewmen, it is suggested that it may resemble figure 5. Increasing experience and learning are shown by progressively heavier shading. Thus, "no prior space experience" is shown as blank. As learning increases and as more experience is

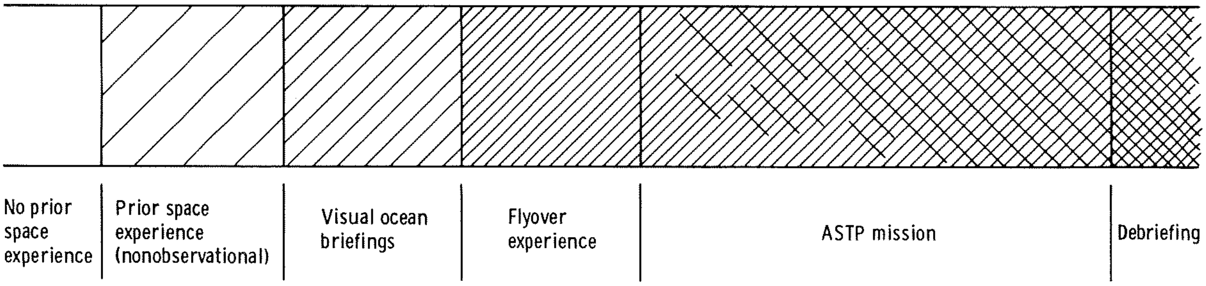

FIGURE 5.—Graph indicating increase in proficiency of ASTP crewmen for making visual observations of ocean features. The density of shading is directly proportional to the increase in proficiency, or "learning."

gained, including the actual space flight and, to some extent, during debriefings, the depth of experience and learning increases (shown by progressively heavier shading).

Space-flight experience exposes the inquiring mind to diverse and spectacular oceanic and atmospheric features. After a space flight, an astronaut might read or be told something about one or more of the features that he had observed and photographed. However, it is unlikely that most astronauts would have pursued the subject in depth. Hence, an untrained observer in space may be compared to a traveler who drives through spectacular scenery and appreciates the view, but does not delve too deeply into the natural history of the area such as the geology or the flora and fauna.

However, premission briefings, if well prepared and presented, can give the astronaut a broad background in oceanography and an understanding of the specific features or phenomena that are clearly discernible from space. Using the analogy of a traveler, briefings might incorporate a park ranger who provides lectures on sights observable from a highway or trails. He might describe the general geology and the principal animals, birds, and trees. This would give the traveler a much better insight into the scenery, but he would have no practical experience in testing and expanding this newly acquired knowledge.

For the astronauts, additional practical experience would be gained during high-altitude ocean flyovers. The traveler, experiencing the same type of learning, would engage in a field trip, carrying a geologic map and a small guidebook to identify common animals and plants. During the flyovers, the astronaut would see many ocean features to be observed later from space. Because he is in control of the aircraft, he can alter its course to make repeated observations of a specific feature, such as those that can only be seen in sunglint. Thus, he is able to observe and learn in a familiar, nonhostile environment. (The latter factor may have been of significant advantage to the ACDR with his 290 hours of space experience, because he would, perhaps, be more comfortable than the other two crewmen without space experience.) The traveler would be able to recognize major geologic features of scenery and to identify the larger animals, birds, and trees. Neither the astronaut nor the traveler would be considered a competent oceanographer or naturalist, but both would be able to carry out more profound observations in unexplored areas and to make important scientific contributions. Whatever was seen, reported, or described would be greatly influenced by information obtained during briefings (lectures) and flyover (field) experiences.

During space flight, additional learning occurs, primarily by (1) the experience gained by the application of newly acquired information in recognizing and describing features, (2) discussions among the crew, each sharing total knowledge and experience, by brainstorming, and (3) ground-to-air transmissions providing new or updated information, new targets and descriptions, and other data. All of these factors would contribute to a cumulative learning process.

It is known that after approximately 2 weeks in space, Skylab 4 astronauts showed a marked improvement in Earth observations. Apparently, 9 days in space, in a low-altitude mission, was not sufficient to demonstrate such a marked improvement.

FACTORS AFFECTING VISUAL OBSERVATIONS

The following items were identified as major factors in the location, identification, and photography of ocean features during ASTP.

Sunglint

Sunglint, or the reflection of sunlight off a water surface, was considered the most important factor in the identification of certain ocean features, particularly those not associated with distinctive cloud patterns. For example, during the ASTP debriefing, the ACDR talked about the importance of sunglint in observing ocean features during the California flyovers: ". . . you'd go one way and could see some of the (internal) waves and some gyres. If you turned around and (flew) down the other way with a different Sun angle, there would be nothing but blue. I was looking for all these things and suddenly they popped out within a second, right there. Just suddenly when the Sun angle changed, everything was there; the waves and the boundary were all there . . . . But before that, there was nothing but just solid blue water—they just suddenly popped." Furthermore, during the ASTP mission, many ocean features were not visible in sunglint for more than approximately 5 to 10 seconds; therefore, it was mandatory to be prepared. The Sun glitter appears in the field of view "instantaneously" and disappears just as quickly. As soon as the Sun angle changes, the glitter pattern is lost.

On revolution 73, the ACDR was looking for the Huelva Front and for internal waves west of the Strait of Gibraltar. He dictated into the tape recorder as follows: "See no current boundaries west of Gibraltar, there." Visibility was good, and he could see the wakes of more than 15 ships in the Atlantic Ocean west of Gibraltar. Interestingly, the crewmen later said that they were able to see ship wakes with or without sunglint. Then, as they approached the target, the ACDR said: "Oh, now I see those internal waves; there (they) are! Right there! All those waves and the boundary off the coastline. The Sun angle changed. There they are, all of them. I couldn't see them before due to the Sun angle. Just got them, a whole series of them." Later, he recorded: "I could really see those internal waves from Gibraltar . . . right at the very last (minute) when the Sun angle changed. That's fantastic out there. You couldn't see them at all from a different Sun angle, though." Again, off the southern coast of Cuba, the ACDR commented: "Look at those big (internal waves) just suddenly pop up . . . ."

It was fortuitous that the target off the Spanish coast was observed in Sun glitter, because if it had not been highlighted in the glitter, it assuredly would not have been observed in the detail described. Instead, the target would probably have had the appearance of nothing more than blue water, with perhaps some indefinable features in the water. It follows that if the Earth observations for the Spanish site were scheduled on other spacecraft revolutions when the spacecraft passed near the site, the Sun angle might not have been optimum for visual observation of the site. This possibility emphasizes the need for careful planning of Earth observations.

Sun glitter may make it difficult to assess colors accurately. For example, while the ASTP crew was attempting to locate and observe red tide near Cape Cod, the DMP reported in an air-to-ground transmission: "We're having trouble telling sunglint from red tide . . . in this area." As a matter of fact, they could not accurately differentiate between red tide and muddy water, although they made an excellent evaluation about the source of the muddy water. The DMP also made the following comment about oil slick observations: "(with) . . . the combination of cloud cover and the Sun angle, we could have oil all over and we'd never know the difference." In addition, during crew debriefing, the crew mentioned problems in defining the seawardmost limit of muddy water from the Orinoco River, "because, in the sunglint, it does have a tendency to look a little tan or something."

Because sunglint is a rather local phenomenon, it cannot always be used to differentiate ocean features. The CMP commented: "In mid-ocean, you can plan on getting most of your data from clouds, and only once in a while getting it from sunglint—when you are especially lucky."

Water Color

Before the mission, a two-sided color wheel composed of carefully selected Munsell color chips was prepared to help the crewmen calibrate desert and ocean colors. According to the ASTP crew, it was difficult to determine ocean color with the color chart. When chart comparisons were made at the window, "the color chart had to be completely in the shade, with the same very bright (scene) out the window being contrasted. Your eye adapted to the bright thing and all the color chart colors tended to look very dark, and much the same because they were in the shadow. If you happen to have the Sun shining in the window, so that it's shining on the color chart just right, then you're in luck." On another occasion, the DMP commented: ". . . I don't have much luck with the color wheel because the wheel's in the shade, and what I'm looking at is in the Sun, and I get absolutely no correlation at all . . . ." Later, the CMP said: "The standard problem we have been having with the color chart is that you have to have it somehow in light so you can compare it with what's on the ground. It's very dark in the cabin compared to outside."

As indicated in the previous discussion about Sun glitter, it was difficult to differentiate red tide, muddy water, and sunglint because of the brownish color of the water in the glitter pattern. But without distinct water-color changes, major current boundaries could not even be located. The ACDR reported: "I just couldn't see a Gulf Stream boundary down there . . . . There's no differentiation in colors."

Water color was also highly effective in determining distances of freshwater outflows from major rivers, such as the Orinoco. However, there was sometimes confusion as to whether a change in water color could be attributed to the ocean bottom, to current boundaries, or to plankton (red tide); such was the case off New Zealand.

Clouds

In some cases, clouds could be used to identify certain ocean features, but they also obscured the ocean surface. In the debriefing, the ACDR said: "As far as the eddies and gyres (are concerned), the big thing that outlined those to me—and I think to everybody else—were those little clouds right around the edges of them. You can really see that. And a current boundary too. The clouds define it often." In the mid-Pacific, the DMP recorded: ". . . I'm passing a very distinctive cloud line laying off across the water which probably marks the edge of a current or an eddy, it's so distinct. However, it's not a convective cloud feature . . . ."

Clouds are a serious problem in target acquisition and identification, particularly if there are only a few seconds available to locate, observe, and photograph a target. Thus, during the debriefing, the DMP said: "We were flying over cloud cover, and we didn't know where we were—as usual." Even if there are breaks in the clouds, say five-tenths cloud cover, the observer cannot see much of the Earth's surface, although it may be possible to identify some features and to make some limited definition or observation. Cloud shadows may also pose problems in target identification and in making rapid, accurate visual observations.

Some areas are cloud covered most of the year; therefore, visual observation and/or photography in these areas cannot be accurately scheduled. Other areas, such as hot desert regions (i.e., the Red Sea, Baja California, parts of Australia and South America, the Middle East, and north Africa) are usually cloud-free most of the year. For areas that are cloud covered most of the time, many opportunities for visual observation, photography, or both must be scheduled. Conversely, in cloud-free areas, few visual observation/photography opportunities need be assigned during mission scheduling. During short, low-altitude missions, this distinction is particularly important because (1) some sites may be cloud covered during all or most of the mission and (2) the crew has only a brief period for target acquisition, observation, and photography. Widely spaced targets, involving a "mix" of cloud-free and cloud-covered areas, would ensure optional opportunities—and time—for making visual observations.

Spacecraft Altitude

A low spacecraft altitude is excellent for visual observation, but this advantage must be balanced against extremely fast motion over the Earth's surface. Because of the high relative velocity, it is difficult to do several things simultaneously; e.g., visual observation and photography. During the ASTP mission, when a target came into view, only 5 to 20 seconds were available to point the camera and photograph the target. This time was insufficient for simultaneous visual observation and photography. If visual observations were desired, there was no time for making a photograph; conversely, if a good photograph was obtained, the observer did not see the scene clearly and therefore could not describe it.

At the ASTP altitude (approximately 220 km), it was possible to see clearly (". . . just like you can from 40 000 ft . . .") such phenomena as the flaring of natural gas, grass fires, contrails, icebergs, snowcapped mountains protruding above clouds, ship wakes, large ocean swells, the stripe on Lake Bonneville salt flat, and hangars at an airport. The crew unanimously agreed that the human eye was adequate for visual observations at lower altitudes, and several observations proved that the eye could resolve small targets. However, the low altitude made it difficult to differentiate (and photograph) larger features, such as tropical storms. Thus, the crew was over a tropical storm and reported: "It doesn't look any different from a whole bunch of clouds . . . ." In other cases, it was necessary to take panoramic (multiple) photographs because the entire scene could not be depicted in one photograph.

The crew also found that at the ASTP altitude, the spotting scope (20×) "was of minimal value" because of the high spacecraft velocity. The same was true of high-power binoculars; 10× binoculars would have been quite adequate for the lower altitude and the high groundspeed. In addition, the crew often lamented that they did not know where they were because they were going too fast.

Because of the low altitude, the high speed, and the spacecraft attitude, with the extremely limited view from a window, the crew often commented that at least two men were required for visual observations.

Spacecraft Attitude

Although there were few complaints about the spacecraft attitude with respect to observing ocean features (perhaps because the sites could be readily located by reference to major landfalls), it was a serious problem when relatively small features had to be located on land. In the normal visual observation attitude, spacecraft window 3 (the hatch window) was oriented parallel to the Earth's surface at the subvehicle point, and the astronauts were seated upside down. A typical conversation regarding this attitude was: "Vance, you know we're upside down? If you're upside down, the Nazca Plain should be on the right. It says to shoot it upside down. No, I'd rather have it right side up so the spacecraft is . . . there's clouds . . . we're approaching the north coast of South America, Peruvian desert, trying to find the Nazca Plain . . . . This attitude is bad . . . . It's really bad when you try to keep your head back like that and look right and left. I'm going to change (it) . . . around . . . . There's no room to twist your head and look upside down" (for visual observation). After reorienting the spacecraft attitude for improving visual observation, the DMP commented: ". . . we're already past (the) site . . . . I guess headed southward to the right—or to the left. I'm confused about this attitude. The south should be the right. North should be to the left. It's got to be; we're traveling east." The CMP said: "We're heading east. We're upside down," and the DMP responded, "seems like it to me, it's got to be that way . . . ." The problem was particularly bad when the visual observation was made while leaving (retrograding) a target, because the view was different from that in the Earth Observations Book. It was much easier to get a lead into a target.

It was also difficult to locate a target when the spacecraft was oriented for near-vertical observation, largely because of the limited window field of view and the rapid groundspeed. After some experimentation, the crew found an attitude that permitted them to see farther ahead as well as to obtain vertical or near-vertical views. However, when they were looking for a specific target in a lead-in, upside down attitude, they found it "extremely difficult to think." For the lead-in to a target, they recommended right side up, pitched down. This attitude was especially important for target identification. "If you're upside down, all these years of training and living down here (on Earth) are certainly thrown out the window . . . . You have to think everything out. There is a 50:50 chance of being right, but we're usually wrong." Finally, only 5 to 20 seconds are available to do everything.

Another problem was target location when the spacecraft was oriented for optimal, near-vertical observation. Because of the limited field of view from the spacecraft window and the rapid groundspeed, it was exceedingly difficult to know the location of the target.

Spacecraft attitude and scheduling also had a role in attempts to observe bioluminescence. For example, the DMP was prepared to look for bioluminescence on the Red Sea and reported: "But, unfortunately, what wasn't factored in here is that we're still in sunglint and I got the sunshine nice and bright right in the window." To conduct experiments on bioluminescence, a long dark-adaptation time is needed, and factors such as clouds and moonlight must be considered.

Spacecraft attitude was important in photography, and in some instances, visual observation was possible, but not photography. Thus, while attempting to perform visual observation in the Boston to New Brunswick ocean area, the DMP said the attitude "was okay for looking, I could see fairly well, but I couldn't get photography because it was a very oblique angle down through the window."

The effect of attitude with respect to Sun position on using the color wheel was described previously. A description of the effect of attitude on the long-focal-length lens follows.

Photography

The major complaints about cameras, lenses, and accessories were (1) the inability to see through long-focal-length (250- and 300-mm) lenses because of light loss; (2) the inability to see through an orange filter (however, during the debriefing it was determined that the problem was not the filter, but that the lens was out of focus); (3) the difficulty in using long-focal-length lenses to photograph small targets (some lenses were so long that the crew just pointed and shot); (4) the inadequacy of the 70-mm film budget (i.e., the crew had to use the 35-mm camera with indoor film when the supply of 70-mm film was exhausted); and (5) the impossibility of photographing a scene viewed from the spacecraft window at an oblique angle because the camera/lens could not be oriented properly.

Aside from obvious technical difficulties, the most important lessons concerning Earth observation are (1) that the film budget should be increased and (2) that more careful thought should be given to optimal lens sizes, because a long-focal-length lens places the observer far from the window, light loss through the lens is great, and at high groundspeeds it is difficult to pinpoint targets and photograph them. Moreover, the DMP said: "A lot of things that you can see with your eyeballs, you just can't see through that reflex (camera)." Although there was a considerable advantage in using the reflex camera because of the capability to frame a picture as the observer sees it, the high groundspeed (allowing, perhaps, 5 seconds to locate, frame, and photograph a picture) greatly affected other benefits adversely.

Window Fogging

The ASTP crew frequently complained about window fogging and the continual need to wipe the windows. Apparently, the fogging was caused by differences in cabin temperature. Thus, window 5 evidently did not fog up, but window 1 did. Earth observation and photography was hampered by this problem.

Dual Tasks

Crewmen complained about having to perform too many tasks in rapid succession. On one occasion, a microbial experiment was quickly followed by an Earth observation using television camera coverage and visual observation/photography: ". . . everybody in there was trying to do different things; it just wasn't very effective Earth obs, plus some cloud cover . . . ."

The crewmen seemed to agree that the best option was to obtain a photograph and then, if time permitted, to describe the target in as much detail as possible. During the debriefing, the DMP said that, most of the time, there was so much to do that "when you got through the pass, you were in the middle of something else. And you even have . . . to backtrack to pick that up. Early in the mission, things were happening too fast. We got very little good data out of it." The CMP concurred, adding: "I'd think, well, I'll have time right after this task to get it quickly on tape. And then, I didn't. The next site would come up and you would get five or six sites stacked up, and then it was all over. And then you would say that I'll debrief the whole thing. By that time, you have forgotten some pertinent parts, and then there wasn't time . . . to debrief the whole thing."

The crewmen reported that they needed repeated passes of a site and more time "because if you have one pass, there's a good chance that something will be bad. But if you have three or four passes, you've got a very good chance of getting a lot of data on it . . . and you shouldn't be very oblique . . . unless it's a major feature."

Because of the many joint operations tasks, it was mentally difficult to prepare adequately for a visual observation. This was especially true during the early part of the mission. Later on, when all three crewmembers worked together, conditions improved: "Once we got through the joint activity period, where we could all three work the problem together, help the guy that had the primary task by looking out the window, and we changed our attitude, I think we got reasonably good results from then on . . . prior to that, it was not very good." It seems reasonable, therefore, to conclude that during a low-altitude mission, involving many diverse tasks, there is simply insufficient time to do highly competent Earth observations.

Description as Opposed to Photography

The crewmen stated that they were able to see more than they could photograph, but that it was inherently difficult to scientifically describe many targets. Before the mission, the crewmen were briefed on the features designated for Earth observation. However, even when the feature was located, the crewmen had difficulty in providing detailed oral descriptions; consequently, they tended to rely on photography. In addition, attempts to sketch features in the Earth Observations Book were hampered by the difficulty of writing or drawing on glossy paper without a proper pen. A typical problem was explained by the CMP, who observed currents, gyres, and pollution in Puget Sound that were difficult to describe verbally. "Puget Sound is not a square tank, it's . . . rather complex . . . and I wanted to draw a picture of what I saw. So I took a pen . . . and I couldn't draw on the pictures; it was too dark anyway . . . . I feel that I lost some data there . . . after it was all over I cussed myself because I even tried to describe it. I should just have tried to take a picture."

During the debriefing, the crew commented that if "we got you good pictures (of a scene), we really didn't see it . . . . And comments may come easily one time and hard the next. For example, you may see something that you can describe very well. You may say, 'I see a circular cloud structure, and I see that it's 20 km across . . . the time I see it is such-and-such.' And you can describe the color maybe. The next time you come up on Sun glitter, you'll see a pattern, you'll see a gyre perhaps in there. And there's no way you can describe that, and you wish you had taken a picture, or you'll wish that you had a pad that you could draw on to fill in. For instance, if you had an outline of Puget (Sound) showing Seattle and two or three prominent landmarks and a pencil in your hand, you could draw in what you see. You need something like that." Thus, outline maps are needed for Earth observation.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

A careful study of the ASTP transcripts and photographs leads to several general conclusions and impressions.

The primary purpose of the ocean observations was to determine whether nonoceanographers could be trained to recognize specific ocean features from space. The record shows that the 16 hours of training (briefings and flyovers) were instrumental in helping the crew recognize features, both as scheduled targets and, elsewhere, as targets of opportunity. The crewmen demonstrated an excellent response and application to their training. Any differences that experts may have in the interpretation of some features must be attributed to the difficulty in teaching complex subjects (oceanography and meteorology) in a few hours. Most oceanographic subjects could be treated only in a superficial manner. Therefore, during training, efforts were made to concentrate on a few ocean features and on air/sea interactions. From the transcript, it is evident what types of phenomena were emphasized in briefings, because all three crewmembers reported similar ocean features with apparently equal proficiency.

Furthermore, their observations went beyond the training. There are several examples. When the crewmen were asked to look for tsunamis (tidal waves) following strong earthquakes in the South Pacific, they quickly responded that it was unlikely they could see such waves from their altitude. The crewmen also made an excellent qualitative evaluation with regard to the source of red water near Boothbay Harbor, Maine; i.e., the origin of the discoloration was sediment carried in a river, rather than red tide. In another instance, the crew reported that water in sunglint had a brownish tint, and it was therefore difficult to distinguish true water color (such as might be caused by a red tide or sediment). This difficulty had been suspected but was not verified until the ASTP crew mentioned it in an unscheduled Earth observation.

Although three of the four targets were obscured by clouds on the day assigned for their visual observation, the observations off the Spanish coast, and many other visual observations embodying a wide range of ocean features (targets of opportunity), demonstrated that astronauts could be trained to recognize important ocean features and phenomena. However, insufficient information is available from this single mission to draw definite conclusions about such factors as the importance of previous space-flight (nonobservational) experience. Available information strongly suggests that nonobservational space experience is not as important as good premission briefings and flyover training.

Solutions to most of the problems affecting visual observations either are of a technical nature that can be solved without further comment or are so self-evident that they require no discussion here. During the debriefing, the ASTP crewmen made several general recommendations for improving visual observations, basically involving improvements in position location, tracking, and sighting devices. They indicated that Col. William R. Pogue was working on this general topic. Pogue, a Skylab 4 astronaut, reviewed the role of the trained observer in visual observations and made a number of useful recommendations for improving visual observations.[1] Stevenson et al. (ref. 7) made some valuable recommendations on visual ocean observations, covering many topics (e.g., sensors, sensor system control, onboard analysis, sensor payload control, and training). No attempt is made to review these important contributions. However, it seems worthwhile to make several recommendations on the basis of ASTP experience.

Flyover exercises should be scheduled for both temperate and tropical waters. The former would include, for example, the waters off southern California and the Baja California coast, and the waters near offshore islands. This area has a wide variety of temperate water and air/sea interactions, and the Baja California area is generally cloud-free. Within the tropical area (e.g., off the Florida coast, the Caribbean islands, and perhaps as far east as Bermuda) are marked changes in water color caused by a wide variety of conditions such as current boundaries, occasional red tides, complex eddies, gyres, and shallow sea floor. Air/sea interactions include tropical storms and many types of interesting cloud systems. An important addition would be the highly desirable inclusion of an oceanographer in the flyover crew, to act as an instructor and observer.

The ASTP crew proved the importance of Sun glitter in recognizing and accentuating features that would be undetected otherwise. Hundreds of photographs (taken since Gemini) have demonstrated the importance of making observations in the sunglint for some, but not all, ocean phenomena. As previously noted, it was fortunate that the Strait of Gibraltar was observed in Sun glitter; otherwise, the detailed features would have been missed by the observer. From a practical point of view, some consideration must be given to the scheduling of experiments to take advantage of sunglint. The position of the spacecraft with respect to the Sun's reflective position on the ocean surface can be calculated long before a mission starts, and where it seems important to view the ocean scene in Sun glitter, this position should be calculated; Earth observations, or photography, should be scheduled for such orbits. These points are especially important if there are military ap-

---

[1] W. R. Pogue: Assessment of Potential Roles for Space Transportation System Crewmen in Making Earth Observations. JSC memorandum to the Manager of the Earth Resources Program, 1976.

plications involving the use of observers in space to detect important oceanographic conditions.

Remote sensors, particularly infrared, would be exceedingly useful instruments for visual observations and photography. Recent research using data from the Defense Meteorological Satellite Program (DMSP), has demonstrated that many surface ocean features can be conclusively detected from infrared imagery. Stevenson (ref. 1) showed that DMSP imagery closely parallels features that can only be seen in the Sun glitter pattern off Spain. However, more research is needed in this important area.

Because successive orbital paths of the ASTP spacecraft precessed new paths over the Earth's surface, it was not simply a matter of waiting until the next orbit to take another photograph or make an observation of a selected site. There are two basic problems. First, each revolution moves approximately 23° of longitude farther west at the Equator. Except for the higher latitudes, where there is some overlap and more frequent repetitive paths over or near a site, it was necessary to wait a minimum of 15 revolutions, or approximately 23.25 hours, until the spacecraft was again near—but not over—the area of interest. If the scene must be viewed in sunglint, the number of possible observations is substantially reduced. Second, all experiments and tasks performed on the spacecraft are carefully scheduled months in advance to optimize available time during the mission. Thus, the tight, inflexible schedule does not allow for common intangibles (cloud cover), which cannot possibly be predicted months, or even a week, in advance. The problem is not restricted to low-altitude missions, but is particularly serious during short missions when only one opportunity is assigned for an Earth observation. The fact that three of the four ASTP ocean targets were "washed out" because of cloud cover on the day they were scheduled emphasizes the serious nature of this problem. For many targets in other fields, such as geology, for which conditions are static or for which no ground investigations are being simultaneously conducted, rescheduling is not a serious problem. But when experiments involve dynamic events, such as in oceanography or meteorology, with armadas of expensive ships and aircraft carrying out ground investigations, it would be beneficial if there was some flexibility in the schedule. The need for flexibility is more serious in short missions than in those of long duration.

If strictly formal Earth observation missions were conducted to provide information to military (or civil) ships, there are effective methods to deal with clouds in many but, perhaps, not all areas of the world. For example, visual and infrared imagery can be used to build a time-data base of ocean and cloud maps of a particular geographic area. Clouds often provide important clues to water conditions. Small breaks in clouds, in random parts of the area of interest, support constant updating of oceanographic conditions and correlations with clouds. However, such detailed ocean monitoring requires the dedication of manpower and equipment. During missions of short duration, combining many diverse tasks, there are high risks in restrictive scheduling of ocean targets, with no opportunity to reschedule should a target be obscured by clouds or not be enhanced by sunglint.

For various reasons, including cloud cover and the availability of time for Earth observations and scheduling of events, it is highly desirable to have several optimally spaced sites and/or repeated sites prearranged within the mission schedule. The problem is magnified on short-duration missions because, with so many tasks to perform on schedule, it is difficult for the observer to concentrate on Earth observations. If he does so, it is probably done "according to the book" or "mechanically" rather than using ingenuity and thought to record deep impressions. This topic needs further study because if the astronaut/observer's primary function is Earth observation, he must be able to concentrate on that one immutable assignment.

An annotated photographic record, or compilation, of ocean features would be useful in two forms. First, a significant compilation (using both aerial and previously acquired space photographs) could serve as a comprehensive training manual for all future Earth observers. Briefings could be organized around this compilation, which could also serve as an excellent onboard manual for flyover exercises. Second, a condensed version could be prepared for use during the mission, for immediate reference purposes. Thus, during air-to-ground transmissions, the manual could be used to clarify instructions or to update Earth observation information. Both printed documents should precede the astronaut/observer ocean training programs (i.e., lectures and flyover exercises) as a means of ensuring an excellent, well-organized training program and of optimizing the crew's time. Information gathered from flyovers and subsequent space flights could be used to update the manuals. The smaller manual, or handbook, should be prepared immediately before the mission launch date, because it would be a synthesis of knowledge and would probably be specifically organized for the mission.

Although it has been demonstrated that non-oceanographers, with or without previous spaceflight experience, can be trained to recognize features and to make Earth observations, it is also apparent that with additional training and experience, they can become even more proficient observers. The crewman can see subjective details that far exceed the resolution of cameras, lenses, and films currently available. This significant advantage needs to be further exploited. Personnel with this subjective insight should be used to the greatest advantage for mission accomplishments.

ACKNOWLEDGMENTS

Acknowledgments are given to Robert E. Stevenson, Office of Naval Research, who permitted the use of his extensive files, provided much information, and reviewed the final manuscript. James A. McShane critically edited the report and proofread the final manuscript. This work was performed under Smithsonian Institution Grant PC6-22373 as a subcontract of NASA contract NAS9-13831.

REFERENCES

1. Stevenson, R. E.: Huelva Front and Malaga, Spain, Eddy Chain as Defined by Satellite and Oceanographic Data. Deutschen Hydrographischen Zeitschrift, vol. 30, no. 2, 1977, pp. 51-53.
2. El-Baz, Farouk: Astronaut Observations From the Apollo-Soyuz Mission. Vol. I of Smithsonian Studies in Air and Space, Smithsonian Institution Press (Washington, D.C.), 1977.
3. Nysen, P. A.; Scully-Power, P.; and Bannister, R. W.: Project ANZUS Eddy: Acoustic Measurement of a Warm Core Ocean Eddy. Paper presented at 90th Meeting of the Acoustical Soc. Am. (San Francisco), Nov. 1975.
4. Scully-Power, Paul D.; Nysen, Paul A.; et al.: A Multisystem Technique for the Detection and Measurement of Warm Core Eddies. IEEE Ocean Conference, 1975, pp. 761-768.
5. Scully-Power, P.; and Twitchell, P.: Satellite Observation of Cloud Patterns Over East Australian Current Anticyclonic Eddies. Geophys. Res. Letters, vol. 2, no. 3, Mar. 1975, pp. 117-119.
6. Stevenson, R. E.; Carter, L. D.; and Vonder Haar, S. P.: Preliminary Report on Visual Observations of the Oceans From Skylab 4. Sec. 17 of Skylab 4 Visual Observations Project Report. NASA TM X-58142, 1974.
7. Stevenson, Robert E.; Carter, L. David; Vonder Haar, Stephen P.; and Stone, Richard O.: Visual Observations of the Ocean. Sec. 11 of Skylab Explores the Earth. NASA SP-380, 1977, pp. 287-338.