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DEVELOPMENT AND TEST OF VIDEO SYSTEMS FOR AIRBORNE SURVEILLANCE OF OIL SPILLS

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United States Coast Guard
Department of Transportation

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16. Abstract

Five video systems – potentially useful for airborne surveillance of oil spills – were developed, flight-tested, and evaluated. The systems are: (1) conventional black and white TV; (2) conventional TV with false color; (3) differential TV; (4) prototype Lunar Surface TV; and (5) field-sequential TV. Wavelength and polarization filtering were utilized in all systems.

Greatly enhanced detection of oil spills relative to that possible with the unaided eye, was achieved. The most practical video system is a conventional TV camera with silicon-diode-array image tube, filtered with a Corning 7-54 filter and a polarizer oriented with its principal axis in the horizontal direction. Best contrast between oil and water was achieved when winds and sea states were low. The minimum detectable oil film thickness was about 0.1 micrometer.

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DEVELOPMENT AND TEST OF VIDEO SYSTEMS FOR AIRBORNE SURVEILLANCE OF OIL SPILLS

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SUMMARY

A program was undertaken to develop and flight-test video systems having potential for airborne surveillance of oil spills. Five systems were evaluated: (1) conventional black and white TV; (2) conventional TV with false color; (3) differential TV; (4) prototype Lunar Surface TV; and (5) field-sequential TV. Wavelength and polarization filtering were utilized in all systems.

The most promising system tested was the conventional black and white TV camera filtered with Corning 7-54 and Polaroid HN 38 filters. The advantages of this system were that oil slicks were displayed in very high contrast, the system was least affected by nonuniform scene radiance, and expensive UV transmitting optics were not required. For virtually every flight over natural slicks in the Santa Barbara Channel, the oil was displayed by this camera/filter combination as a bright white against a dark water background. Similar results were obtained during U.S. Coast Guard Airborne Oil Surveillance System (AOSS) tests, provided that sea swells were about one foot or less. The minimum detectable oil slick thickness with this system was about 0.1 micrometer.

The other systems were not without merit; each served a useful purpose, and the experience derived from them can guide future research. The conventional TV with false color detected oil extremely well under diffuse lighting conditions, but was usable only if the scene radiance was uniform. The differential TV system detected oil, but the disadvantage of aligning two cameras outweighed the advantages. The prototype Lunar Surface TV camera was used to try out a novel idea of using a single camera to view two modes of polarization. Experience with this system led to the development of a dedicated field-sequential camera system. Unfortunately, the dedicated field-sequential camera is not fully operational at this date.

The results showed that video/optical techniques can be used to significantly enhance the contrast between oil and water, but that certain inherent problems existing in airborne optical

surveillance of oil spills need further attention. These problems limited the usefulness of many of the systems investigated here. A major problem was that of viewing a low-content, low-brightness target, such as oil on water, in a scene where the brightness varied across the field of view. Variations in brightness were caused by sun glint, by changes of reflectance with angle in a large field of view, and by sun/cloud effects. These variations on a black and white TV system produced a gradation in picture brightness from white to black across a video monitor. This was not too serious a problem for black and white systems, because the eye can accommodate large changes in black and white brightness; however, this variation rendered false-color techniques virtually useless because a color was assigned to each grey level, and the eye had difficulty with the kaleidoscope of colors. A second problem was that the variation in brightness between water and boats or land was often so large that the dynamic range of the video system was exceeded, and detail in the water surface was lost. These problems did not always exist. For example, false-color techniques have been used with excellent success under uniform overcast skies, and the effects of bright objects such as boats have been eliminated by overriding the iris or gain in a video system in order to detect water details. For routine surveillance operations, however, these problems need attention.

INTRODUCTION

In the fall of 1970, the Ames Research Center participated in the U.S. Coast Guard-sponsored Southern California Oil Pollution Experiment, the objective of which was to evaluate various techniques for remotely detecting oil on water. Ames evaluated radiometric techniques based on measuring reflected sunlight and developed the following conclusions[1]: (1) oil could best be seen when viewing light reflected in the ultraviolet and red portions of the spectrum, and (2) enhancement could be achieved by measuring the difference between the polarization components of reflected light. The radiometer used in these studies viewed only a small area on the ocean surface; however, it was recognized that for surveillance purposes imagery would be much more useful. It was also recognized that a potential technique for increasing the subtle contrast between oil and water was false-color enhancement. Based on these considerations, a joint effort between the Coast Guard and NASA/Ames was begun in 1972 to develop these radiometric principles and false-color potentials into usable video systems, and to flight-test them.

[1] Millard, J. P., and Arvesen, J. C.: Airborne Optical Detection of Oil on Water. Applied Optics, Vol. 11, No. 1, Jan. 1972, pp. 102-107.

The first system developed was a differential TV system for displaying the difference between the polarization components. It utilized two bore-sighted TV cameras having common wavelength filters and orthogonal polarizers; in real time, one image was subtracted from the other and the resultant image was displayed in false color. The original intent was to develop this into a night system, but calculations showed that low-light-level TV systems would probably not detect oil slicks below about half-moonlighting conditions. The difference in cost between low-light-level cameras and conventional silicon-diode-array cameras, usable to about dusk, resulted in a decision to establish the feasibility of the technique using silicon-diode-array TV cameras. The system was first tested in July 1972 aboard NASA's Convair 990 aircraft during the Ocean Color Expedition. During this Expedition, the aircraft flew over a tanker apparently spilling oil, and the oil was displayed on the TV monitor in false color. In subsequent months this differential system was tested aboard Cessna 401 and Cessna 402 aircraft. These tests showed that oil slicks were easily detected by this technique, but generally no more easily than with a one-camera system.

In January 1973, a novel technique was evaluated for utilizing a single TV camera to sense the state of polarization of a scene. The technique utilized a single image tube with a spinning filter wheel in front. Polarizers, alternately rotated 90°, were mounted in the wheel and the signal through each actuated a color gun on a monitor. Thus, the color of the video picture was proportional to the state of polarization of the scene being viewed. To evaluate this technique, a prototype Lunar Surface TV camera was borrowed from NASA's Johnson Space Center. The color filters were removed from the filter wheel of the camera and replaced with polarizers. The camera, modified in this manner, worked well in the laboratory with two pieces of polaroid film held at orthogonal angles as the target, but it did not detect oil slicks well. The problem was attributed to the fact that the filter holders were boomerang shaped, and as they rotated in front of the image tube good polarization discrimination was not achieved. During flight tests of this camera, sun glint and nonuniform scene radiances caused portions of the video picture to appear saturated, making interpretation of results difficult.

In May, 1973 a contract was let for the development of a dedicated field-sequential TV camera. This camera was to have a high signal-to-noise ratio, an electronic filter for removing low frequency variations in the signal caused by nonuniform scene radiances, and threshold detection for color-flagging high or low portions of a video signal which might correspond to oil spills. Unfortunately, development problems were experienced with this system, and it is not yet fully operational.

Concurrent with development and evaluation of these various systems, a single conventional silicon-diode-array TV camera was being flight-tested.[2] This camera was filtered with a Corning 7-54 filter and a polarizer oriented so that its principal axis was in the horizontal direction. This camera proved to be the most practical of those investigated. It was the least sensitive to changes in scene radiance, and displayed oil on water with high contrast. This camera system was evaluated in the Coast Guard Airborne Oil Surveillance System tests in September and October, 1974, the final effort of this program.

VIDEO SYSTEMS

The five video systems evaluated in this study are shown in figure 1. Table I lists the individual components and system weights and powers.

Basic Theory

An airborne sensor viewing oil on water "sees" light reflected at the surface plus light backscattered from beneath.[1] The reflected light comes from that portion of the sky in the specular direction. The backscattered light comes from direct sunlight and from skylight that penetrates the water surface from all directions.

Wavelength and polarization filtering[2, 3] were employed in all systems to enhance the contrast between oil and water. The rationale for selective filtering was that it allows surface features of water to be emphasized, rather than subsurface features. Results from the 1970 Southern California Oil Pollution Experiment showed that best contrast was achieved in the near-ultraviolet and optical-infrared portions of the spectrum. The explanation is that in these portions of the spectrum water absorbs much of the backscattered light and causes the contrast between oil and water to be determined primarily by surface reflectances. Oil has a higher reflectance than water and thus appears brighter.

Polarization filtering further enables surface features to be enhanced. In general, a polarizer oriented with its principal axis in the horizontal direction enhances surface reflected light, and when

[2] Millard, J. P.; Arvesen, J. C.; Lewis, P. L.; and Woolever, G. F.; Video Systems For Real-Time Oil-Spill Detection. Proceedings of the Second Joint Conference on Sensing of Environmental Pollutants, Instrument Society of America, Pittsburgh, Pa., 1973, pp. 355-361.

[3] Millard, J. P.; and Arvesen, J. C.: Polarization: A Key to an Airborne Optical System for the Detection of Oil on Water. Science, Vol. 180, June 15, 1973, pp. 1170-1171.

TABLE 1.– SYSTEM COMPONENTS

Component	Description	Weight (lbs)	AC Power (Watts)	Comments
System 1	Conventional TV– Black and White	(a) 22 (b) 56	(a) 40 (b) 100	(a) System with 7-in. TV monitor (b) System with 14-in. TV monitor
TV Camera	Sanyo Model VCS-3100	12	15	2/3-in. Silicon-diode-array tube; autocontrolled iris
Monitor	Panasonic Model, TN-63	10	25	7-in. black and white
Monitor	Conrac Model SNA 14/R	44	85	14-in. black and white
System 2	Conventional TV – False Color	148	450	
TV Camera	Sanyo Model VCS-3100	12	15	2/3-in. silicon-diode-array tube; autocontrolled iris
Processor	Int. Imaging Systems Differential Video Processor Model 4490	64	230	8-color system
Monitor	Tektronix Model 654	52	150	Color
Oscilloscope	Tektronix Model 432	20	55	
System 3	Differential TV	160	495	
TV Cameras (2)	Sierra Scientific Minicon	24	60	1-in. silicon-diode-array tube; manual or remote iris
Processor	Int. Imaging Systems Differential Video Processor Model 4490	64	230	8-color system
Monitor	Tektronix Model 654	52	150	Color
Oscilloscope	Tektronix Model 432	20	55	
System 4	Lunar TV	70	102	Prototype Lunar Surface camera
TV Camera	RCA Model QTV-9	11	12	Silicon intensifier tube (SIT)
Monitor	Sony Model PVM-1200	59	90	Color: modified for field-sequential
System 5	Field-Sequential	153	398	
TV Camera	ZIA Assoc. Inc. Field Seq.	16	190	1-in. silicon-diode-array tube; autocontrolled iris
Processor	ZIA Assoc. Inc. Field Sequential Processor	33	Incl. in above	To enhance low contrast scenes and minimize nonuniform radiance effects
Encoder	Telemation Model TCE-1600A	15	38	
Monitor	Panasonic Model TN-63	10	25	
Monitor	Sony Model PVM-1200	59	90	Color; modified for field-sequential
Oscilloscope	Tektronix Model 432 or R453	20	55	
Tape Recorder	Int. Video Corporation Model 825A	75	450	Used with all systems; modified for color
Filter 1	Corning 7-54	N/A	N/A	Transmits below 420 nm and above 670 nm
Filter 2	Kodak Wratten 92	N/A	N/A	Transmits above 620 nm
Filter 3	Kodak Wratten 89B	N/A	N/A	Transmits above 680 nm
Filter 4	Optics Technology 166	N/A	N/A	Transmits from 410 to 600 nm
Filter 5	Optics Technology 787	N/A	N/A	Transmits from 390 to 560 nm
Filter 6	Optics Technology IR Absorbing Glass	N/A	N/A	Absorbs above 700 nm
Filter 7	Polaroid Polarizer HN 38	N/A	N/A	Visible polarizer
Filter 8	Polaroid Polarizer HR 1.25	N/A	N/A	Optical-infrared polarizer

oriented in the vertical direction enhances subsurface light. To be more specific, figure 2 illustrates the reflectance for the horizontal and vertical components of water and of an oil having an index of refraction of 1.57. The reflectance is plotted versus viewing angle, 0° being in the nadir direction. These curves indicate that (1) the reflectance of the horizontal component is large, especially at high angles of incidence; (2) oil is always brighter than water if only the horizontal component is viewed; (3) the reflectance of the vertical component is comparatively low; and (4) a crossover in contrast between oil and water occurs near the Brewster angle, approximately 53°, for the vertical component; that is, from nadir to about 53°, oil is "brighter" than water, but beyond 53°, water is "brighter" than oil.

The photographs in figure 2 illustrate the advantage of viewing the horizontal polarization component in preference to the vertical. These photographs were taken with two cameras having polarizers rotated 90° with respect to each other. The scene is an oil spill contained by a barrier. In the center is a thin film of oil, exact thickness unknown, and toward the bottom, within the barrier, is a thicker pool of oil. The left photo was taken with a polarizer oriented to transmit the horizontal component, and the right photo used a polarizer that transmitted the vertical component. Although this particular day was partially overcast, the advantage of the horizontal component is readily seen. The thick slick stands out vividly in the left photo.

On the basis of these photographs, enhancement in contrast should be obtainable by a difference technique. The right photo contains information primarily from light backscattered from beneath the water surface (background information). The left photo contains information from both backscattered plus reflected light (background plus signal). By subtracting one image from the other, the thin oil slick should stand out vividly. This differencing of images forms the basis of the differential technique.

System 1: Conventional TV Camera -- Black and White

This system is composed of a silicon-diode-array TV camera with zoom lens, and a black and white TV monitor (see table 1). The camera specifications are: 6-MHz frequency response, 500-line resolution, 43-dB signal-to-noise ratio, 5000-1 automatic light compensation, 2/3-inch image tube, and 5:1 (15 mm-75 mm) zoom lens. Various filters were mounted in front of the lens, and the camera was operated with either the 7-inch or 14-inch monitor illustrated in figure 1.

System 2: Conventional TV Camera – False Color

The technique is to slice a black and white video signal into a number of segments and to false-color any or all of them. The system is composed of the same camera as used in System 1, a false-color processor, and a color monitor. The processor has better than 20-MHz frequency response, and better than 100:1 signal-to-noise ratio. It has eight levels of color, and can distinguish a 3 percent change in video signal. It is equipped with a split screen, calibrated to indicate the video level of any color, and also has a planimeter to indicate the percentage of picture occupied by any color.

System 3: Differential TV

This technique utilizes two bore-sighted cameras, each viewing through a polarizer oriented 90° to the other. In real time, one image is subtracted from the other and the resultant image is displayed on a monitor. By means of this technique, redundant information (unpolarized radiation) is canceled and the contrast between oil and water due to polarization differences is enhanced. A second possible improvement in contrast is based on the fact that skylight polarization varies with position in the sky. An airborne observer viewing an oil slick sees different portions of sky reflected by oil and water. Thus he sees the polarization characteristics of two different portions of sky modified by the reflectance characteristics of oil and water.

The system is composed of two silicon-diode-array TV cameras, the false color of System 2, and a color monitor. The processor was designed to subtract one image from another in real time. The TV cameras contain 1-inch image tubes, 18-MHz bandwidth, and a 100-1 signal-to-noise ratio; the cameras are not equipped with automatic-controlled irises.

System 4: Lunar TV

The purpose of this system was to evaluate a technique for color-flagging oil on water. The technique consists of rotating a filter wheel, containing up to three different filters, in front of a TV image tube, and allowing the video signals through each filter to drive separately the color guns on a monitor. When a disparity between oil and water exists in any one filter region, the corresponding color gun will be affected and oil will be displayed in a color different from that of the surrounding water.

To evaluate this technique, a prototype Lunar Surface TV camera, RCA Model QTV-9, was borrowed from NASA's Johnson Space Center. This camera is a field-sequential type, using a

spinning filter wheel. The color filters were removed and replaced with polarizers alternately rotated 90°. Thus, the camera was sensitive to the state of polarization of the scene being viewed.

System 5: Field-Sequential TV

This system was designed to be a dedicated field-sequential camera system for oil spill detection, and operated on the same principle as the Lunar Surface TV camera. It consists of a TV camera, processing unit, and a color monitor; the TV camera employs a 1-inch silicon-diode-array image tube. Designed to sense low-contrast targets, the preamplifier was optimized for a 300:1 ratio of peak-signal-to-rms-noise with a 3-MHz bandwidth. Two unique features were designed into this system. First, it was designed to eliminate nonuniform radiance effects by filtering the lower frequency information from the video signal. Second, threshold detection was incorporated so that maximum and minimum signals through each filter could be color flagged. Figure 3 illustrates the signal processing of this camera system. The camera has a 10:1 zoom lens.

RESULTS

The video systems were tested on Cessna 401 and 402 aircraft. The TV cameras were mounted in the nose of the aircraft, and the electronic equipment was mounted in racks on the seat rails of the cabin. Figure 1 illustrates some of the racks of equipment, and figure 4 illustrates a special aircraft nose that was built for mounting the TV cameras. (The tubes shown in the figure are used in another project.) In all cases, the nose-mounted TV cameras viewed downward at 45° in order to sense a large horizontal component of polarization. Figure 4 also illustrates the mounting of a small TV monitor in front of the copilot's seat.

System 1: Conventional TV Camera – Black and White

This system was tested numerous times over natural slicks in the Santa Barbara Channel. Various wavelength and polarization filters (see table 1) were inserted in front of the optics; the filter combination that produced best all-round results was a Corning 7-54 and a Polaroid HN 38 polarizer oriented to transmit the horizontal polarization component. The Corning 7-54 blocks out the visible and transmits the near-ultraviolet and optical infrared. With this filter combination, the camera system detected slicks on virtually every flight with better contrast than seen by the unaided eye. Figure 5 illustrates typical results acquired with this system over the Santa Barbara Channel; the oil appears as a bright white against a dark background. In some instances the sky conditions

were such that the eye could not detect the slicks, but the system did. This occurred in two separate instances corresponding to a clear day and a day when fog/haze conditions prevailed. The Kodak Wratten 92 filter and polarizer were observed to give good performance under overcast skies, and to penetrate haze better than the human eye. For general use, however, the Corning 7-54 plus polarizer gave the most consistently good results.

The system was also evaluated during the Coast Guard Airborne Oil Surveillance System (AOSS) tests off the Pacific Coast in September and October, 1974. These tests involved the spilling of known quantities of oils, and the evaluation of airborne sensors for detecting them. Two types of experiments took place: one involved large static spills, where 500 gallons each of diesel, midgravity crude, and Bunker-C oils were generally spilled, and the other involved dynamic spills where a moving ship spilled small quantities of diesel or mid-gravity crude.

During these tests, a Corning 7-54 plus polarizer filter combination was used in this camera system. The results show that each of the static spills was detected with very high contrast when the seas and winds were calm (sea swells about 1 foot and winds about 5 knots or less) but with higher seas and winds, the slicks were displayed with very low contrast. Under calm conditions, the slicks were also detected with high contrast the day following a spill. Figure 6 illustrates video tape imagery acquired the first and second days of a spill for diesel, mid-gravity crude, and Bunker-C oils. The first day of spill imagery is on the left, and the second day's imagery is on the right; diesel is at the top, and Bunker-C is at the bottom. On the second day, the oils were so strewn and intermingled on the sea surface that positive identification of oil types was not assured.

During the dynamic spill tests, diesel oil was detected with high contrast when the ship was moving at 4 knots, and spilling at a rate of 2.4 gallons per minute (provided the seas were calm, as described in the foregoing paragraph). After about 2 hours, the slick had thinned to a point where it could no longer be detected well. No other oils were dynamically spilled during these calm conditions.

The AOSS tests and flights over the Santa Barbara Channel revealed a number of important factors regarding airborne surveillance of oil spills and the behavior of the black and white TV system.

1. The most ideal conditions under which to detect oil slicks exist under a uniform overcast. For these conditions, the sunlight is uniformly distributed to all portions of the sky, making a large amount of light available to be reflected from the water surface from any view direction. The slicks are easily detected by the video system under this condition.

2. Under clear skies, most of the slicks evaluated appear bright relative to water when viewed with the TV system, except when viewed in a direction toward the sun. When viewing in the sun's specular direction, oil appears bright if the oil specularly reflects the sun to the video system, and oil appears dark if it is not in direct specular alignment. Note that as oil calms the sea, both oil and water will probably not specularly reflect light to the same point. Figure 7 illustrates some solar effects. The top photograph illustrates the sun specularly reflecting off an oil spill during one of the AOSS dynamic spill tests. On this day, the sea swells were about 2 feet and winds were about 13 knots. The slick could be detected well only by looking in the sun's specular direction; and as can be seen, it shows up exceptionally well. The middle photograph illustrates that an oil spill can appear dark when looking in the specular direction, and the lower figure illustrates sun shading effects. Here, the dynamic range of radiance in the scene is larger than the video system can tolerate, causing one portion of the image to be a saturated white and another to be saturated black.

3. There appear to be oil film thickness effects which have not been evaluated. As seen in figures 5 and 6, the oils generally appear bright white against a dark water background. The lower photograph in figure 5 illustrates, however, that some oil thicknesses appear dark. The oil spill thickness limitations have not been established.

4. There does exist a thickness where oil films become so thin that the TV system cannot detect them, but the eye can. This thickness is believed to be about 0.1 micrometers.

5. The silicon-diode-array vidicons "bloom" when a bright object such as a ship enters the scene (fig. 6); it is often difficult to identify both the ship and water features. Either one can be identified at the sacrifice of the other by adjusting the video level.

6. An "anti-bloom" silicon-diode-array image tube was mounted in the existing TV camera. The results show that the picture was grainy and that it was not as sensitive to low-light conditions; it generally offered no distinct advantage for use in oil spill detection.

7. The polarization characteristics of the atmosphere may sometimes adversely affect the technique of using a polarizer oriented in the horizontal direction. During the first AOSS test, the oil slicks were detected with very little contrast. On the following day, which was also somewhat hazy, it was observed that a horizontal polarizer held to the eye limited visibility through the atmosphere. In other orientations of the polarizer, the atmosphere sometimes appeared more transparent. Thus, there may exist some weather conditions where the best polarizations for viewing oil and looking through the atmosphere are incompatible.

8. The majority of tests were made with the Corning 7-54 plus polarizer combination, which generally has proven to be better than other filter combinations. During the AOSS tests, a Kodak Wratten No. 92 and Polaroid HR 1.25 infrared polarizer were used on two occasions under light haze conditions with good success. Thus, it is felt that the Corning 7-54 plus polarizer combination is best, but that more testing of the infrared filters may be required to justify eliminating them from further use.

System 2: Conventional TV Camera – False Color

The video signals from the black and white TV camera were false-colored in real time. In tests over the Santa Barbara Channel, this technique proved to be a good one for detecting anomalies on water surfaces. Figure 8 illustrates a case where the system was operated so that natural water was displayed as yellow and oil was displayed as blue and white. It is believed that the blue and white pertain to different thicknesses of oil. In this case, the blue is thought to pertain to a thin portion of slick, since it extends around the perimeter of the slick. A very useful mode of operation of this system is to display water in black and white and oil in color. This enables an operator to easily recognize ground and surface features.

A major problem with the false-color techniques is caused by sun glint and nonuniform scene radiance. Since the magnitude of the video signal, in this technique, is sliced into several levels and a color applied to each, a nonuniform radiance scene will appear as a kaleidoscope of colors. Under these conditions, an operator has great difficulty in detecting oil. The problem did not exist under uniform overcast conditions, and good results were also obtained under clear sky conditions when sun glint was not viewed.

System 3: Differential TV

The differential TV system was evaluated aboard NASA's Convair 990 aircraft during the 1972 Ocean Color Expedition; figure 9 illustrates the system and results. The aircraft was flown over the wake of a ship that appeared to be spilling oil. The detected wake appears in brown and blue, and the sea appears as red and yellow.

Subsequent field tests of the differential system over the Santa Barbara Channel showed that (1) good contrast between oil and water was achieved with this system, but generally no more so than with a one-camera system; (2) the two-camera "difference" technique minimizes undesirable lighting effects caused by sun glint in a portion of the field-of-view; and (3) the necessity of aligning two cameras appears to outweigh the advantages.

System 4: Lunar TV

The results of laboratory tests of the lunar TV system are shown in figure 10. Two pieces of polaroid, rotated 90° to each other, were used as the target. The lower left figure shows how the scene appeared to the human eye. The polaroid appeared a dull grey, and the surroundings appeared in color. The lower right figure shows the image acquired through the modified Lunar Surface TV camera. Here, the pieces of polaroid are displayed in blue and red, and the background appears in black and white. It was hoped that over water, water would appear in black and white and oil in color.

This modified camera system was tested aboard a Cessna 401 aircraft over the San Francisco Bay. The results were not good; slicks were only faintly observed on the TV monitor. The poor performance was thought to be due to three factors. First, the shape of the filter holders was such that good polarization discrimination was not achieved. Second, the camera had a rather low signal-to-noise ratio (about 27dB). Finally, sun glint and nonuniform scene radiance effects often produced partially saturated images, making interpretation difficult.

System 5: Field-Sequential TV

There were development problems with the dedicated field-sequential system. One major problem prevented a successful flight before termination of this project: the low-reflecting water necessitated that the iris on the zoom lens be wide open. Unfortunately, this particular lens produced a very high level of shading (nonuniform transmittance) when wide open. The camera then enhanced this video signal. As a result, the picture appeared as though one were looking through a dark porthole, and the video processor was not capable of displaying the intended scene as required. Because the camera was never successfully operated over water, the circuit to minimize nonuniform radiance effects was never fully evaluated. It appears, however, that this circuit might produce a problem. The circuit acts as an edge enhancer, and eliminates the low frequencies that contain information interior to the edges. As a result, an observer may have difficulty in recognizing specific features in the field of view. Another problem associated with the field-sequential camera is a definite 1/30-Hz flicker, which can be annoying to an operator. Nevertheless, the system does have potential. In the laboratory, it was capable of displaying the polaroid test targets (fig. 10) with high color contrast.

COMMENTS AND CONCLUSIONS

Significant finds of this study are: (1) greatly enhanced detection of oil spills, relative to that possible with the unaided eye, can be achieved with TV systems; (2) this enhanced detection can be achieved with an inexpensive, conventional TV camera, filtered with Corning 7-54 and Polaroid HN 38 filters, and displayed on a black and white monitor; (3) expensive UV transmitting optics are not required; (4) this enhanced detection was always achieved in tests over the natural slicks in the Santa Barbara Channel and over Coast Guard test spills if the seas were calm; (5) false-color enhancement can be performed with good results under overcast skies but a problem of nonuniformity in signal, caused by sun glint on clear days, remains to be solved; (6) the differential technique minimizes this sun glint problem; (7) the two-camera differential technique does not offer sufficient gains in contrast, relative to a one-camera system, to compensate for alignment problems; (8) the field-sequential system requires further development and flight test; (9) a major problem with video systems, and one that merits further attention, is that the dynamic range of brightness in a water scene is often larger than the video system can accommodate; and (10) a silicon-diode-array tube, adjusted for water viewing, will often "bloom" when viewing a bright object such as a boat or land.

With an appropriately filtered black and white system, oil is almost always displayed as a bright white against a dark water background. Exceptions occur when oil thicknesses are less than about 0.1 micrometer, and when viewing in a direction where water, rather than oil, specularly reflects light to the TV camera. Maximum detection thickness is unknown. Except for rather pronounced effects in the specular direction, little difference in contrast was noted with direction of approach to an oil spill during midday observations. In evening hours (and this should apply to early morning hours), visual observations indicated a preference for viewing in directions either toward or away from the sun. Under overcast skies, slicks are easily detected and no angular dependence exists.

For the future, three courses of action are recommended:

1. The conventional black and white system should be flight-tested to substantiare oil thickness limits of detection.

2. The field-sequential system should be further evaluated by replacing the existing low-speed zoom lens with a high-speed (low shading) lens, and flight-tested.

3. Consideration should be given to a camera system configured to (a) continually rock back-and-forth so as to cover a large area of view, (b) contain a slowly rotating polarizer to compensate for atmospheric polarization effects and cause an oil spill image to pulsate for easy detection, and (c) contain a remotely adjustable "gamma" circuit to change the system gain for various scene lighting conditions. A joy-stick override should be provided on the rocking portion of system for versatility and target tracking. The adjustable "gamma" circuit will provide a means of partially compensating for nonuniform scene radiance effects.

ACKNOWLEDGMENTS

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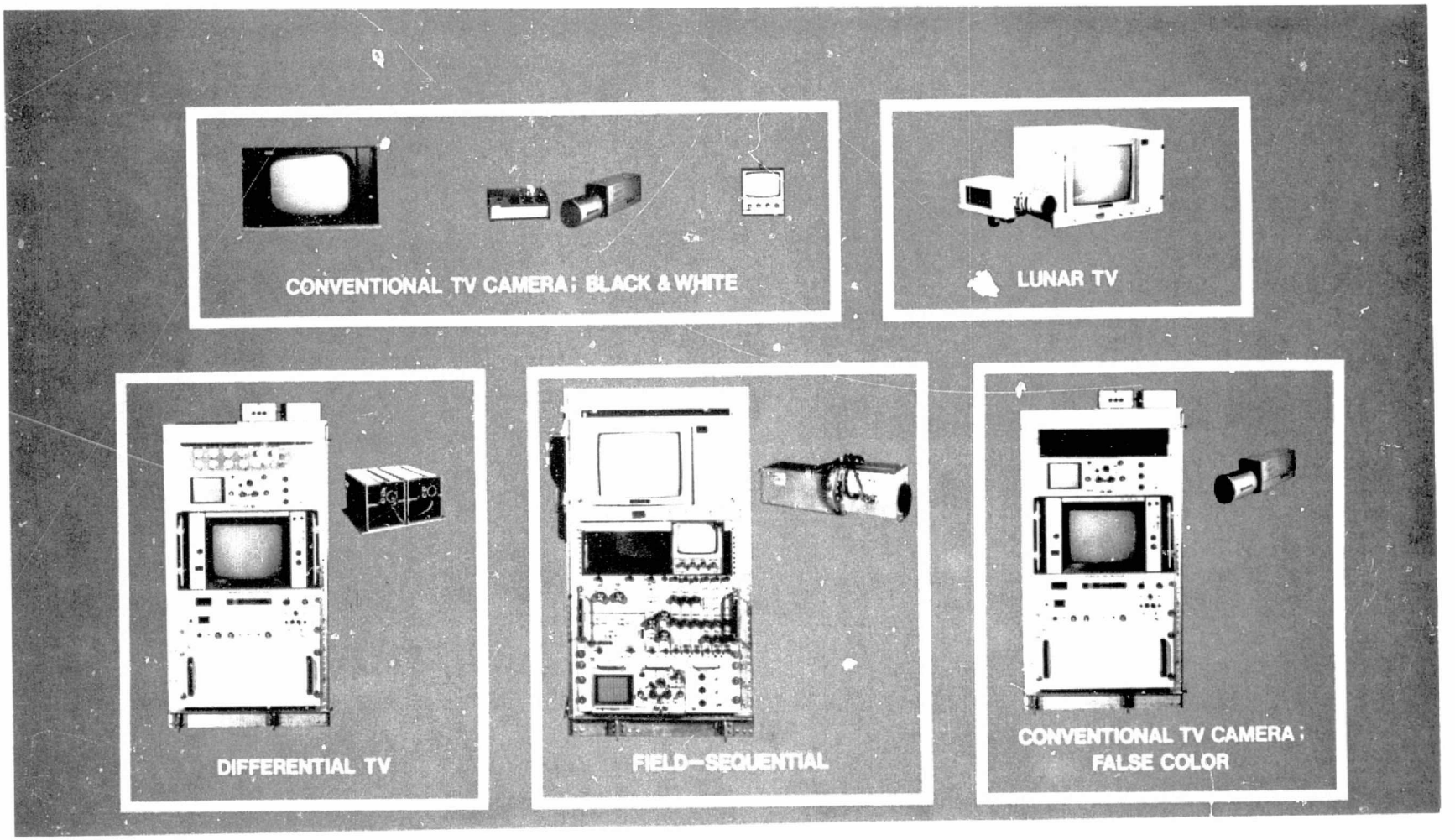
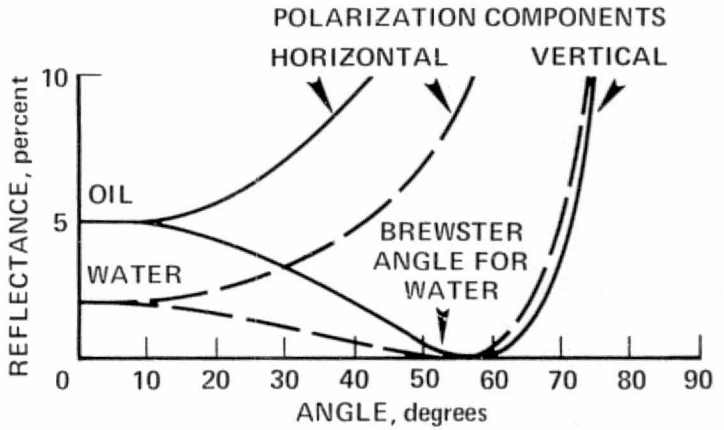


FIGURE 1.— VIDEO SYSTEMS EVALUATED IN THIS STUDY.

BASIS FOR

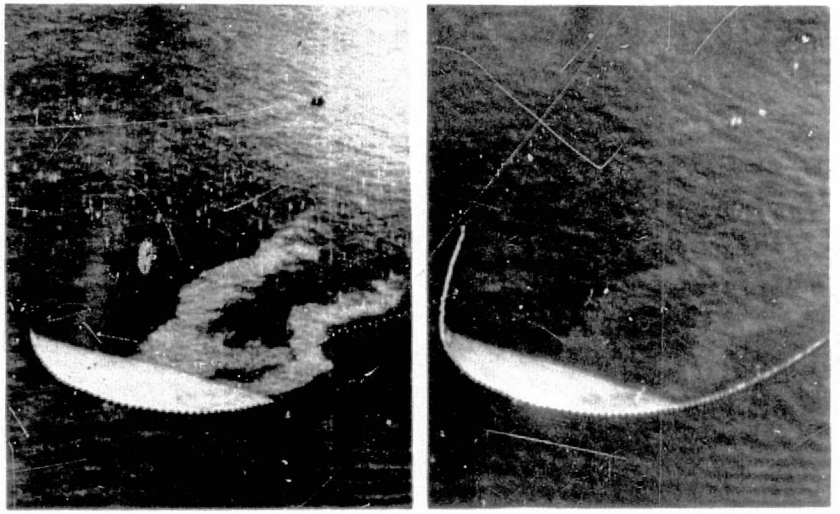
DETECTING OIL SPILLS

BY POLARIZATION TECHNIQUES



REFLECTANCES OF OIL AND WATER ARE DIFFERENT FOR BOTH POLARIZATION COMPONENTS OF INCIDENT SKYLIGHT.

PHOTOGRAPHS OF AN OIL SPILL ILLUSTRATE THE ADVANTAGE OF VIEWING THE HORIZONTAL POLARIZATION COMPONENT.



The left photo contains information from both light reflected at the surface and backscattered from beneath.

The right photo contains primarily information from backscattered light.

That is, the left photo contains signal plus background information, and the right one contains primarily background information.

By subtracting one photo from the other, the thin oil slick in the center should stand our vividly.

FIGURE 2.– POLARIZATION CHARACTERISTICS AND EFFECTS.

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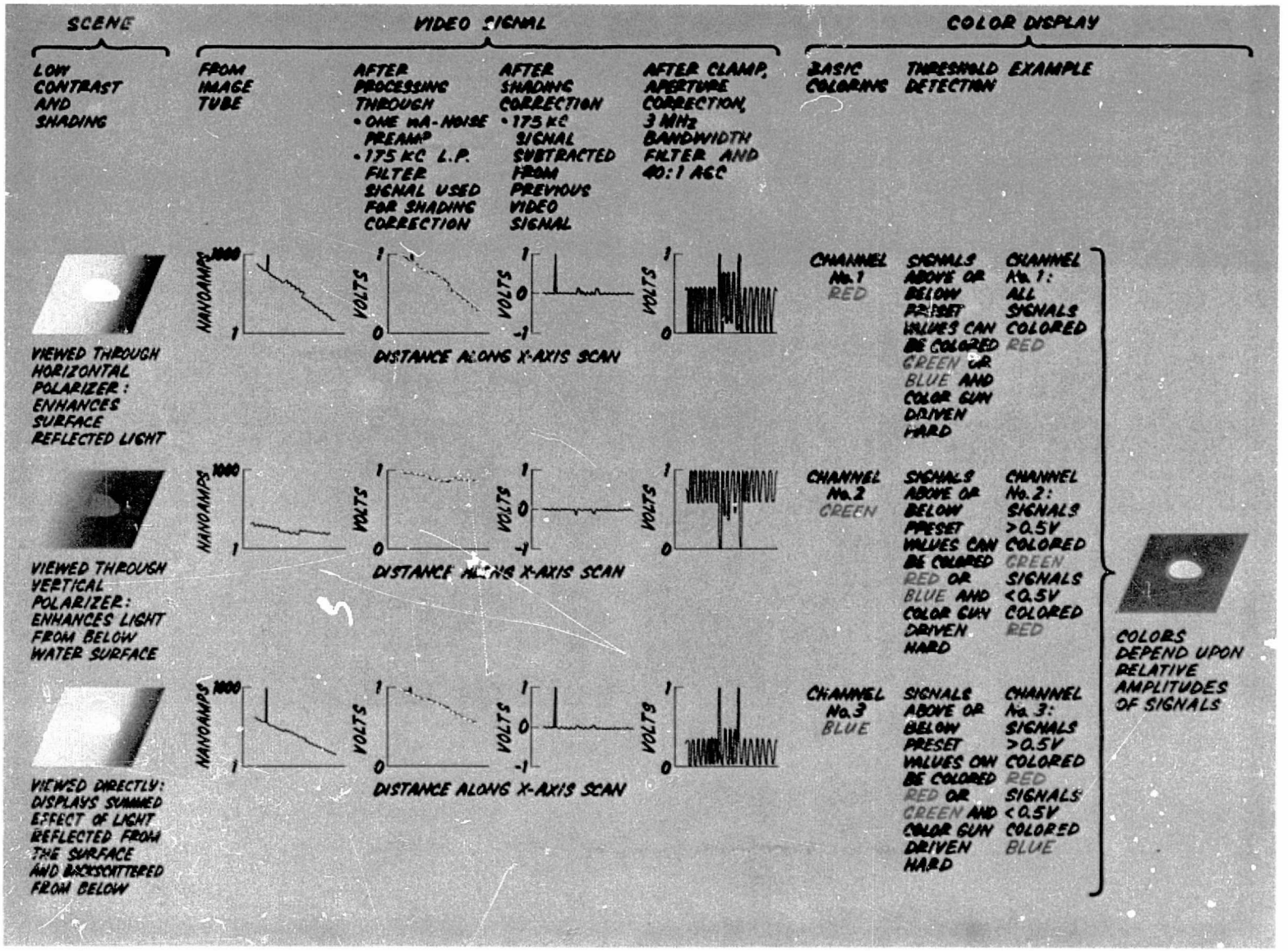

FIGURE 3. SIGNAL PROCESSING FOR FIELD-SEQUENTIAL TV CAMERA.

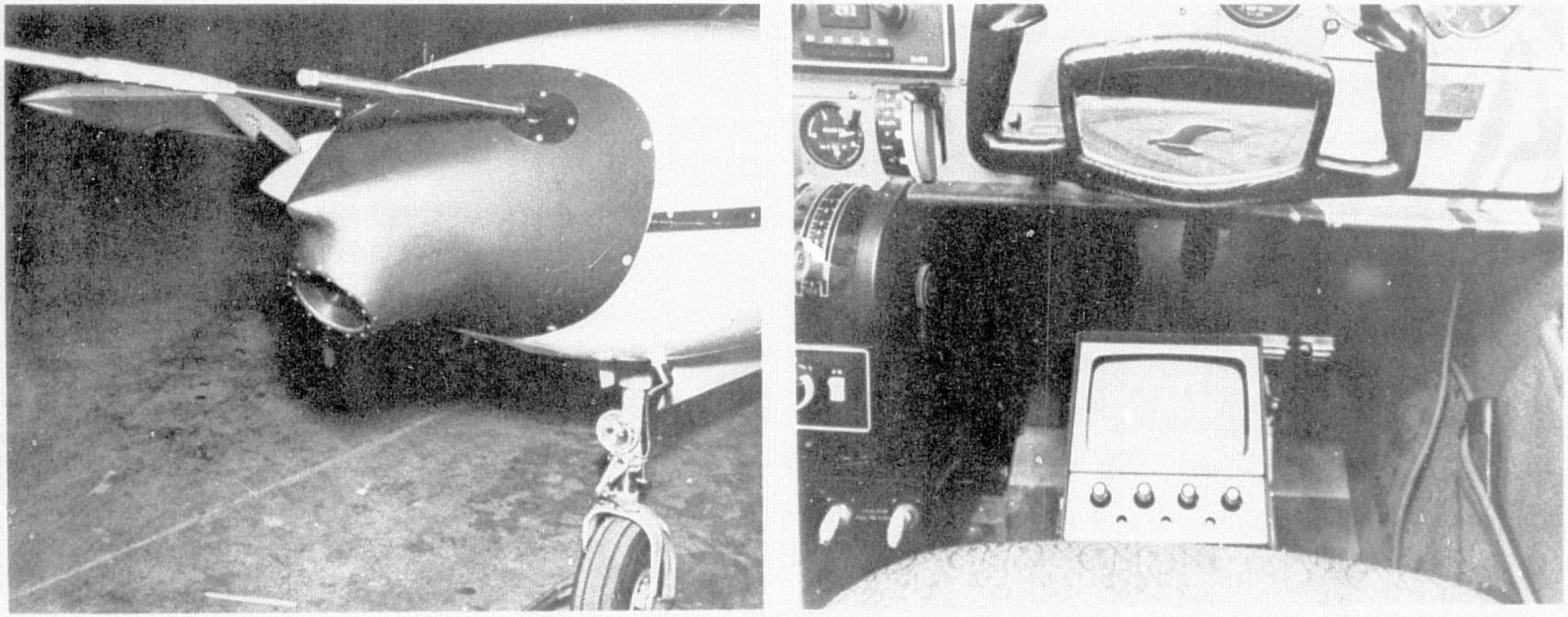

FIGURE 4.– AIRCRAFT INSTALLATION OF EQUIPMENT.

LEFT: SPECIAL NOSE IN WHICH TV CAMERAS WERE MOUNTED.

RIGHT: SMALL TV MONITOR IN FRONT OF CO-PILOT'S SEAT.

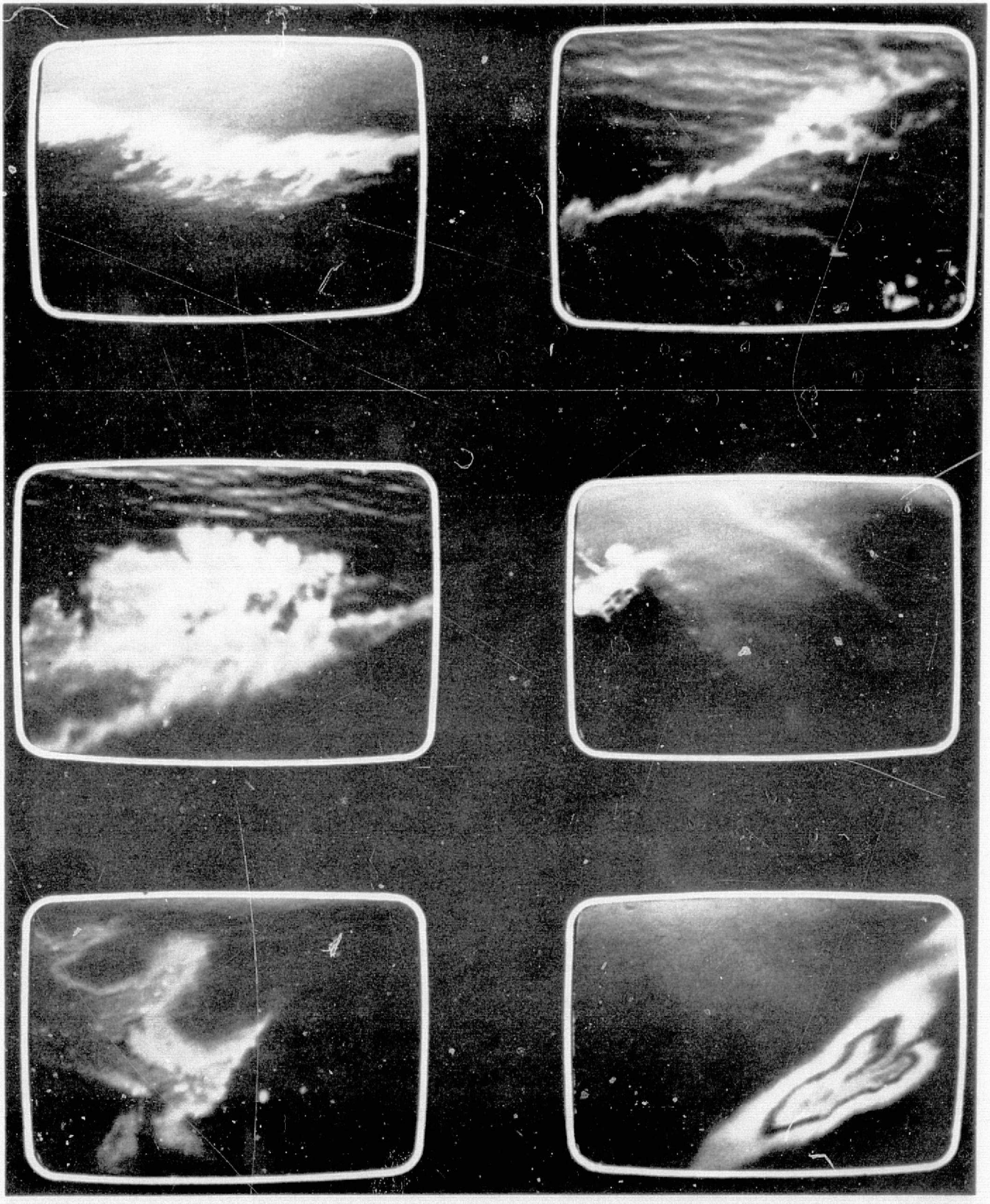

FIGURE 5.– IMAGERY ACQUIRED WITH CONVENTIONAL BLACK AND WHITE SYSTEM OVER NATURAL SLICKS IN THE SANTA BARBARA CHANNEL.

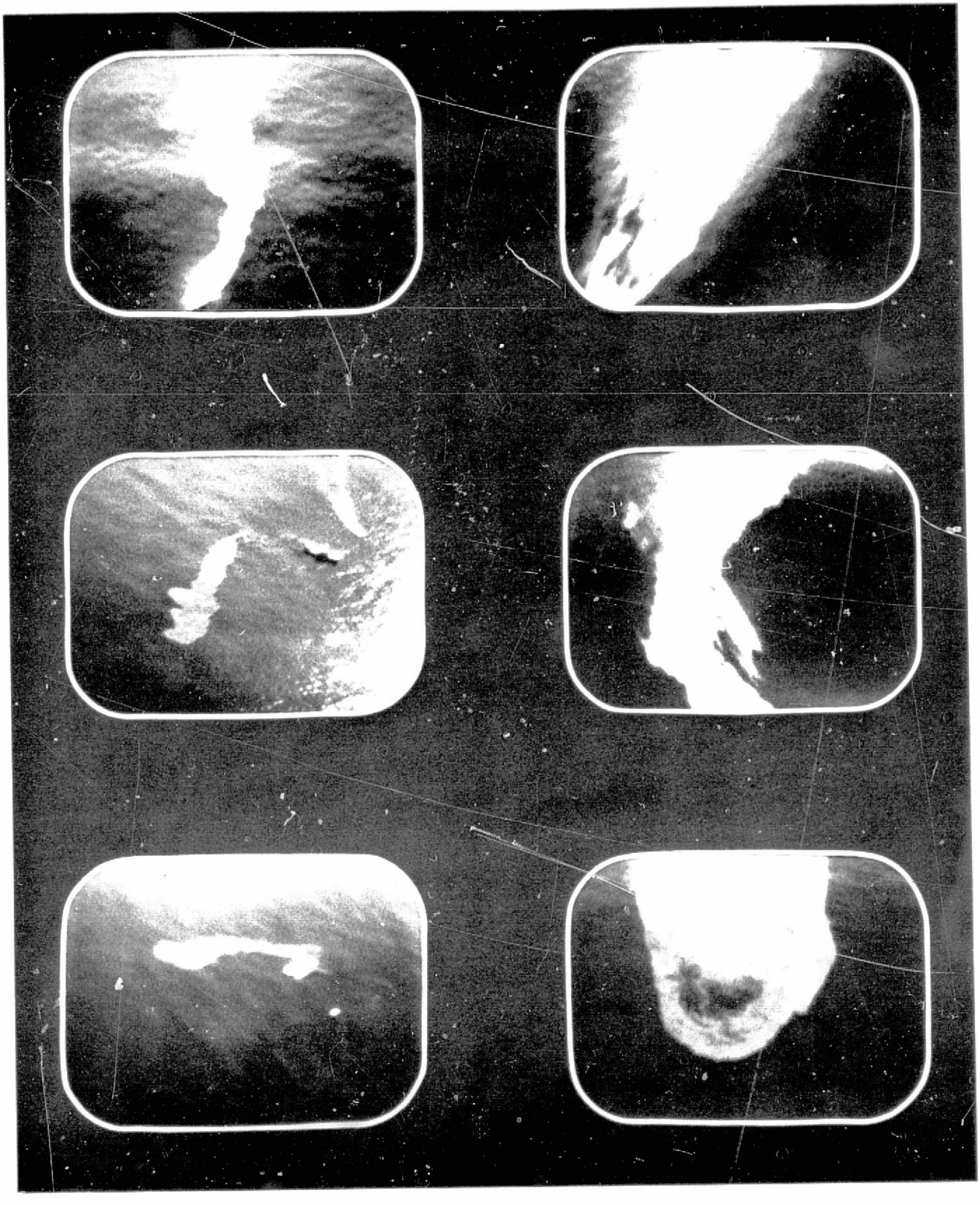

FIGURE 6. IMAGERY ACQUIRED WITH CONVENTIONAL BLACK AND WHITE SYSTEM OVER AOSS OIL SPILL TEST SITES.

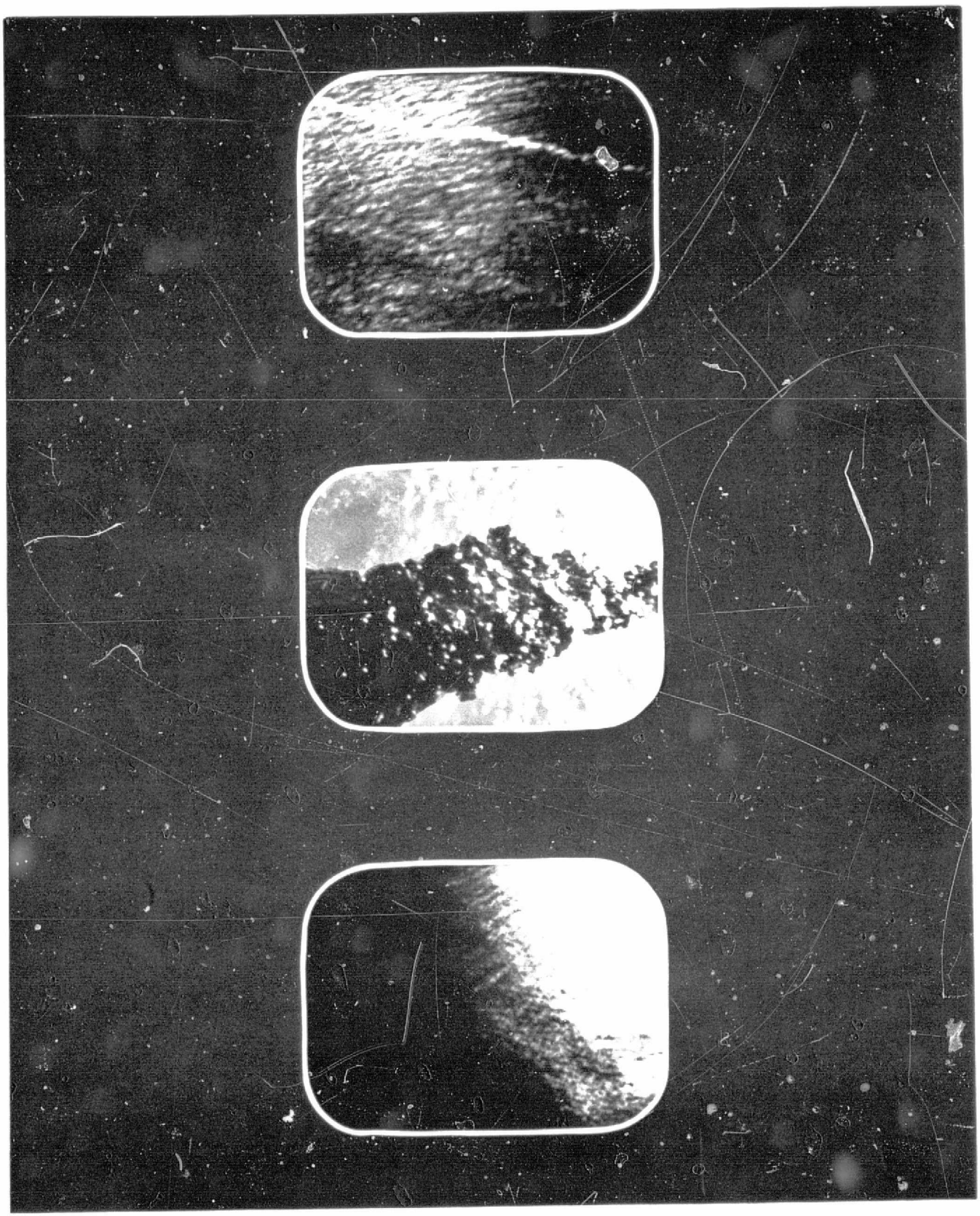

FIGURE 7. — ILLUSTRATIONS OF SOLAR EFFECTS.

FIGURE 8.— FALSE-COLOR ENHANCED IMAGE OF OIL SLICK.

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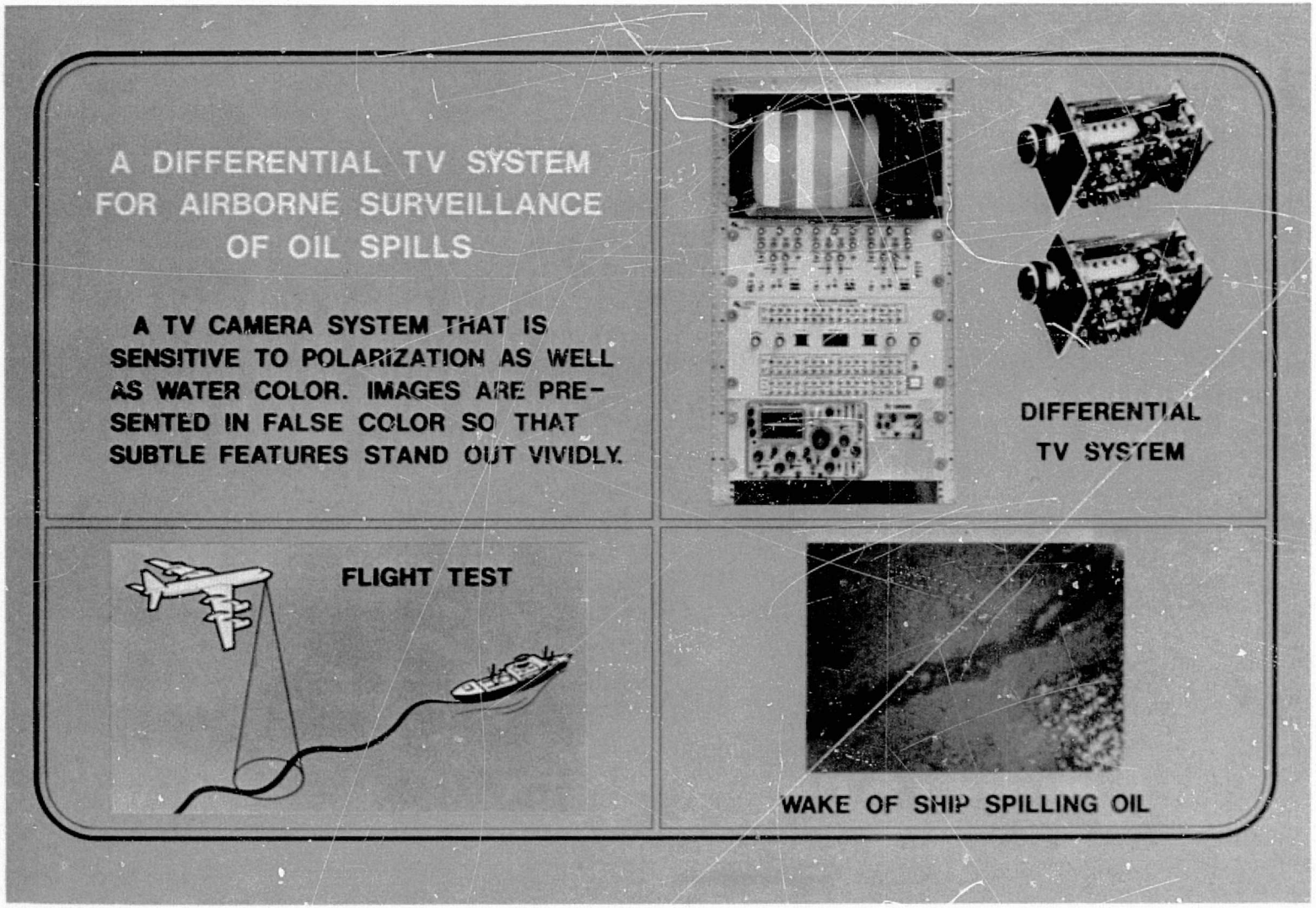

FIGURE 9.– DIFFERENTIAL TV SYSTEM AND IMAGERY.

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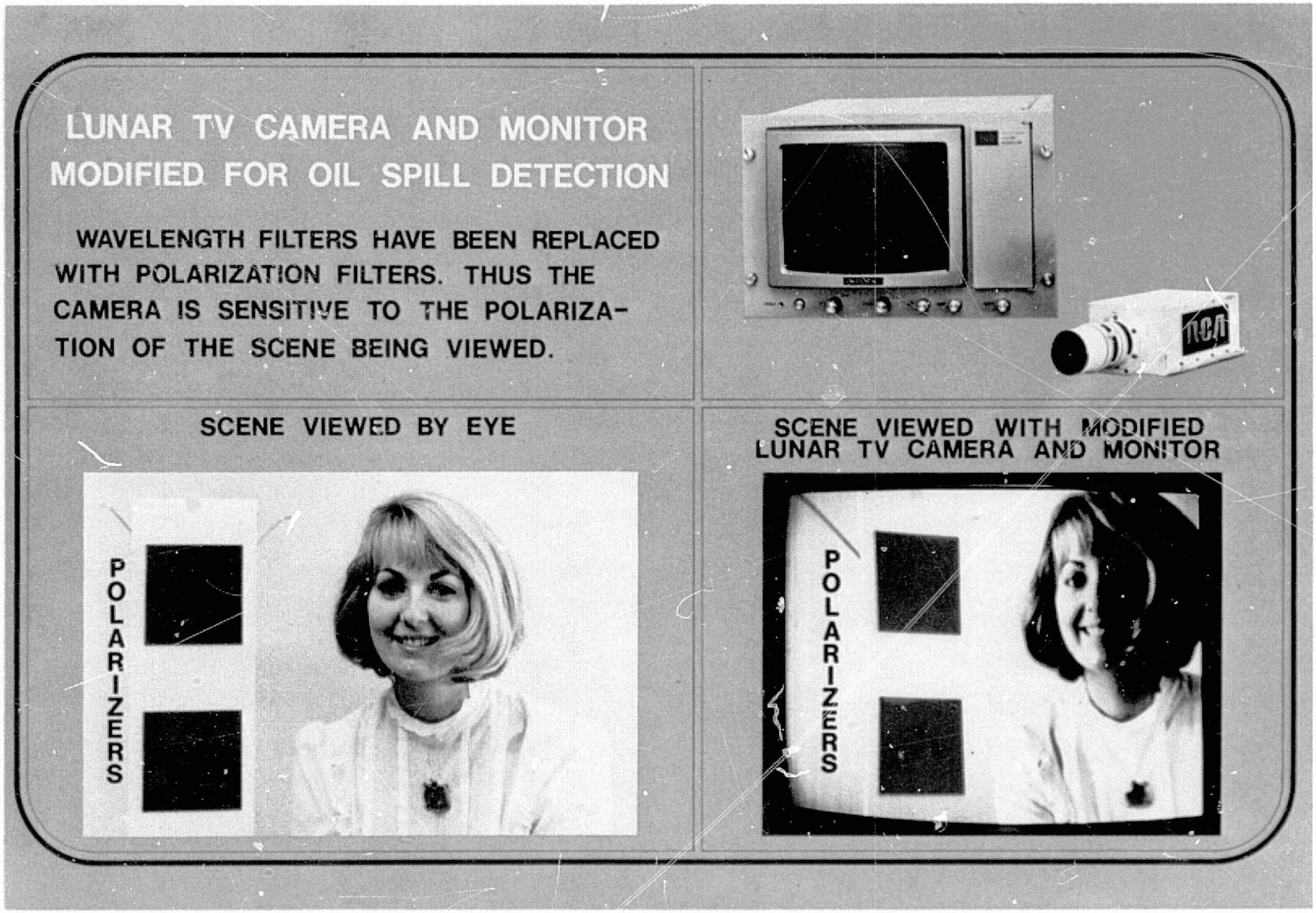

FIGURE 10.– LUNAR TV CAMERA AND LABORATORY RESULTS.