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**DEVELOPMENT AND FIELD TESTING  
OF A LIGHT AIRCRAFT OIL  
SURVEILLANCE SYSTEM (LAOSS)**

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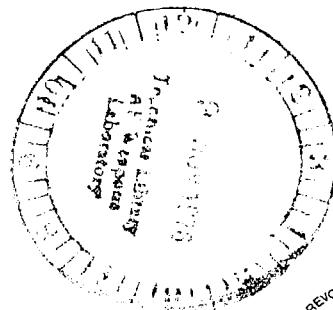
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16. Abstract  An experimental device consisting of a conventional TV camera with a low light level photo image tube and motor driven polarized filter arrangement was constructed to provide a remote means of discriminating the presence of oil on water surfaces. This polarized light filtering system permitted a series of successive, rapid changes between the vertical and horizontal components of reflected polarized skylight and caused the oil based substances to be more easily observed and identified as a flashing image against a relatively static water surface background. This instrument was flight tested, and the results, with targets of opportunity and more systematic test site data, indicate the potential usefulness of this airborne remote sensing instrument.					
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# DEVELOPMENT AND FIELD TESTING OF A LIGHT AIRCRAFT OIL SURVEILLANCE SYSTEM (LAOSS)

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## SUMMARY

This program was undertaken to develop and evaluate a polarization filtering device for use with a video system designed to detect and document oil spills through video tape recordings.

Using a test site where small controlled oil spills could be viewed from an aircraft, a series of flights were made to test the capability of the experimental instrument and to identify factors affecting its practical use. In addition, the apparatus was utilized on numerous flights where targets of opportunity were observed and recorded.

The results indicate that the system is usable under all daylight conditions, i.e., before sunrise and after sunset so long as there is enough skylight to permit visual observation. Oil film thickness did not appear to have a major effect upon observation techniques. Viewing distance also did not appear to have a major effect upon the system as the instrument appeared equally effective at distances ranging up to several miles, although the reduction in target image size at greater distances may present a practical limitation. The effects of sun and view angle were also assessed. On the one hand, where sky state was such that clouds blocked direct sunlight from illuminating the scene, the normally critical effects of solar elevation and azimuth were almost totally negated. View angle was also not critical but it appeared that shallow ( $30^{\circ}$ ) views may be slightly superior to steep ( $60^{\circ}$ )

view angles. On the other hand, where there was direct sunlight, there appeared to be a rather uniform curve of diminished response as the sun approached its highest point. The diminishing effects of direct, overhead sunlight can be overcome with the use of view angles that position the observer between the sun and the target.

The results indicate that the use of polarization filtering with a standard portable video camera can significantly enhance the contrast between oil and water. The instrumentation package developed during this program can be handheld aboard light aircraft and shows great promise for detecting and producing hard copy records of oil spills.

## INTRODUCTION

Previous research by Millard and Arvesen<sup>1,2,3</sup> indicates that polarization filtering can enhance the contrast between oil and water and, therefore, facilitate the detection of oil targets on water surfaces. This project was designed to use polarization filtering techniques to develop a low cost, light weight, remote sensing instrument for use in oil spill surveillance with light aircraft.

Other systems which have proven successful in oil surveillance have, in general, proved to be complex, expensive, and incapable of use in light aircraft.<sup>4</sup> In the search for alternative oil surveillance systems, the prior work of Millard and Arvesen, NASA Ames Research Center, showed the most promise for a possible reduction to a simple instrumentation package. The present project is an extension of this prior work. However, the significant difference in the application of hardware is in the use of a single closed circuit television (CCTV) camera combined with a motor driven polarization filter to offer a rapid comparison of the horizontal and vertical components of reflected polarized skylight.

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<sup>1</sup>Millard, J.P.; Arvesen, J.C.; Effects of Skylight Polarization, Cloudiness and View Angle on the Detection of Oil on Water. American Institute of Aeronautics and Astronautics, Paper No. 71-1075, 1971.

<sup>2</sup>Millard, J.P.; Arvesen, J.C.; and Lewis, P.L.: Development and Test of Video Systems of Airborne Surveillance of Oil Spills. TM-X-62, 429, 1975.

<sup>3</sup>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.

<sup>4</sup>Edgerton, A.T.; Bommarito, J.J.; Schwantje, R.S.; and Meeks, D.C.: Development of Prototype Airborne Oil Surveillance System. CG-D-9075, 1975.

## OBJECTIVES

The project was designed with two objectives in mind.

### Parametric Data

It was proposed that data be collected to assess the effectiveness of this instrument as it related to solar and view angle geometry, sky state conditions, and to test the instrument's capability for discriminating among oil types and oil film thicknesses.

### Targets of Opportunity

Using a number of possible sources to be found in the San Francisco Bay Area, it was proposed that the instrument be used to locate probable oil spill targets and that, whenever possible, ground truth verification be performed in order to prove the reliability of the instrument. A further objective of the target of opportunity phase was to establish the capability of the instrument to give a negative indication for a possible target which could appear to an observer as a possible oil target but which in fact would not be oil

## PROCEDURE

To accomplish these objectives, the following special equipment and procedures were used.

### Equipment

CCTV: In order to develop a light weight system that could be used in a light aircraft, it was necessary to select a unit that was fully portable and independent of the aircraft electrical system since 110 AC conversion systems capable of operating CCTV equipment are impractical for light aircraft. The unit selected was a Panasonic 3085 Camera using an 8:1 Fuji zoom lens, and a Panasonic 3082 Videotape recorder. The camera was mounted on a modified gunstock to improve recording

techniques for field use (see Figures 1-3). This camera's principal difference from conventional CCTV camera units was the special installation of the Newvicon photo-image tube.

Newvicon Photo Image Tube: The spectral sensitivity curves for the Newvicon tube are shown in Figure 4. Compared with silicon vidicons, the Newvicon yields higher resolutions and a diminished blooming effect, in response to intense light, factors important in our choice of a vidicon.

Kodak 18A Filter: Wavelength filtering was employed to enhance the contrast between oil and water, the rationale being that this would allow surface features of the water to be emphasized rather than subsurface features. Previous research has indicated that the best contrast can be obtained in the near-ultraviolet and optical infrared portions of the spectrum<sup>2</sup>, the regions of maximal transmission for the 18A filter. It is in these portions of the spectrum that water absorbs much of the backscattered light and causes the contrast between oil and water to be determined primarily by surface reflectances. Oil, having a higher reflectance than water, therefore appears as a brighter image.

Polarized Filter Rotation: Based on previous work indicating that polarization enhances the contrast between oil and water<sup>2</sup>, we developed a system for rotation of the polarizing filter which would permit the rapid comparison of the vertical and horizontal light components. Rotation of the filter at approximately 60 rpm (240 polar plane changes per minute) produced a video image which would flash or "strobe" in the presence of oil, making the detection of oil targets greatly simplified.

## Site

Permit Procedures: In order to have a test site that was environmentally safe, a special, diked-off area in the Albany, California land-fill area was selected for controlled oil spills. (See Figures 5 and 6). Long and unanticipated delays were encountered in going through the official permit procedures to the satisfaction of the appropriate Federal, State and local authorities in order to proceed with the project.

Containment: Since it was necessary to guarantee that this project would not pollute the local environment, containment of the controlled oil spill was effected through the use of oil booms within a diked-off area. The containment booms, 33 meters long, were originally set up so that three target areas could be used to view three types of oil. As this proved to be too small a target for airborne observation, the three booms were made into one large, 100 meter perimeter boom.

Environmental Considerations: The use of the booms proved to be, for local environmental considerations, a compromise as it was difficult to get exact data on oil film thicknesses in a small enclosed area. The wind had a tendency to "pile up" the oil along the leeward side of the booms before the oil had time to spread out to a natural thickness.

## RESULTS

### Targets of Opportunity

Vessel Discharge: One of the first targets detected by this system was a vessel discharge which later was described by the vessel operator as the result of pumping water from its fire system tank. This observation remains an unresolved dispute, since the target observed by LAOSS gave the definite flashing response characteristic of oil from only a small portion (less than 15%) of the total spill area.



Richmond, California, Oil Ponds: The Richmond Standard Oil Refinery on San Francisco Bay is generally a good test site for airborne oil surveillance systems development. The ponds, which are visible in the lower right center of Figure 7, as light colored ovals, cannot be seen with the polarizing filter rotated  $90^{\circ}$  as in Figure 8. They appear to contain petroleum products and seem to be used as settling ponds. (Note that Figures 7 - 16 are presented in "polar plane pairs", where comparisons can be made between views with  $90^{\circ}$  rotational differences in the polarizing filter position. The continuous rotation of the filter appears to produce a rapid blinking of the target on the CCTV monitor as the filter moves through polar-plane changes).

Surprise Target, Restaurant Refuse: On one particular flight, a blinking "oil target" response was observed by the instrument in an area where oil slicks were not expected to be found, i.e., a shallow water location ostensibly isolated from industry (see Figures 9 and 10). Ground truth verification was possible since this observation was reported to local USCG officials who determined that the "oil target" appeared to be kitchen grease, apparently discharged from a nearby waterfront restaurant. It should be noted that this target was detected only as a result of its blinking on the monitor and was hardly visible to the naked eye.

Creosote: Another example of the sensitivity of this instrument involved the observation of an oil slick that was thought to be coming from a boat exiting the Richmond, California Channel area. A closer observation of the video tape record, where motion can be observed, shows that the oil slick was in fact in place before the arrival of the boat. USCG response to this observation indicated that oil was in fact creosote that had leached from newly installed pilings (see Figures 11 and 12). This target was observed at an altitude of 500 meters and at the time it was not anticipated that such a thin film of oil would appear as such a strong image.

Pillar Point, California, Oil Spill: A large oil spill several miles in length was reported off Pillar Point in the last week of August, 1975. Low cloud cover over the ocean made aerial reconnaissance impossible until one week after the spill was initially reported, when a coast-line search was carried out. Flying south from San Francisco at 2660 meters, a Cessna 182 carried the instrument to the reported location, but nothing was found immediately. Continuing the search, the remaining streaks of the major oil slick were found 29 miles offshore and 70 miles south of the originally reported location. (See Figures 13 and 14). The fact that this instrument was able to locate small slicks of less than 70 meters in size, after it was thought that the spill had broken up and become undetectable, points to the potential usefulness of this instrument as a practical operational tool.

Proof of the Negative: On several occasions, water discoloration, stains, or other possible "false target" images which were apparent to the observer were viewed with the instruments. These targets did not produce the characteristic "flash" that an experienced observer would associate as a probable oil target. In these cases, the targets were found to be turbidity caused by ships in shallow water, the phenomenon of wind sheer (see Figures 15 and 16), which from a great distance can appear as an oil slick, or areas of "red tide" or algae blooms.

#### Parametric Data

Oil Types: Samples of Mid Gravity Crude Oil (API Gravity 21), Bunker Fuel Oil (API Gravity 12), and Diesel Oil (API Gravity 35) were compared in terms of their discriminability. Although there appeared to be differences in the reflectance characteristics of oil types, oil viscosity, wind conditions, and the time required for different oil types to reach a "natural" spread thickness before the oil became windblown to the container boundary made it difficult to determine whether the different appearances were a function of film thickness, oil type or interaction.

In order to determine the capabilities of the system for discriminating among many different types of oil, or to establish identification keys for oil typing, a much more thorough investigation will be necessary where a variety of factors can be better controlled in a laboratory tank situation.

Film Thickness: Uniformly thick films of oil were not obtained because wind caused the oil to pile up at one edge of the container barrier. The film thicknesses were estimated to be between 1000 to 4000 nm. But, it should be emphasized that small oil spills in surface wind conditions gusting up to 20 knots tend to make any attempt at accurate assessment of film thickness impractical. This parameter too can only be accurately determined in a laboratory tank situation.

Sky State: Circular flight paths were flown around the oil target to assess observation conditions as affected by viewing azimuth relative to the sun's position. Viewing angles were established by using ground reference points of known distances from targets to set the radius of the circular flight path and using aircraft altimeter to vary the altitude so that the viewing angles would be determined trigonometrically, e.g., flying over a ground reference point 333 meters from the target at an altitude of 333 meters would give a view angle of  $45^{\circ}$ . It should be noted that the use of a zoom lens to keep the target large may have tended to create the impression that different view angles were employed. This is merely a camera illusion.

#### Overcast Sky

Although it has been reported that overcast days are best for locating water surface oil targets<sup>1,5</sup> it is of further significance to note that under overcast sky, or

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<sup>5</sup>Welch, R.I.: Remote Sensing in California Water Resource Management. Proceedings of American Society for Photogrammetry, 1968; 330-344

in any situation where even partial cloud cover obscured the direct light of the sun from the target, view angle, sun angle, or view azimuth relating to the sun had minimal effect on target image brightness, ie., the contrast between the water and the oil target surface remained relatively constant.

#### Clear Sky, Direct Sunlight

View Azimuth and Solar Angle: In this discussion, rather than use degree measurement for observations which can best be described as approximate, it is more convenient to describe azimuth view by "clock" position references where the sun will always be at the "12 o'clock" position, and the view azimuth will always be referred to as the position on the clock of the viewing instrument.

It was clearly noted in this study that perception of reflected polarized light, which appears to be highly directional, was very pronounced where the sun's position was near the horizon and became less pronounced as the sun approached its zenith. Therefore, depending upon latitude and season, mid-day would generally be a poor time to observe the effects of reflected polarized skylight. For the San Francisco Bay Area, during the month of October, a "best" viewing azimuth relating to the sun's position was not apparent between the hours of 1000 and 1400. At about 1545 hours, when the sun's elevation was between  $30^{\circ}$  and  $45^{\circ}$ , best view azimuth positions were surprisingly at the "5 o'clock" and "7 o'clock" positions. Figures 17-28 illustrate a series of images of test spills recorded from various view angles. Although it may have been logical to assume that some linear increase and decrease in the contrast between the oil target image and water would result from a 360 degree turn about the target, this never appeared to be the case. Instead, assuming the circular flight to begin at the "12 o'clock" position, (viewing the target directly away from the sun), the target image brightness decreased as the observation position moved from "12 o'clock" to "3 o'clock". Conversely, brightness increased as

the "5 o'clock" position was approached where the target, almost directly in line with the sun, rapidly began to increase in brightness to its brightest point (see Figures 17, 21 and 25) just before the entire image was "washed out" by the sun glare. It is apparent from these photos that viewing angles between  $30^{\circ}$  and  $60^{\circ}$  were equally effective in producing maximal contrast between oil and water in direct sunlight.

A review of some of the video tapes suggest that there also appeared to be a brief "null zone" that occurred immediately prior to and immediately after the "glare out" at the "6 o'clock" position. That is, rather than assume a single uniform brightness between the "5 o'clock" and "7 o'clock" positions where the direct light of the sun merely obscures the "6 o'clock" position with a high intensity glare, it would appear that two distinct prime view azimuth directions exist on either side of the reflected sun glare (see Figures 29-44). Both of these view azimuth directions appeared to be less than 10 degrees wide.

As a result of this, a search pattern for water surface targets would be best designed to position the observer to view into, rather than away from the sun. This assumes that the observer is trained to observe that the best view azimuth for a bright sun day is likely to be found in the most difficult area to see, i.e., about 8 to 12 degrees into either side of the direct reflected glare of the sun.

View Angle: Although considerable effort was made to maintain precise view angles, there did not appear to be significant differences among view angles of 30 degrees, 45 degrees and 60 degrees (see Figures 17-28).

Distance: Distance did not prove to be a major factor affecting the capability of the system to detect oil. That is, if a target was in viewing range, and if the critical circumstances of view azimuth and sun position would permit, the oil target

could be observed. The alternations of the polarization filter enhanced oil/water contrast and permitted detection of oil targets over distances ranging as great as 6 miles.

### Other Findings

Review of the video tape record of the Pillar Point oil slick (August 27, 1975) demonstrated an unanticipated capability of this oil surveillance system. Video tape evidence suggests that the system is capable of differentiating a variety of oil spill ages.

Sixteen days after the initial report of the 13 mile long Pillar Point oil slick, a target of opportunity search was made to locate remnants of the major slick, (see discussion above, and Figures 7 and 8). A number of small "oil type" targets began to "flash" on the view finder scope of the instrument. However, these targets proved to be significantly different than any other oil type target observed during this study. From an altitude of 2700 meters, small areas of the water surface gave off "oil reflectance signature" which we have come to recognize with the LAOSS instrument. As these probable oil targets were approached, bright streaks of material which appeared to have the cohesive "oil type" appearance could be observed by eye. However, these very prominent bright streaks did not appear to "flash" when observed through the rotating polarized filter of the instrument, and were therefore initially ignored as a probable oil target. The material that did "flash" appeared as a light, thin film, oil slick. It should be noted that both types of material generally appeared in the same area, i.e., the probable thin film oil target seemed to surround the more prominent appearing brighter material.

It is quite possible that this was an example of an ageing process in which ocean wave activity separated oil into at least two components, the highly volatile substance

which evaporated into the atmosphere and the lower volatility mass which increased in density, and finally became heavier than water, eventually sinking.

## CONCLUSIONS

The results obtained indicate that the LAOSS system is extremely useful in the detection of oil on a water surface background. The observations of targets of opportunity as well as the more systematic demonstrations performed at the test site suggest that the system will function under a variety of light levels, sky conditions, sun, view and azimuth angles. Although the contrast between oil targets and water is not constant under all conditions, the results indicate that the images recorded under most of the observation conditions encountered permit the detection of even very small quantities of oil on water.

These observations suggest a number of areas in which future research should be helpful. Because of the difficulties encountered in controlling a number of parameters investigated during the period of this contract, it would appear that recordings made under the same conditions, which can be varied more systematically in a laboratory tank situation, would yield more definitive conclusions regarding sun angle, film thickness and oil type. In addition, it is felt that an important surveillance function could be performed utilizing a stationary system mounted either on the Golden Gate or Oakland Bay Bridges where a continuous record of vessel traffic and possible spills could be made. Preliminary discussions with video systems engineers indicate that such equipment could be constructed and installed quite easily and that with time-lapse capability, a continuous video tape record could be made which would permit the detection and identification of illegally discharging vessels.

Finally, it is our conclusion that the results obtained indicate that this system

should continue to be operated to locate and document oil spills. The potential usefulness of this LAOSS system suggests a technique which can be utilized throughout the coastal and inland jurisdiction of the Coast Guard to supplement the visual detection of spills by aerial surveillance. We are hopeful that the results presented in this report warrant the investment of further time, energy and financial support to continued documentation of the utility of this system.

#### ACKNOWLEDGMENTS

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## FIGURE CAPTIONS

- Figure 1: Side view of Light Aircraft Oil Surveillance System (LAOSS) showing video camera with polarizing filter rotator attached to zoom lens. Chassis box directly below zoom lens contains potentiometer which varies rate of filter rotation.
- Figure 2: Close-up of LAOSS filter rotation system showing rubber drive wheel in contact with gear of filter housing.
- Figure 3: Side view of LAOSS in position for operation.
- Figure 4: Spectral sensitivity of various vidicons.
- Figure 5: Location of test site.
- Figure 6: Aerial view of test site, showing circular conformation of oil boom (approximately 100 meter circumference) inside diked area of Albany, California land fill. Long axis of rectangular shaped diked area is approximately north-south with north at the right end of photo.
- Figure 7: Oil refinery ponds, Richmond, California. Figure 7 shows two small ponds with presence of oil lower right center. Figure 8 shows the same area with polarizing filter  $90^{\circ}$  from Figure 7 with ponds no longer visible.
- Figure 9: Berkeley waterfront. Figure 9 shows slick from restaurant kitchen cooking grease (ground truth by USCG). Figure 10 is of the same area with  $90^{\circ}$  change in filter orientation.
- Figure 10: Figure 10 is of the same area with  $90^{\circ}$  change in filter orientation.
- Figure 11: Richmond waterfront. Figure 11 shows creosote leaching from newly painted pilings (ground truth by USCG). Figure 12 is of the same area with  $90^{\circ}$  change in filter orientation.
- Figure 12: Figure 12 is of the same area with  $90^{\circ}$  change in filter orientation.
- Figure 13: Aerial views of Pillar Point oil spill at approximately  $37^{\circ}00' \text{ N } 122^{\circ}50' \text{ W}$  taken from an altitude of 1100 meters, approximately 2 miles from the spill. Figure 13 shows the spill with the polarizing filter in the horizontal and Figure 14 in the vertical position.
- Figure 14: Figure 14 in the vertical position.
- Figure 15: Berkeley waterfront. Although "flat spots" caused by water surface wind sheer also appeared to strobe in a manner similar to an oil target, the vertical component (Figure 15) shows the wind sheer to be observed as the darker (upper streak) compared to the oil which was hardly visible. The horizontal component (Figure 16), although intensifying both targets, shows the oil (lower streaks) as the brighter images.
- Figure 16: The horizontal component (Figure 16), although intensifying both targets, shows the oil (lower streaks) as the brighter images.
- Figure 17: Aerial views of bunker fuel oil (12 gravity) inside boom as plane circles site with approximately  $60^{\circ}$  view angle at 1545 hours. Sky condition was broken clouds and sun angle between  $30^{\circ}$  and  $45^{\circ}$ . Figure 17 was taken looking in a northwesterly direction ( $315^{\circ}$ ) and Figures 18-20 in approximately  $90^{\circ}$  increments.
- Figure 18: Figures 18-20 in approximately  $90^{\circ}$  increments.
- Figure 19: Figures 18-20 in approximately  $90^{\circ}$  increments.
- Figure 20: Figures 18-20 in approximately  $90^{\circ}$  increments.

Figure 21: Taken ten minutes later than Figures 17-20 at approximately  $45^{\circ}$  angle  
Figure 22: of view. All other conditions are the same as in Figures 17-20.  
Figure 23:  
Figure 24:

Figure 25: Taken 15 minutes later than Figures 21-24 at approximately  $30^{\circ}$  angle  
Figure 26: of view. All other conditions are the same as in figures 17-20. Note  
Figure 27: that in each of these three sequences of Figures the one taken looking  
Figure 28: in a northwesterly direction (approximately  $10^{\circ}$  to either side of a base-  
line looking directly into the sun) shows maximal contrast between oil  
and water.

Figures 29 - 44: These figures attempt to show the "null" zone that appears to immediately precede and follow the two optimum view positions to be found on either side of the sun's glare, immediately opposite the sun. Figures 29 - 36 are not continuous from a single flight pass, however, note the great difference of reflectance with such a small difference in viewing azimuth between Figure 30 and Figure 35. Figures 37 - 44 are from one continuous pass and attempt to show the "null" zone. As aircraft flies in counter-clockwise direction, Figure 38 shows increased brightness over 37 as the 6 o'clock position opposite the sun is approached.  
Special Note: Rotating filter was in motion and blocked out the high glare position at the 6 o'clock position during the pass, however, note how the target position of Figure 30 places its azimuth position between the respective positions of Figures 39 and 40. Target brightness appears to fade from the 12 o'clock to the 9 o'clock/ 3 o'clock positions respectively, then appears to grow brighter as the 6 o'clock point is approached. About  $10^{\circ}$  before reaching the 6 o'clock point (Figures 30, 38), oil target flares up at its brightest until obscured totally by sun glare. Immediately after the glare, for less than a second or two (Figure 39) oil target is still visible. However, after the second flash target becomes lost in a "null" zone (Figures 35, 40).

Figure 1

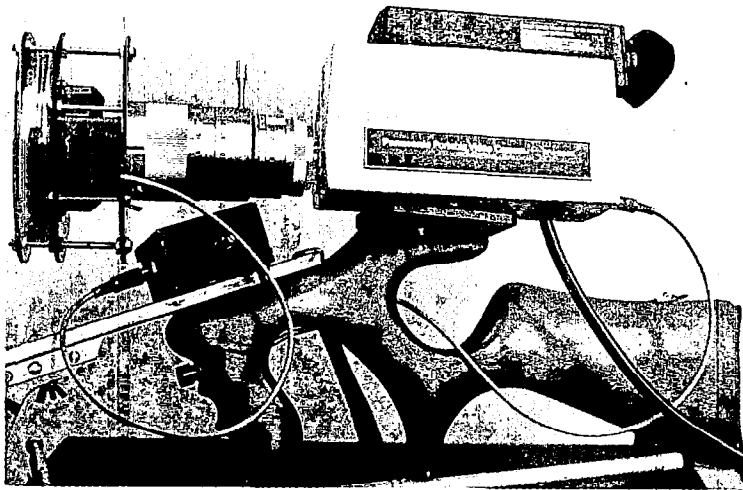


Figure 2

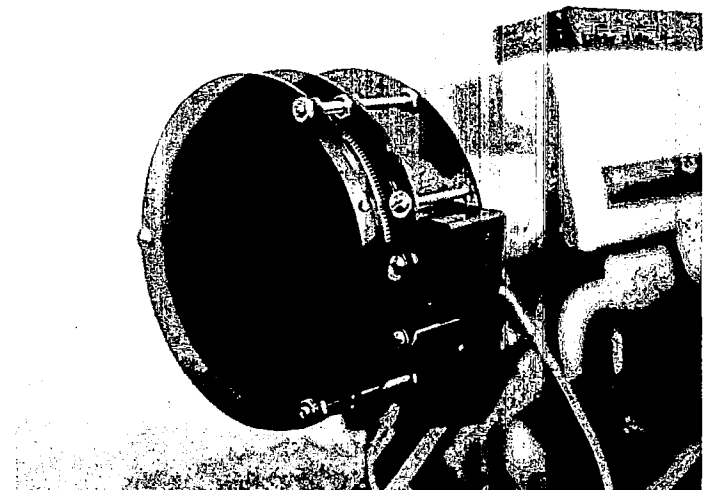
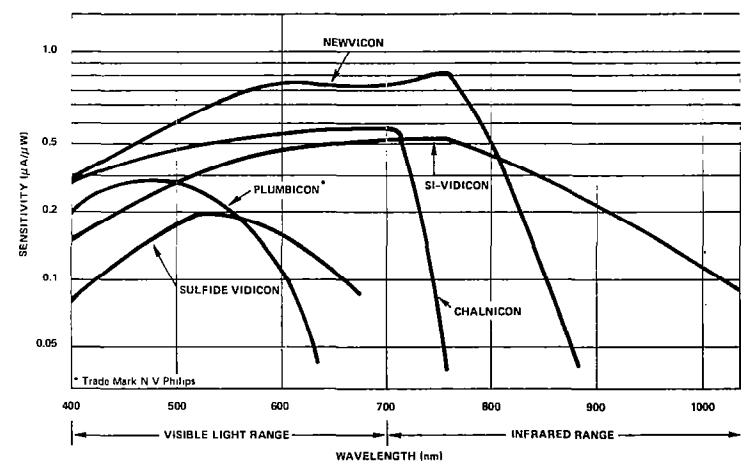


Figure 3



Figure 4



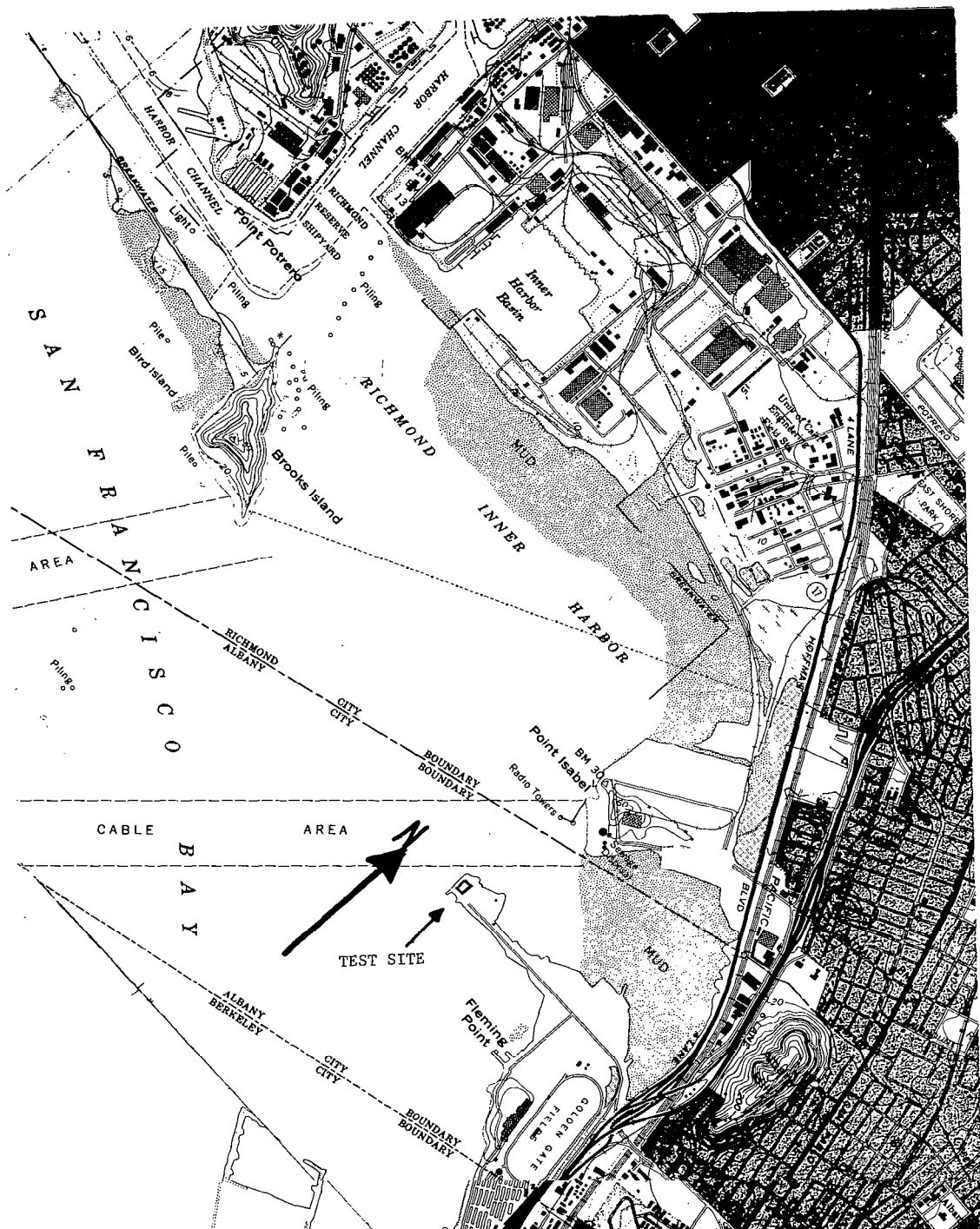


Figure 6



Figure 7



Figure 8



Figure 9



Figure 10

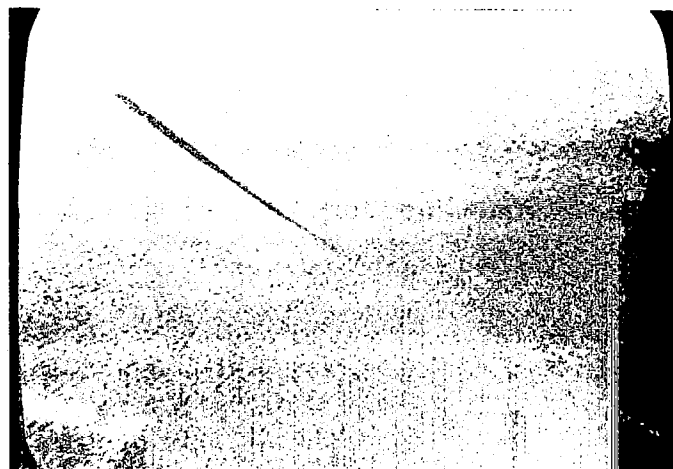


Figure 11

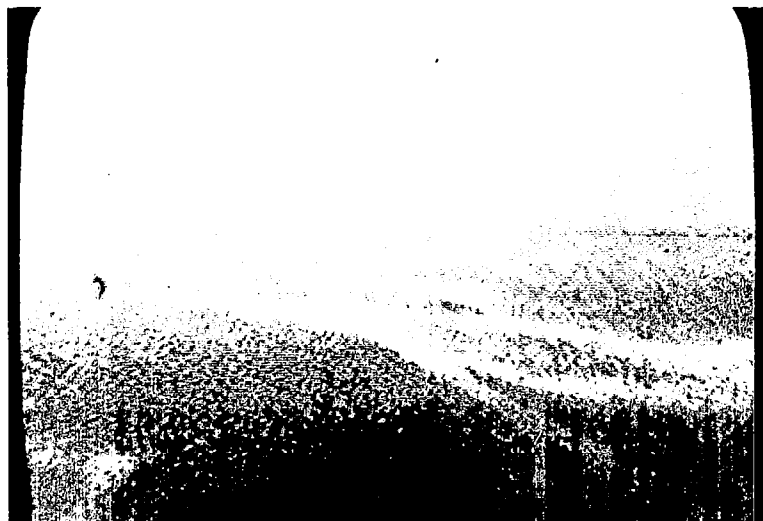


Figure 12

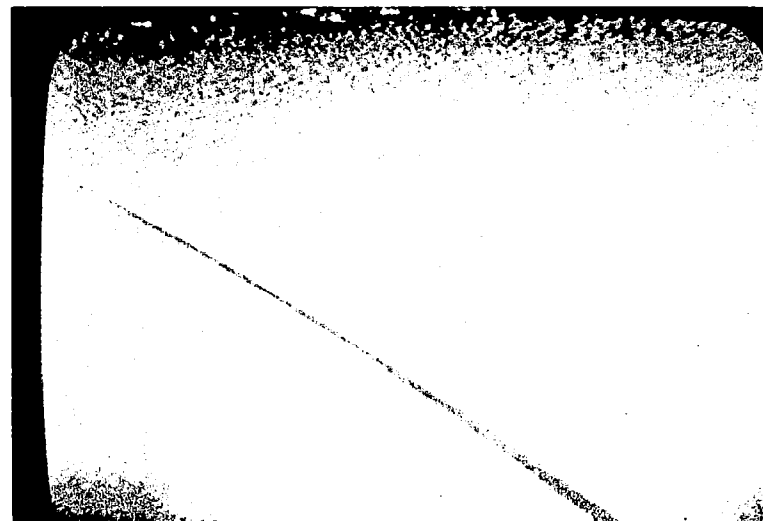


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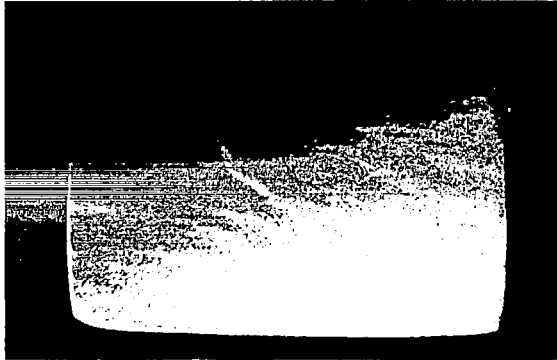


Figure 14



Figure 15

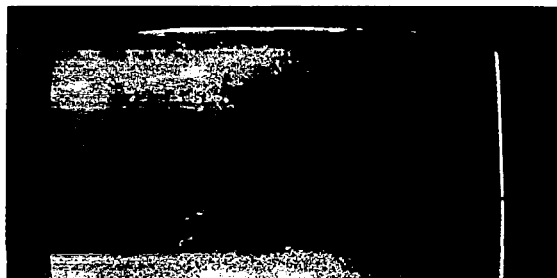


Figure 16



Figure 17



Figure 18

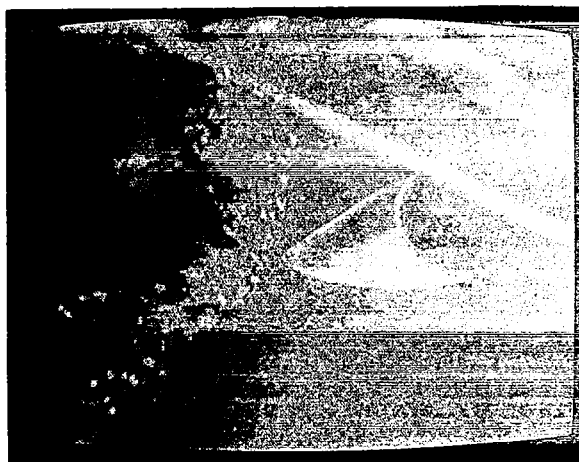


Figure 19

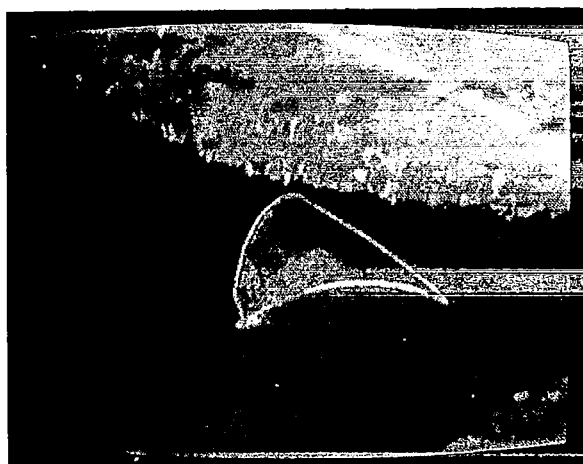


Figure 20

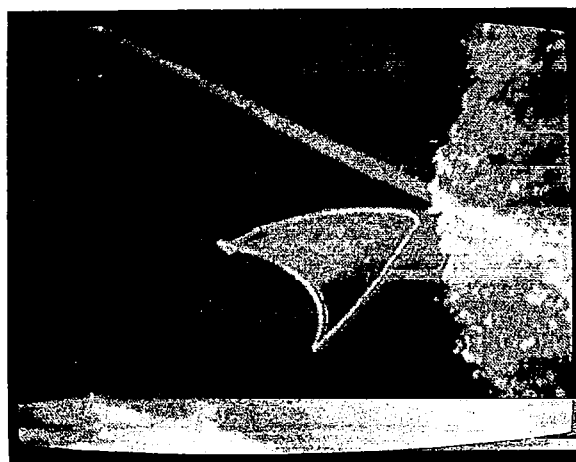




Figure 21



Figure 22

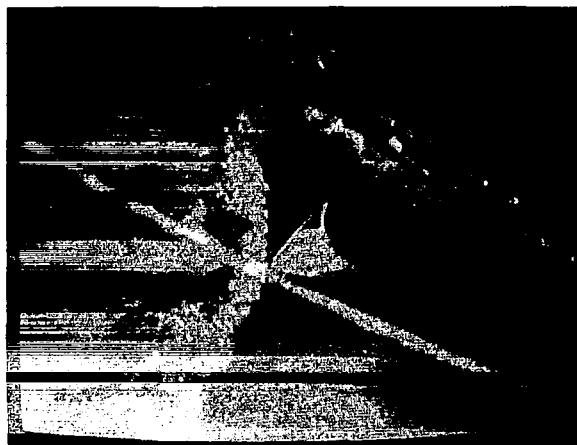


Figure 23

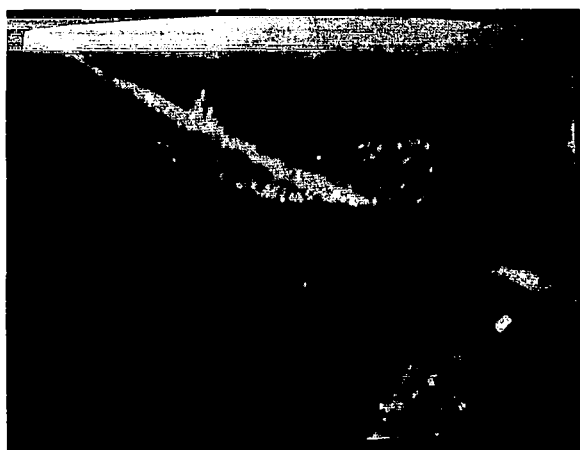


Figure 24

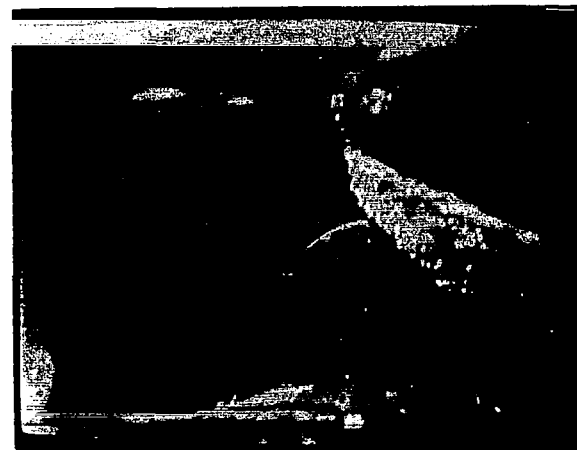


Figure 25

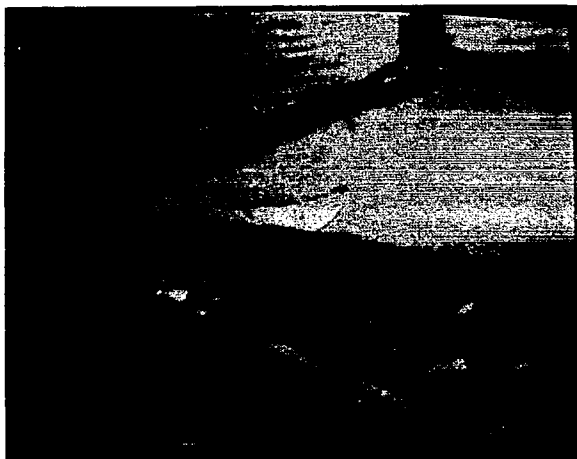


Figure 26



Figure 27



Figure 28

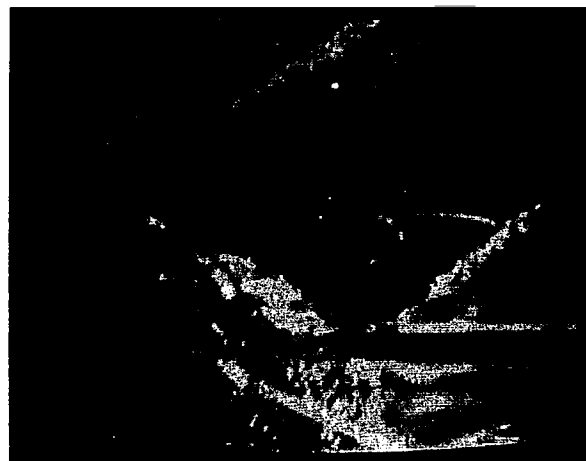


Figure 29

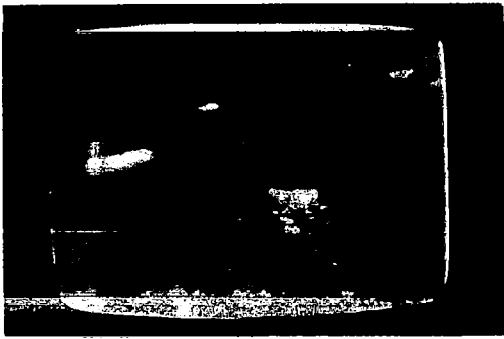


Figure 30



Figure 31

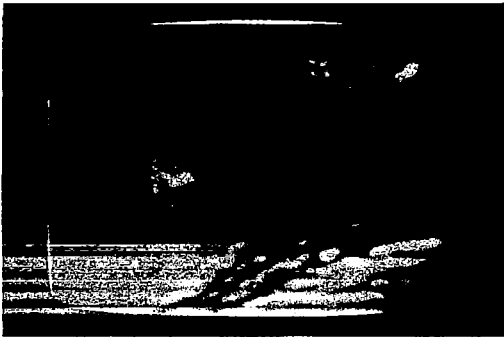


Figure 32

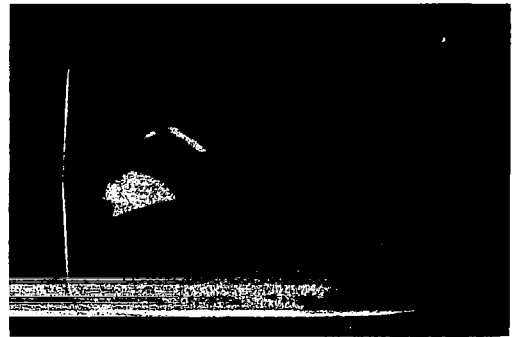


Figure 33



Figure 34



Figure 35

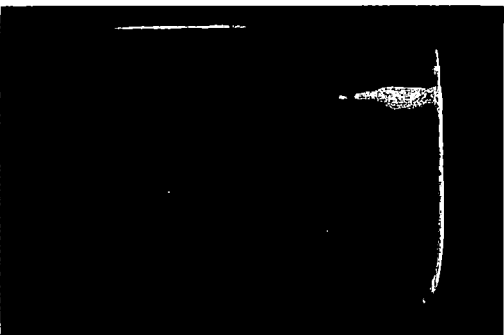


Figure 36

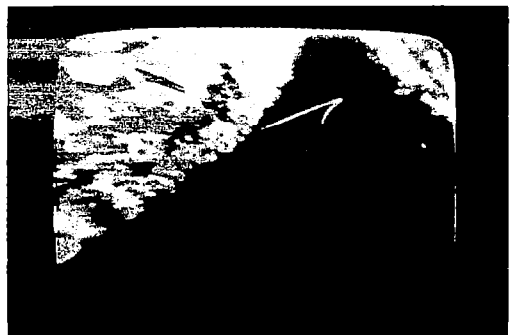


Figure 37

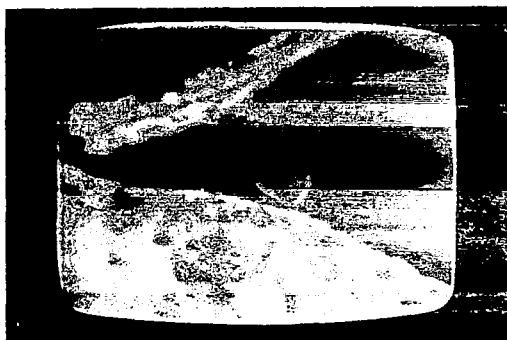


Figure 38

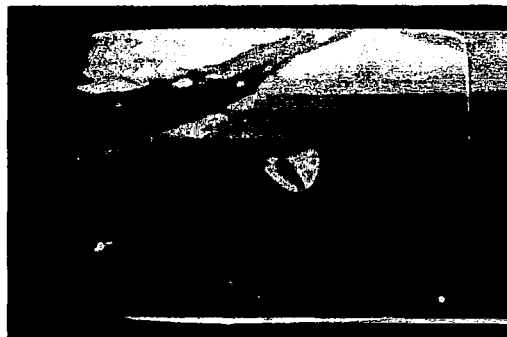


Figure 39

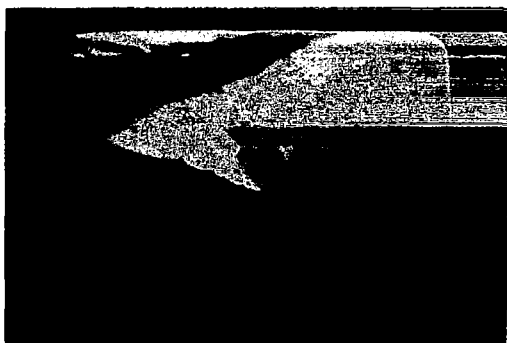


Figure 40



Figure 41



Figure 42



Figure 43



Figure 44

