Airborne Surveillance Technology Options for Improving Oil Spill Clean up and Response

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LIST of ABBREVIATIONS, SYMBOLS and ACRONYMS

Term	Abbreviation or Symbol
Aeronautical Radio, Incorporated	ARINC
Black and White	B&W
Command, Control, and Communication	C3
Charge-Coupled Device	CCD
Commercial Spin-off of Germany's Equivalent of NASA	DLR
Department of Defense	DoD
Environmental Research Institute of Michigan	ERIM
Federal Aviation Administration	FAA
Forward-Looking Infrared	FLIR
Flight Management System	FMS
Federal On-Scene Coordinator	FOSC
Field of View	FOV
FPI Associates, Incorporated	FPI
Geographic Information System	GIS
Global Positioning System	GPS
Intermediate Frequency	IF
Instrument Flight Rules	IFR
Inertial Navigation System	INS
Input/Output	I/O
Infrared	IR
MAR, Incorporated	MAR
MPB Technology, Incorporated	MPB
Marine Spill Response Corporation.	MSRC
MSRC Surveillance System	MSS
Multiplexer	MUX
Noise-Equivalent Radiance	NER
Noise-Equivalent Temperature Difference	NETD
Operational Test Bed	OTB
Pulse Repetition Frequency.	PRF
Research and Development	R&D
Radar Cross Section	RCS
Synthetic Aperture Radar	SAR
Side-Looking Airborne Radar	SLAR
Spill Operations System	SSC
To Be Determined	TBD

Term	Abbreviation or Symbol
TRW, Incorporated	TRW
The Stratos Group.	TSG
Television	TV
Ultrahigh Frequency	UHF
United States Coast Guard	USCG
Ultraviolet	UV
Video Cassette Recorder	VCR
Very High Frequency	VHF
Video Home System	VHS

Airborne Surveillance Technology Options for Improving Oil Spill Clean up and Response

Abstract

The Airborne Surveillance Technology Options for Improving Oil Spill Clean up and Response Design Trade Study was conducted between 6 June and 8 October 1991. This final report contains a summary of the options available to achieve an operational capability for airborne surveillance of oil spills. It includes analyses of available sensors, processing, aircraft, and system alternatives in terms of performance, availability, cost, and risk. The intended purpose of this report is a factual presentation of the alternatives for a procurement decision by the Marine Spill Response Corporation.

1.0 Introduction and Background

This technical report summarizes the findings and provides conclusions and recommendations of options and alternatives for improving oil spill response operational capability using airborne surveillance. It was completed at the end of 1991.

Many factors guided this analysis. One primary consideration included identifying commercial sensor and processor equipment that could be available for initial operation in 1993. Although the focus was near term, options were not restricted solely on the basis of availability for 1993. A second consideration was identifying the types of aircraft that would be suitable for both rapid response and extended surveillance operation. Costs, delivery schedule, engineering and integration risks, performance, and system configuration options were defined and evaluated.

1.1 Study Approach

The study approach consisted of several technical elements:

1. An information needs analysis (Barber *et al.* 1992) was performed as a way to assess the needs and equipment requirements that surveillance could impact;

2. An assessment of aircraft alternatives and deployment concepts was performed. Small and large aircraft using factors such as response time, mission endurance time, payload capacity, and cost were compared;

3. A commercial vendor survey and an assessment of sensors and video equipment were also performed. Data sheets, technical specifications, and selected drawing packages were gathered. Key factors in this assessment (other than performance) were previous testing and product line availability;

4. Processor hardware and software sizing and commercial availability were defined for a common processor functional architecture emphasizing a common processor that can be modularly upgraded for future oil spill information extraction advances;

5. Flight management system (e.g., GPS, radios, INS) commercial packages were surveyed;

6. A mechanical installation analysis and concept level drawings of various equipment were developed to confirm formfit (i.e., weight and space) capacity of candidate aircraft types to carry different equipment packages;

7. Systems analysis was performed on the gathered data. This included defining and assessing equipment/aircraft configuration options, analyzing an interface to the MSRC Spill Operations System (SOS), and combining requirements from various sources.

1.2 Report Contents

This report is organized so that subsequent sections build on previous sections:

- Section 2: Summarizes MSS Requirements that were developed. These requirements provide a basis for comparing system options.
- Section 3: Discusses which sensors and video equipment are available and compares the performance of various sensor types for oil surveillance.
- Section 4: Provides a summary analysis of the sensor processor functions, alternatives for growth, and interfaces to geographic information systems (GIS).
- Section 5: Discusses types of aircraft, capacity, and capability for MSS requirements.
- Section 6: Provides candidate MSS system options and their performance comparisons. Each option is evaluated against the MSS requirements in Section 2.
- Section 7: Provides data and assessment of costs, risks, and integration and engineering issues for acquiring each option.
- Section 8: Provides the conclusions and recommendations derived from the study.

2.0 MSS Requirements Derivation

Two approaches were used to derive the basis for a surveillance system: 1) *An Analysis of Historical Oil Spills and Current Cleanup Requirements to aid in Selecting New Technology for Spill Cleanup Operations* (Barber *et al.* 1992) developed an analytical approach using USCG records and their own experience and 2) The Stratos Group conducted an empirical study (TSG 1992). This section summarizes the findings of the combination of these two approaches.

2.1 Analytical Approach

Barber *et al.* (1992) examined the historical records from 1971 of major oil spills to define oil spill scenarios. The spills were grouped into one of the categories shown in Table 2.1.

Table 2.1 Oil Spill Categories

Category	Number
Structural Failure	2
Collisions	6
Explosions	3
Oil Handling Facilities	5
Groundings	21
Offshore platforms	1
Other	3
Total	41

From (Barber et al. 1992)

These cases were studied to determine: 1) the similarities and differences among the categories; and 2) the information needs that must be satisfied to accomplish an effective spill response with each category. These were then broken down into information elements, which formed the basis for requirements that a surveillance system would have to fill if it were used in spill response (Section 2.3).

Some details of the information elements were provided by researching the actual case histories of several spills and gleaning from them the daily and after-action reports that were filed. Unfortunately, not all of the information necessary for the purposes of this study was contained in these reports. Some of the omissions were no doubt due to the lack of surveillance data.

2.2 Empirical Approach

The empirical derivation of MSS requirements was made by visits to MSRC regional offices and staff interviews to determine MSRC needs. Information was gathered that was not in the historical literature, such as intended employment strategies, response needs, coverage areas, information update rates, and estimates of usage.

2.3 MSS Requirements

Information from the study was used to derive the following MSS requirements:

- Detect oil (and its altered states) on water and on land.
  - Detect petroleum sheen.
  - Detect oil slicks 0.1 mm and thicker.
  - Detect and identify windrows > 30 m in width.
  - Detect oil on beaches.

- Reject false targets.
  - Detect and identify natural oils, surfactants, non-oil thermal disturbances, and wind slicks.
  - Discriminate between oil slicks and oiled debris.

- Determine the location of the spill.
  - Locate and identify the spill source.
  - Determine the condition of the spiller.*
  - Locate suspected or confirmed spills at unknown locations.
  - Locate oil that has reappeared on the surface.

- Determine the boundaries of the slick.
  - Determine the latitude and longitude.
  - Identify the position relative to the shoreline and sensitive areas.
  - Identify the position relative to response assets.

- Determine oil thickness.
  - Determine its relative thickness to improve recovery efficiency.
  - Identify the thickest oil.
  - Detect patches of thicker oil within the overall slick.
  - Map the location and orientation.
  - Measure its absolute thickness.
  - $\leq$ 0.5 mm for dispersant decision.
  - $\geq$ 3.0 mm for burning decision.

- Estimate the quantity (volume) of oil.

- Determine the oil state (e.g., liquid, mousse, or tar balls).

* Items from the *MSS Concept of Operations*.

- Determine the type of oil spilled.

- Determine the oil trajectory and fate.
  - Measure ocean surface currents (speed and direction).
  - Measure surface wind (speed and direction).
  - Measure slick drift (speed and direction).
  - Measure slick growth rate (speed and direction).*
  - Measure sea state.
  - Compute future position.
  - Predict future oil state.
  - Predict land fall.
  - Detect and identify oil sheen due to equipment failures.
  - Monitor dracones for leaks.
  - Detect and identify oil sheen due to equipment inefficiencies.
  - Determine the effectiveness of containment/diversion barriers.

- Operate day and night.
  - Support recovery operations 24 hours/day.

- Operate under adverse weather conditions (e.g., clouds, fog, rain, etc.).

- Operate during heavy sea states.

- Operate over deep or shallow water.

- Operate 200 nmi from shore.
  - Provide a minimum of four hours on station.*

- Respond to a call (i.e., arrive onscene to collect imagery) within five hours of notification.
  - Spill may be as far as 500 nmi from the response location.*

- Provide processed information to the user within 15 minutes of imagery collection.

- Update the requested information every six hours.

- Provide the following area coverage described in Table 2.2.*

- Meet to be determined (TBD) operational availability rate.*

- Be operational after 1993.

* Items from the *MSS Concept of Operations*.

Table 2.2 Area Coverage Requirements

Activity	Size (nmi^2)
Initial Spill Assessment	50-100*
Direct Support to Skimmers	50-300*
Recovery Area Surveillance	300-1000*
Wide Area Detection and Monitoring	1000-5000*

3.0 Sensor Alternatives

Sensing oil on water is a difficult task. Many factors can affect the oil signature; it can change over a short period of time, even within a relatively narrow spectral band. In addition, there are other naturally occurring phenomena that can create false images. The detection mechanisms and ambiguities for the sensors studied are shown in Table 3.1.

Table 3.1 Detection Mechanisms

Sensor	Detection Mechanism	Ambiguities & False Alarms
TV	Reflected sunlight difference	Acid spills, fish oil
UV Scanner	Reflected ultraviolet energy difference	Acid spills, fish oil
IR Scanner/FLIR	Emissivity and temperature difference	Daily contrast crossovers, ship wakes, oil platform water discharges, effluents from plants
Microwave Radiometer	Emissivity difference	Thickness detection ambiguity (single frequency radiometer)
Radar (SLAR)	Short-wave damping RCS* difference	Wind slicks, water layering, kelp beds, surfactants, calm water
Laser Fluorescence	Visible fluorescence induced by UV laser	Other naturally occurring fluorescence

**RCS = Radar Cross Section*

Because of the ambiguities and changing oil signature, it is unlikely that any single sensor will reliably detect oil in all situations. However, by using two or more sensors that operate in different spectral bands or detect different oil characteristics, it is possible to build a surveillance suite that can reliably detect oil 24 hours a day in adverse weather conditions.

An example of this was during the Tenyo Maru oil spill at Neah Bay, Washington, in August 1991. Fog and low clouds restricted the times and altitudes at which surveillance aircraft could collect imagery. For the most part, the slick contained small patches of bunker oil and diesel fuel a few microns thick.

Figures 3.1a and 3.1b are images from the ultraviolet (UV) band (357-381 nm) and the thermal infrared (IR) band (7.17-12.11 μm). The IR band shows a large dark area in the middle of the image tracking to the upper left. Taken by itself, this image might indicate oil in the dark area; in fact, the dark area is the disturbance caused by a boat pulling a boom through the area. The UV band shows a bright area, which is the oil sheen.

Figure 3.2a is a natural color visible image of the same area and Figure 3.2b is a color composite of the UV/IR bands. The slick is discernible in the visible image, but it is much more evident in the composite image. This type of imagery would very quickly key the analyst to the oil and reduce both the workload and the possibilities for error. Also, by comparison, the true areas of thicker oil may be located and are shown in red.

In the following sections, each sensor is discussed individually, including each sensor's nominal performance characteristics, strengths and weaknesses.

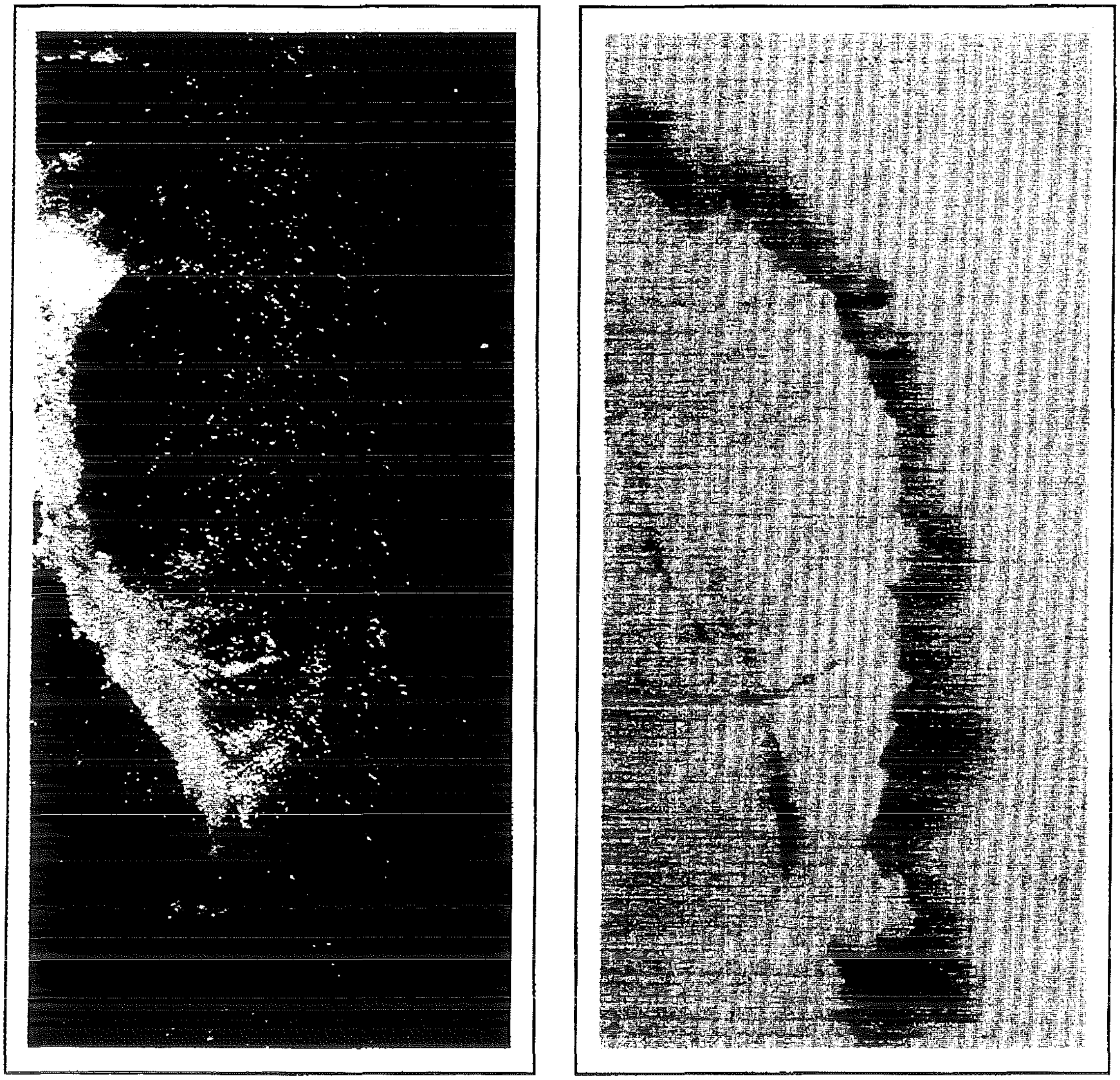
3.1 Television Cameras

Sections 3.1 and 3.2 summarize the analyses performed for television (TV) cameras and forward-looking infrared (FLIR) cameras, respectively.

Television-type sensors come in three main varieties, visible spectrum, UV enhanced, and IR enhanced. Because the handheld version of the IR is very similar to the FLIR, it will not be discussed in this section. The following sections will discuss the visible and UV cameras.

3.1.1 Visible Light Sensors

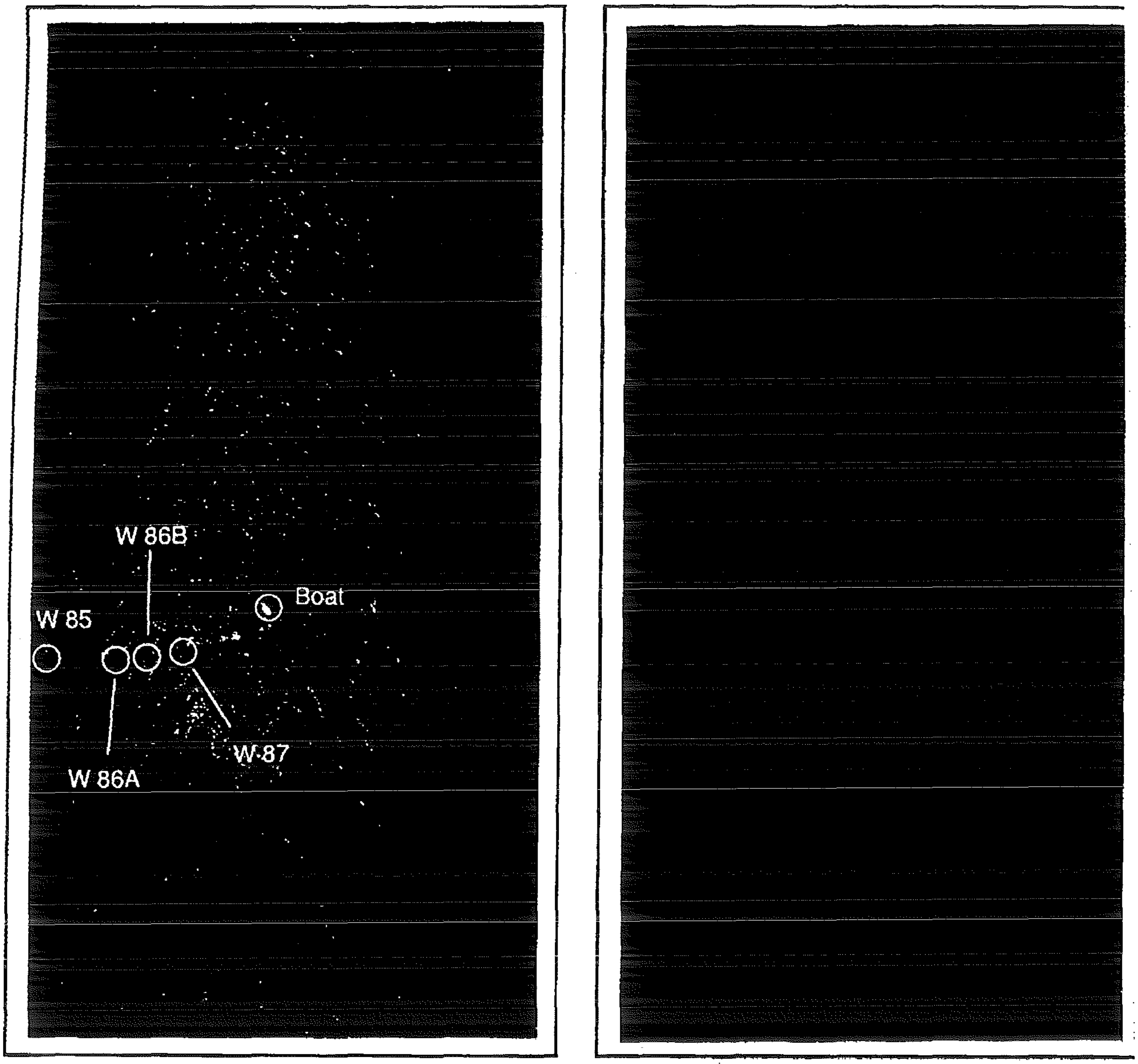
High performance charge-coupled device (CCD) color cameras are readily available. These cameras provide high resolution color images and can be recorded on super VHS recorders. They provide better resolution than the two other sensor types and would be useful to identify ships and other assets on the ocean. They can also detect the color changes caused by oil on water. In this regard, they would not have an advantage over the unaided eye except for the magnification provided by the lens and the ability to record the scene for replay. Table 3.2 provides the specifications for a representative sample of CCD color cameras.



a. UV (357 -381 nm)

b. IR (7.17 - 12.11 μm)

Figure 3.1 *UV/IR Band Imagery for Run 5*



a. Natural Color
(Contrast Enhanced)

b. Processed UV (Blue)
IR (Red) Composite

Figure 3.2 *Color Composite for Run 5*

Table 3.2 CCD Color Camera Parameters

Specification	Sony XC-711	Panasonic D5010	COHU-8310
Minimum Illumination (lx)	25	10	1
CCD Imager Size (in.)	2/3	2/3	1/2
Resolution, h x v	350 x 485	380 x 350	460 x 350
Shutter Speed (s)	0.016-0.0001	0.016 only	0.016-0.0001
Size, l x w x h (in)	6 x 2.2 x 2.0	18 x 10 x 10	8.5 x 2.5 x 3
Weight less lens (lb)	0.78	7.2	1.5
Power req. at 12 VDC (W)	5.5	6	4.5
Field of View			
Wide Angle	30.7° x 22.8°	30.7° x 22.8°	22.6° x 17.0°
Telephoto	3.2° x 2.4°	3.2° x 2.4°	2.3° x 1.7°
Cost Range ($K)	3-5	3-5	3-5

The primary advantages of the CCD color cameras are their availability, relatively low price, and high resolution.

The primary disadvantages of the CCD color cameras are that they do not work at night and they have limited advantages over the human eye for detecting oil. Figure 3.3 shows the COHU-8310 camera.

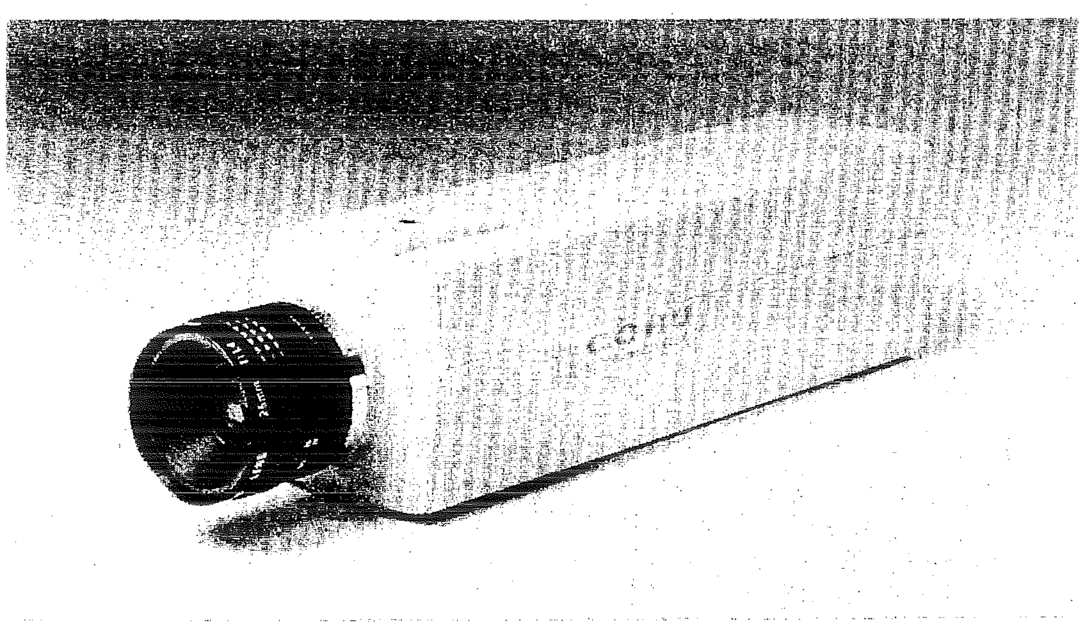


Figure 3.3 COHU-8310 Color CCD Camera

Also included in this class of sensor is the lowlight level TV. This camera uses an intensifier to amplify the available light, extending the usefulness of the CCD camera into nighttime hours. Because the sensor needs some light from the scene, it will not work in complete darkness. Most of the sensors require starlight or moonlight to produce a useful image. One sensor was identified that would work in overcast starlight; however, it was extremely expensive. Consequently, IR sensors were deemed more appropriate for nighttime use.

3.1.2 Ultraviolet Sensors

The passive UV sensor collects UV energy (0.32-0.38 μm) from the sun, which is reflected from the scene. Ultraviolet reflectance for oil is greatest for a thin oil film or oil sheens and is much greater than the surrounding water, providing a high contrast image of the water and the oil. As the oil thickness increases, the UV reflectance decreases and the sensor receives less reflected UV energy. The contrast decreases until no discernible oil/water image is received. This sensor is best used to map the thin oil at the edge of the slick and to establish the boundaries of the slick. It an be used as a cuing device because a sheen normally surrounds the thicker oil, but this sensor will not work at night because there is no UV energy to be reflected by the scene.

There are three varieties of UV sensors in this class, a UV enhanced CCD, a UV Vidicon, and a UV intensified CCD. The UV intensified CCD is the best choice because it will provide usable imagery over the widest range of lighting conditions. Care must be taken to prevent damaging the camera by pointing it directly at the sun or other high intensity source. Table 3.3 provides specifications for representative UV intensified CCD cameras.

The main advantages of UV sensors are detecting thin oil and cuing the operator to areas that may contain thicker oil. The results can confirm observations made in the visible or IR spectrums.

The UV sensor has two primary disadvantages: It only works in daylight and its lenses, which pass UV energy, are not standard optical products. Some fixed focal length lenses are available from 70 mm to 200 mm. The study did not locate any zoom lenses that were usable in the UV. There are optical houses with experience in disassembling lenses, removing the antireflection coatings, recoating for UV transmission, and reassembling the lenses. However, these services represent an additional cost and a time delay.

3.2 Forward Looking Infrared

Infrared sensors detect emissivity and temperature differences in the IR band. There are two atmospheric "windows" in which these sensors operate, 3-5 μm and 8-12 μm. Both of these bands can be used to detect oil; with the 8-12 μm band providing the best all-around performance. These sensors detect oil that is much thicker than the sheen detected by the UV sensors. They do not detect thin oil under most circumstances. For this reason, the UV and IR sensors complement each other. Table 3.4 provides the specifications for the IR cameras.

The advantages of the IR sensors are their day/night capability and their abilities to indicate thicker from thinner oil and to penetrate some haze and light rain. The disadvantages of IR sensors are their increased complexity and their temperature crossover/contrast reversal. The increased complexity is due to the need to cool the detector. Present IR detectors must be

Table 3.3 Ultraviolet Intensified CCD Camera Parameter

Specification	ITT F4577	Xybion ISS-255U	COHU-5600
Minimum Illumination (fc on faceplate)	2 x 10^{-8}	10^{-6}	10^{-6}
Size, l x w x h (in)*	9.1 x 3.3 x 4.6	7 x 2 x 4	TBD
Weight* (lb)	5	25	2
Power Source (VDC)	15	11-15	12
Power Required (W)	10	5	10
Synchronized I/O	Option	Option	Option
Intensifier Life (h)	N/A	N/A	2000
Field of View			
Normal (75mm), h x v	9.5° x 7.1°	9.5° x 7.1°	9.5° x 7.1°
Telephoto (200mm), h x v	3.6° x 2.7°	3.6° x 2.7°	
Coat Range ($K)	25-50	25-50	25-50

**Without Lens*

Table 3.4 Infrared Camera Parameters

Parameter	Loral Mark III	Kodak KIR 0310
Spectral band (mm)	8-12	3.4-5.5
Type	Scanning	Staring
Resolution, h x v	N/A	640 x 486
Minimum Resolvable Temperature (°C)	0.13	0.13
Video Output	RS-170	RS-170
Digital Output	N/A	12 bit
Field of View		
Wide Angle	16.6° x 10.0°	12.4° x 9.2°
Telephoto	4.0° x 4.2°	3.1° x 2.3°
Cooling	Stirling	Stirling
On-Gimbal Weight (lb)	12	13
Off-Gimbal Weight (lb)	9	12
Power required at 28 VDC (W)	N/A	45

N/A = not available

cooled to provide adequate performance. Cooling is accomplished by using liquid nitrogen or a closed-circuit cooler. Both methods increase costs, logistics, and maintenance requirements.

IR sensors are unable to discriminate objects from the background when the temperatures are very close together, this is called crossover. For externally heated objects, such as oil and water, this generally occurs twice a day. During this time, no oil/water discrimination can be made. Contrast reversal, which takes place during the crossover phase, occurs when an object that is normally hotter during the day cools more than the background at night. The object that is usually "white" (hot) becomes "black" (cold) on the display. A knowledgeable operator is required to interpret the data. Oil complicates the problem because it can be cooled by the evaporation of its more volatile components. This can cause numerous crossovers during the day as the sun's heating changes due to cloud conditions and evaporation changes due to wind conditions. Figure 3.4 shows the Kodak KIR-0310 camera.

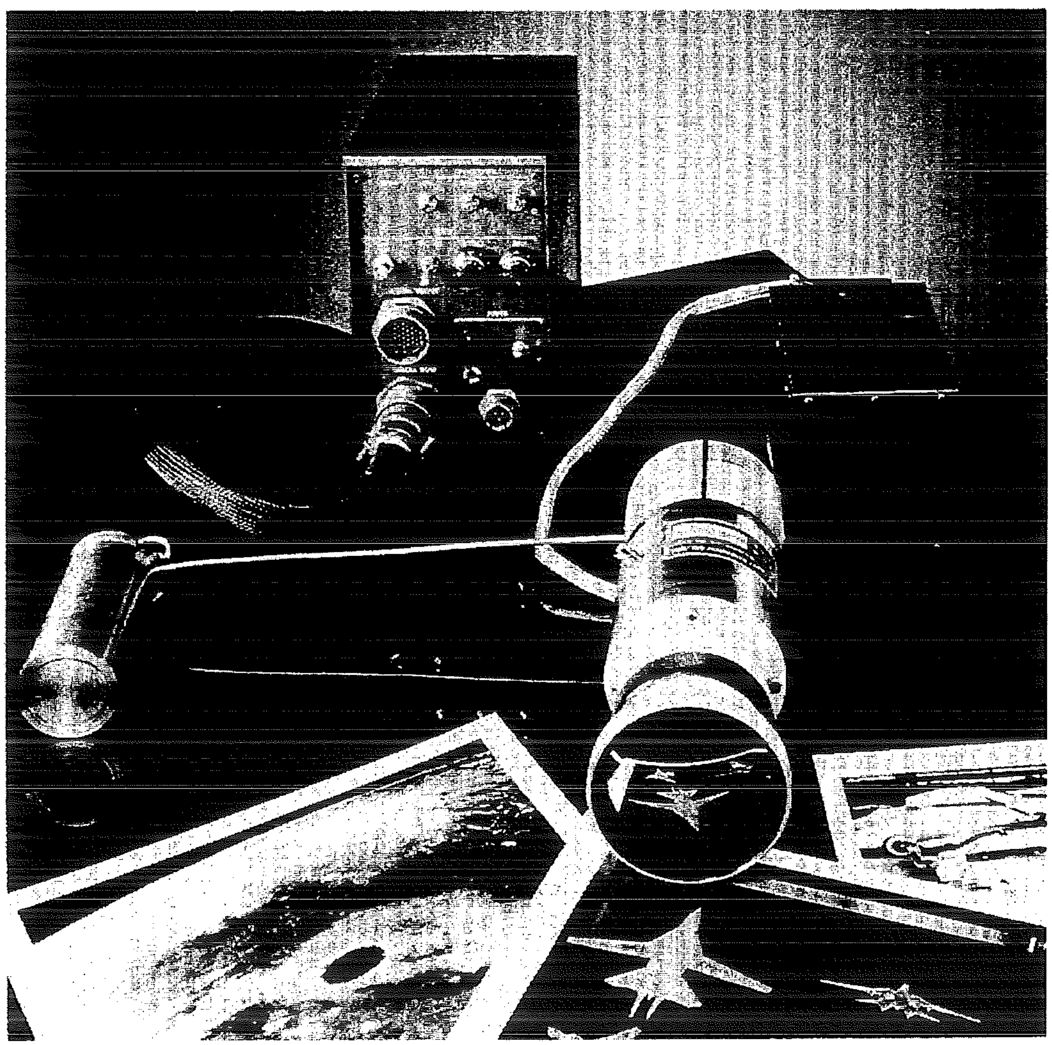


Figure 3.4 *Kodak KIR-0310 Infrared Camera*

3.3 Ultraviolet / Infrared Scanner

Ultraviolet and infrared scanners will be discussed together because the only UV scanner currently in production is a dual-band UV/IR sensor. As stated earlier, the UV/IR bands complement each other: the UV images the thinner oil that surrounds the slick and the IR images the thicker oil.

Table 3.5 shows the operating parameters for the Daedalus UV/IR scanner pictured in Figure 3.5. The Daedalus is a proven sensor. It is currently part of the pollution detection suites in many European countries. It can also be purchased as a standalone sensor package with its own controls and displays. For an integrated sensor suite, a significant amount of weight could be eliminated by allowing the central processor to control the sensor and perform the signal processing.

Table 3.5 Daedalus UV/IR Scanner Parameters

Parameter	Value
IR Bandpass	8-12 mm
IR Instantaneous Field of View	2.5 mrad (5.0 available)
IR NETD	< 0.2° C
UV Bandpass	0.32-0.38 mm
UV Instantaneous Field of View	5.0 mrad
UV NER	< 0.05
Scanner Field of View	86°
Power Required at 28 VDC	1530W
Scanner Head Weight	36 lb
Control and Display Weight	150 lb
Cost	$490K

The UV channel suffers the same problem as the UV enhanced TVneither work at night. During the day, the UV channel will detect thin oil. The IR channel will not detect oil during those times of the day when thermal crossover occurs. The IR channel does have night capability as well as some haze and fog penetration. Because the two bands share a common optical path, the images are registered with each other. This is a distinct advantage because the images can be compared without additional image processing.

There are other IR scanners available, such as those built for military use. Although they provide excellent resolution and coverage, these scanners are usually expensive and would require considerable modification to incorporate the UV channel.

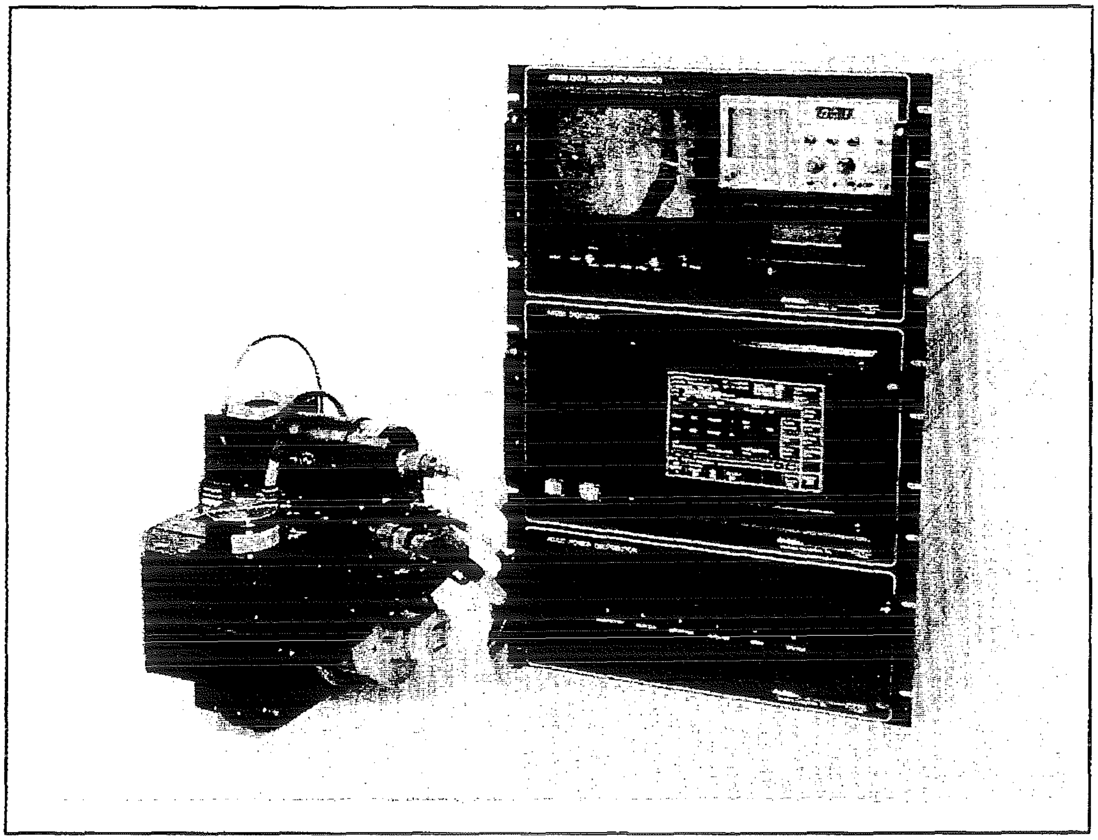


Figure 3.5 Daedalus UV/IR Scanner

3.4 Microwave Radiometer

A microwave radiometer detects oil by sensing the emissivity difference between the oil and the surrounding water. It senses naturally emitted and reflected energy but does not transmit any energy of its own. Radiometers have the advantage that they can penetrate haze, clouds, fog, mists, or very light rain. Table 3.6 shows the operating parameters for the Ericsson microwave radiometer pictured in Figure 3.6.

Table 3.6 Ericsson Microwave Radiometer Parameters

Parameter	Value
Frequency	35 GHz
IF Band	1 GHz
Polarization	Horizontal
Angle of Incidence	25°
System Noise Temperature	850 K
Sensitivity	0.5 K
Integration Time	15 ms
Power at 28 VDC	280 W
Weight	71 lb
Cost (sensor only)	$400K

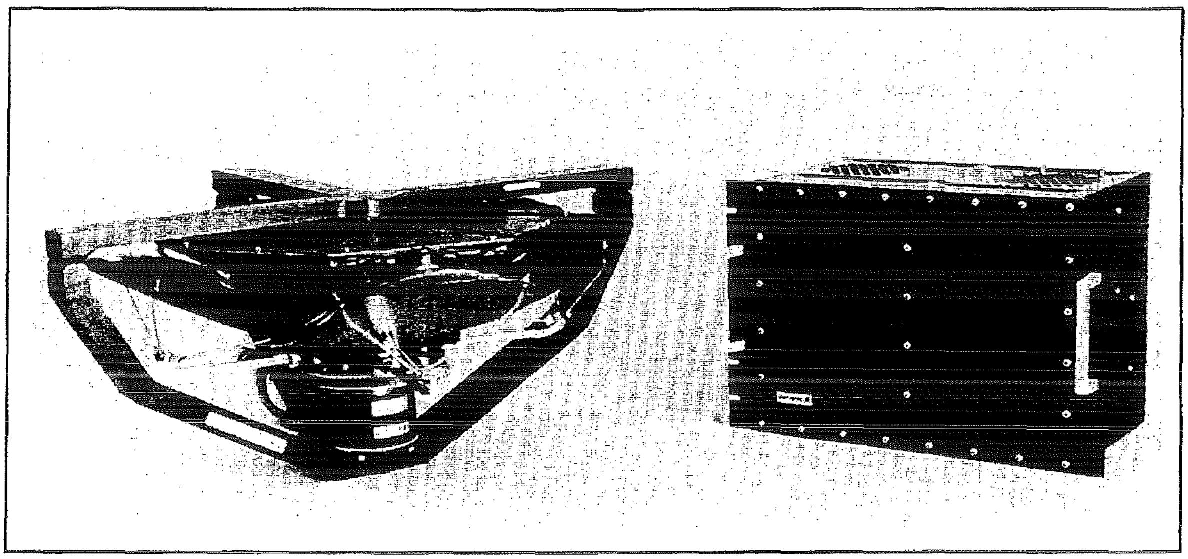


Figure 3.6 Ericsson Microwave Radiometer

The Ericsson radiometer was the only production radiometer located during the study. Several companies have experimental prototype systems or obsolete radiometers that are no longer in production. TRW, MPB, and DLR have prototype radiometers that may be available in the future.

A radiometer operates much like a radar; its resolution is a function of its frequency (wavelength) and the size of the antenna. For a given frequency, the larger the antenna the better the resolution. Due to size restrictions on most aircraft, the resolution of airborne radiometers is not as good as the UV and IR sensors.

Along with its basically all-weather performance, the radiometer has the potential to provide relative oil thickness measurements. The amount of energy received by the radiometer can be related to the thickness of the oil. On the display, this oil will appear brighter or with a positive contrast to the water. Unfortunately, the energy cycles through maximum and minimum values giving the same reading for various thicknesses of oil. Thus, thicker oil could appear with the same contrast as thinner oil (Figure 3.7 shows this response). Without additional information to determine which portion of the curve the radiometer is on, it is not possible to solve the ambiguity. By using multiple channels or sweeping through a series of frequencies, it would be possible to determine relative thickness. The 5.0-GHz curve also cycles through maximum and minimum values for increasing thickness, but on a longer period than the 35.0-GHz system. By combining the two readings, it would be possible to determine the thickness.

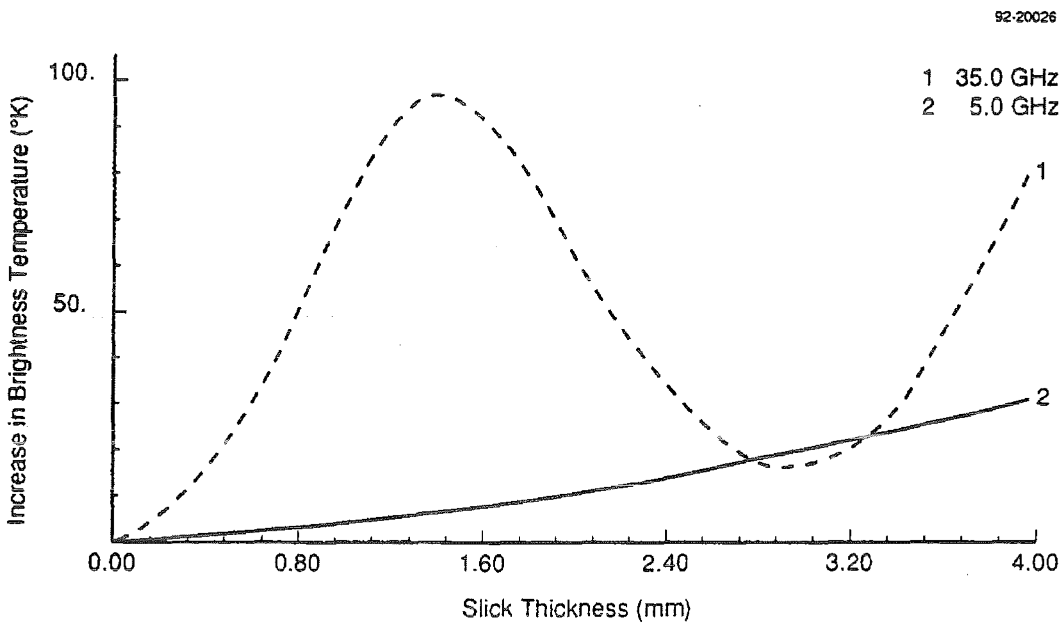


***Figure 3.7** Brightness Temperature Versus Oil Slick Thickness*

Dual or multiplechannel radiometers have been built, but none are currently in production. MPB, in Canada, does have a dual-channel radiometer that could be completely reprogrammed for oil use. The Germans currently have a three-channel radiometer, built by DLR, installed in a Dornier 228. It will be flight tested beginning in 1993.

The Ericsson radiometer is a forward oblique-looking sensor. The depression angle is 25°. This gives the system a constant incidence angle with the surface, which eliminates some of the calculations that are required if the incidence changes. However, for any given altitude, the line of sight is over twice the altitude, the resolution provided is not as good as a downward-looking sensor would provide, and the coverage is reduced.

3.5 Side-looking Airborne Radar

The previous sensors all have had relatively narrow coverage capabilities and operate at ranges close to the aircraft. The side-looking airborne radar (SLAR) provides wide-area coverage and can image at a distance from the aircraft. This provides an improved capability to search for spills of unknown or uncertain locations, allowing the entire slick to be mapped much more efficiently than with the other sensors. The SLAR will operate at day, at night, and in virtually all weather conditions; only very heavy rain will affect the SLAR.

Table 3.7 describes the Terma SLAR, pictured in Figure 3.8, which is representative of the SLARs considered.

Imaging radars detect oil by sensing the reduced radar cross section (i.e., reduced radar return) caused by the damping effects of oil on water. Oil damps the short waves on the ocean surface causing more energy to reflect away from the sensor, which reduces the return. This type of "no show" area can also be caused by natural surfactants, fish oils, reefs, and calm winds.

Table 3.7 TERMA SLAR Parameters

Parameter	Value
Frequency	9375 MHz
Peak power	20 kW
Pulse Width	250 ns
PRF	0-2000 Hz
Resolution	40 m x 0.5°
Antenna Length	12 ft
Coverage (for oil detection)	10-15 nmi (both sides of A/C)
Power at 28 VDC	700 W
Weight	242 lb
Cost (sensor only)	$400K-500K

Two types of imaging radars were considered, the SLAR and the synthetic aperture radar (SAR). The SAR provides better resolution and contrast than the SLAR, but is also much more expensive. SLAR was chosen because the potential performance improvements with SAR did not justify its increased costs. There is some uncertainty about the amount of performance gain available with SAR; more research is needed.

SLAR resolution is stated as two numbers. The first number, in this case 40 meters, is the dimension of the resolution cell perpendicular to the aircraft flight path. The second number, in this case 0.5°, is the dimension along the aircraft flight path. This number represents the antenna's physical resolution, which, in a SLAR, is determined by antenna length. For a SAR, the antenna size is "synthesized" to be much greater than its physical size and, therefore, provides improved resolution.

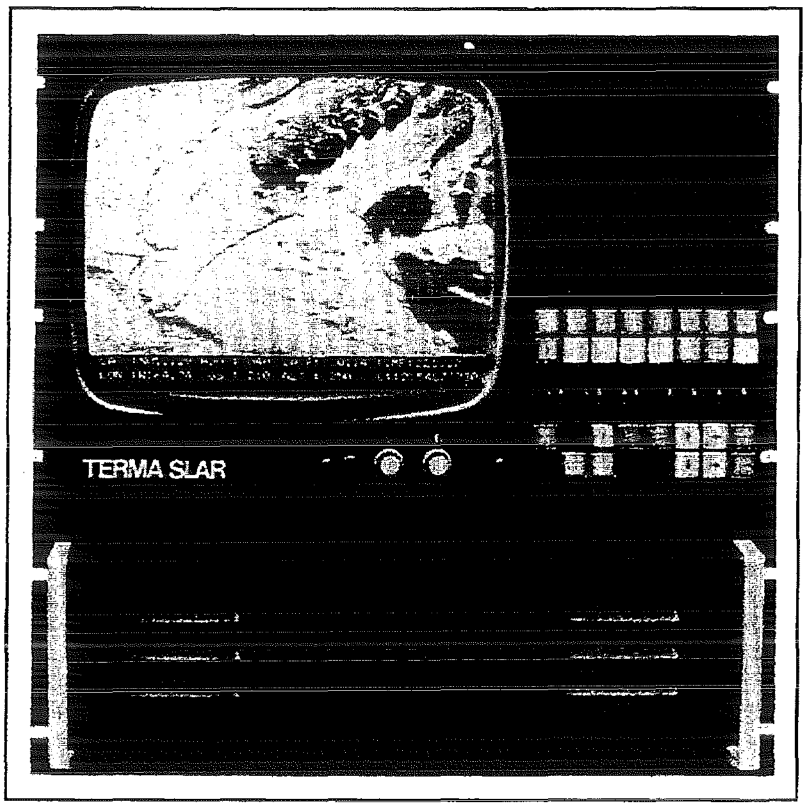


Figure 3.8 *TERMA SLAR*

3.6 Laser Fluorosensor

Sensors of this type apply based on the fact that oil will fluoresce in the visible spectrum when excited by a UV source. A UV laser pulses the surface, while a visible light sensor records the return signal. The visible sensor is "gated" to look at only the returns within the time frame of the expected fluorescence. The visible return is separated into many channels and analyzed to determine if a characteristic oil signal has been received. The rate and timing of the decay can be used to identify oil and even the region that produced it. With extremely accurate time gating, the sensor could determine oil thickness or, by adjusting the gate, track oil underwater. The sensor will work during both day and night, but requires a clear line of sight to the water for both the UV laser pulse and the return visible signal. Clouds, fog, and even a heavy haze could degrade or deny system performance.

The following companies or institutes were contacted for information on laser fluorosensors:

- Barringer Research
- British Petroleum Company
- Dornier Aerospace
- Kaman Aerospace
- Stanford Research Institute

British Petroleum is currently flying two laser fluorosensors to prospect for oil deposits. These sensors are extremely high powered and search for very small amounts of oil from natural seeps. The lasers are spot sensors that look directly beneath the airplane. They are designed to detect oil, but not necessarily to map its location.

Stanford Research Institute currently operates an airborne laser system for air pollution studies. The institute is taking steps to modify the system so it can measure the surface.

Barringer Research is currently building a thirdgeneration sensor for Environment Canada. The sensor uses some parts from previous systems. It is intended for further research, particularly for detecting oil on or near ice. The sensor is currently a spot sensor, but future plans include adding a scanning mechanism.

Dornier has also installed a prototype laser fluorosensor in one of their aircraft. Test flights were conducted in August 1991, but no results are available.

Kaman Aerospace has not built a laser sensor for oil, but has used lasers for other sensors built for the Department of Defense (DoD). Kaman estimated that it would take 18-24 months and $2 million to build a system.

Titan Spectron is currently delivering a groundbased system used to detect gas leaks in pipelines. This system could be adapted for airborne use, even though it currently weighs over 2,000 pounds.

None of these laser fluorosensor systems can be recommended at this time. Although the technology has been demonstrated, several problems still need to be solved. A scanning system would be necessary to map the oil; such systems are still in development. A method to present the data to an operator must also be developed. The current systems record between 16 and 32 channels of data from individual spectrum bands. The oil fluorescence is characterized by a specific spectrum shape and time decay. Processing this signal and displaying it to an operator in real or near real time has not been accomplished. In addition, the systems are heavy and very expensive. Such systems would require the entire payload capacity of the smaller aircraft considered in this study.

3.7 Sensor Comparison

It is very difficult to compare sensor performance. Sensors operate in different bands, and are defined in different terms; even basic parameters such as resolution are defined differently. In an attempt to provide an even comparison, parameters will be fixed and one set of definitions will be used. Although specific performance will vary depending on the model design, relative performance between types of sensors is generally unchanged. Table 3.8 compares sensor performance.

All sensors were compared at an aircraft altitude of 2000 feet above the surface. The UV/IR scanner is the only sensor that normally looks straight down. The rest all operate in the oblique. Gimbal-mounted and handheld sensors could point straight down, but perform best at approximately a 30° depression angle. (A depression angle is measured from the horizon, positive down.) The Ericsson radiometer has a 25° depression angle.

Resolution will be defined as the dimensions of the area imaged by one element of the detector. The element chosen was the one on the optical axis of the system. For the UV/IR, it was the element directly under the aircraft. The SLAR resolution is given as defined above except that there was no optical axis; the element chosen was in the middle of the swath.

Coverage is given in cross track dimensions. The slewable sensors were assumed to be pointed in the direction of the aircraft motion (straight ahead). The oblique sensors cover a keystone-shaped area. Their coverage is given for the point where the optical axis intersects the surface.

Area coverage rates were computed assuming an aircraft speed of 160 knots and allowing the sensor to operate in a pushbroom fashion.

The laser fluorosensor is not represented in Table 3.8 because no firm design data was available. In general, there are no limitations on the laser fluorosensor that would prevent it from performing as well as or better than the UV/IR sensor in resolution and coverage. Many of the details are engineering issues and do not require technology breakthroughs. Laser fluorosensors could approach the visible band sensors in resolution performance depending on the detector used.

Table 3.8 Sensor Performance Comparison

Sensor	Coverage (ft)	Resolution (ft)	Area Rate (nmi^2/hr)
TV*			
Wide Angle	1600	3.4 x 3.4	42
Telephoto	160	0.34 x 0.34	42
FLIR*			
Wide Angle	880	1.3 x 1.3	23
Telephoto	220	0.34 x 0.34	5.8
UV/IR			
Wide Angle (5.0 mrad sensor)	3730	10 x 10	98
Telephoto (2.5 mrad sensor)	3730	5 x 5	98
Radiometer **	1385	100 x 100	36
SLAR (both sides of A/C)	61,855	130 x 290	1628

** Depression angle for TV and FLIR equals 30°*
*** Depression angle for radiometer equals 25°*

4.0 Processor Alternatives

Although the sensors described in Section 3 can each be purchased with their own processor and display, a common processor and display is useful to operate multisensor surveillance systems. This section summarizes an analysis performed on the functions, components, risk, and costs of a processor and alternatives.

A modular processor approach based on commercial hardware is needed to provide the flexibility and capacity for improved capability. Commercially available multisensor oil surveillance systems are based on 80386 or 80486-class computers with little functionality other than to provide a sensor display and link interface. To optimize the information available from multisensors, the processor for future oil surveillance should:

1. Receive, display, and store data from the sensors.
2. Assess data quality and extract oil related information.
3. Receive data from the global positioning system (GPS).
4. Provide geofrequencing and geocorrection of imagery.
5. Record locations of ships, platforms, and buoys.
6. Generate combined chart information and image products.
7. Create charts for ground units.
8. Transmit data to surface units.

Figure 4.1 illustrates a high level block diagram of the proposed MSS processor architecture.

4.1 Modular Processing Architecture

A modular architecture capable of performing the designated tasks was defined to service the functions just discussed. The functional descriptions presented in this section summarize the operations for the complete system. These alternative configurations are subcomponents of a four-phase modular system that provides a wide range of performance options for airborne surveillance support to the MSRC mission.

4.1.1 Electronic Display System

The electronic display system represents mature technology which has been operationally flown. The surveillance suites offered by Swedish Space Corporation (SSC) use this approach. As such, it is the baseline point of departure for the MSS processor modularity concept.

In this baseline, operators view raw sensor data in a real-time mode. A manually operated image analysis workstation is used to display reduced resolution sensor data in a scrolling window. Image processing operations are limited to gain/offset adjustments for each sensor's collected data. This architecture will not perform image geocorrection, coregistration, or other more sophisticated forms of image processing and enhancement; it will provide coordinated displays, simultaneously, of data from multiple data collectors. It will rely on the imagery analyst's capabilities to compensate for distortions induced by the sensor platform. Locations of oil, and physical position and/or condition changes, will be visually noted and manually logged by the onboard analyst. The analyst will communicate the information, via voice, to the appropriate field personnel.

4.1.2 Image Processing System

The image processing system represents the next level of technical capability for the MSS modular architecture. It will contain all capabilities found in the electronic display system. Additionally, onboard sensor data processing will be accomplished. Data from entire flight passes will be buffered and saved in memory. Ancillary GPS/INS data will be accessed and used to geocorrect, resample, and register collected image data. Full resolution sections of processed imagery will be displayed by the image analyst for exploitation.

A set of imagery analysis software will allow the analyst to perform a variety of conventional imagery manipulation routines (e.g., contrast stretch, high/low pass band filtering, colorization, etc.). These tools will allow the analyst to use data from multiple sensors to detect oil, evaluate its condition, and determine position changes more effectively. In addition to imagery analysis tools, the onboard analyst will have image annotation tools available. The analyst will output simple graphical (binary) products, which may then be faxed to ground- and sea-based personnel. These products will also be stored on disk or tape for later retrieval.

4.1.3 Geographic Information System Management System

The GIS management system will contain the functionality of the image processing system. It will enhance this capability and place it in the context of a geographic information system. This will allow the onboard analyst to integrate multiple flight passes and combine wide-area images with detailed coverage. Additionally, it will provide the means for merging vector (graphic) and alphanumeric data with merged imagery products. This ability to merge multiple types of data will allow the analyst to generate products that could map the oil spill over the extent of the spill area, provide a temporal map of the spill as it evolves, and provide layers of information for the ground and sea-based personnel supporting the cleanup efforts.

Additionally, the GIS management system would include tools necessary to support real-time mission flight planning in the aircraft. With the capability of the GIS management system, these changes could be made more effectively and the results documented more completely.

This architecture could also take advantage of an optional highspeed data link to strategic ground elements. This may be necessary to handle the more sophisticated output products generated by the airborne system and the data covering an extended spill area.

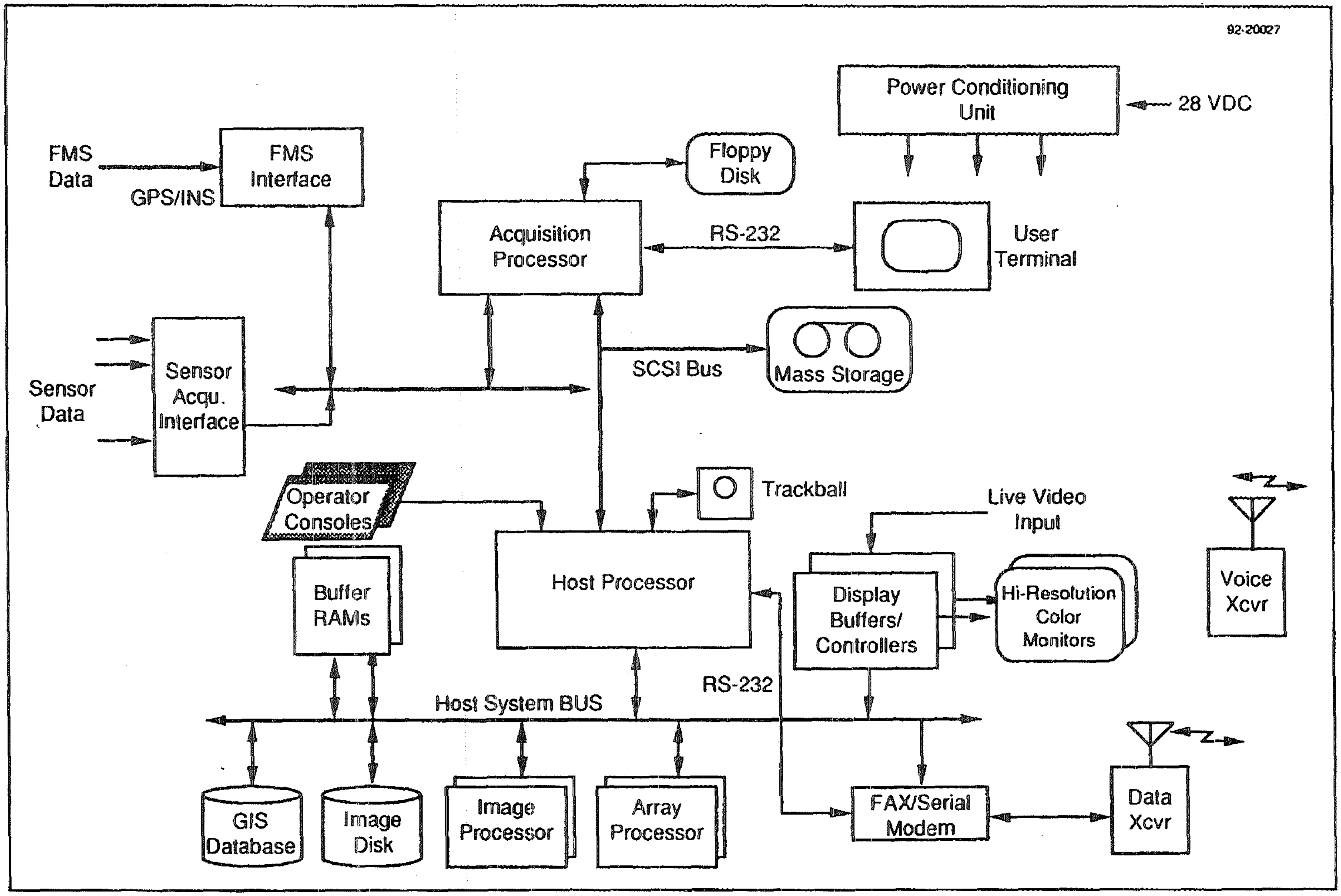


Figure 4.1 MSS Processor Architecture

4.1.4 Integrated GIS Management System

The integrated GIS management system extends the functional integration of surveillance and spill operations. The airborne GIS is tied closely to shore-based and other air-based GIS capabilities. This allows for an increased integrated support capability during cleanup operations.

In addition to the GIS-based system configuration discussed in Section 4.1.3, the integrated GIS management system would become an integral part of a command, control, and communication (C^3) network that is designed to facilitate effective oil spill tracking and cleanup. Additional data and information on buoy positions, cleanup vessel positions, and spill position/characteristics will be captured and used for real-time situation monitoring. This would include predictive modeling of the oil spill given input data on weather, sea state, and other prevailing conditions. This predictive model would be used in mapping and planning additional airborne collection activities.

The integrated GIS management system would also be able to receive vector (graphic) data from other airborne systems. This system architecture would support an aircraft-based coordination role that would, in turn, better support the ground and sea-based cleanup management efforts through a centralized point of contact.

4.2 Operational and Functional Comparisons

All four processing configurations are designed to meet derived MSS operational requirements. The manner in which they are met and exceeded differentiates the four levels of processing.

The electronic display system could be fielded with current technology. In fact, this system has been demonstrated on small spills. This approach places a large burden of imagery analysis and real-time exploitation on the airborne analyst. Larger spills would require handling of diverse data sets over extensive areas. The electronic display system architecture is not designed to work in a coordinated fashion with other airborne assets on the scene. Coordinating the real-time modification of flight lines and other chores that may require on-scene evaluation would be difficult to implement.

The image processing system would provide extra tools for the imagery analyst to accurately evaluate multiplesensor imagery data and reference them to common reference frames. This would allow the analyst to view different data sets, collected from several sensors, over several points in time. The analyst could then diagram the changes in the oil spill position and characteristics and relay graphic output to the ground and seabased personnel. This level of processing would provide higher quality imagery products.

The GIS management system would allow the analyst to generate products containing image and graphic components. This would allow the analyst and ground management personnel to view several different "dimensions" of information in one product. Additionally, the analyst would be able to reference these layers of information to critical areas identified by ship-based coordinators. These critical locations may change as the spill situation evolves.

The integrated GIS management system architecture is designed to support coordinated collection, data processing, exploitation and dissemination. It would provide specialized products supporting the ship-based cleanup crews as well as products for shore-based management personnel.

Table 4.1 summarizes subsystem impacts for each of the configurations discussed. This table indicates impact levels based on the importance of each tradeoff area. For example, the image processor component of the image processing subsystem would have a low technical impact in the electronic display system architecture, but a high impact in both the GIS management and integrated GIS management systems. This indicates that image processor technology may be a critical component in the GIS management system designs.

4.3 Component Survey

An MSS modular processor architecture will provide component as well as functional modularity. The architecture is based on a standard central processor supported by a variety of auxiliary boards and peripheral devices that provide special functions and speed not readily available on the central processor. The central processor controls the overall operation of all boards and directs data between boards. Examples of the auxiliary boards and peripheral devices are sensor interface cards, array processors, image processor accelerators, mass storage devices, and radio modems. These items add flexibility by allowing the system to grow and provide new functions without redesigning the basic system.

Once the basic system is operating, new sensors can be added by adding or reprogramming the existing sensor interface cards. Image processing functions and mass storage can be increased by adding array processors or accelerators. The modem would allow different formats or data rates to be used by changing the card. While each addition would require integration and possibly some new software, these tasks could be completed faster and at less expense than starting over with a new processor design.

Table 4.1 MSS Processor System Configurations Versus Subsystem Impact Level

Processor Configuration Subsystem	Electronic Display System	Image Processing System	GIS Management System	Integrated GIS Management System
Acquisition Subsystem				
Sensor Acquisition Interface	Low	Medium	High	High
FMS Interface	Low	Medium	Medium	Medium
Acquisition Processor	Low	Medium	High	High
Mass Storage	Low	Medium	High	High
User Terminal	Low	Low	Medium	High
ImageProcessing Subsystem				
Host Processor	Low	Medium	Medium	High
Display Buffer/Controller	Low	Medium	High	High
Operator Consoles	Low	Low	Low	Low
Color Monitor	Low	Low	Low	Low
Image Processor	Low	Medium	High	High
Array Processor	Low	Medium	High	High
Image Disk	Low	Medium	High	High
GIS Database	N/A	N/A	Medium	High
Dissemination Subsystem				
Fax/Serial Modem	N/A	Low	High	High

Several varieties of central processors and auxiliary cards are available. These items support various bus specification and commercial software packages.

4.4 Processor Cost Estimates

Table 4.2 provides the cost estimates established for each processor alternative based on the modular architecture described and the available commercial components. Each of these estimates assumes the processor alternative was developed from "scratch" and that no previous development had been accomplished. The difference in cost between each alternative represents the approximate cost to move from one level to the next.

Table 4.2 Processor Alternative Cost Estimates

Processor Alternatives	Initial Unit Cost	Recurring Unit Costs
Electronic Display System	$ 725K	$225K
Image Processing System	$1,300K	$300K
GIS Management System	$1,850K	$350K
Integrated GIS Management System	$2,150K	$400K

4.5 Summary

The modular MSS processor architecture concept defined in this study is required to avoid costly duplication and to provide growth flexibility. Each level provides increased capability and functionality. These increases would provide more complete information about the spill in a more convenient format. Each successive level is more expensive and requires a longer development and delivery schedule.

The modular approach would allow a first generation system to be put in place in 1993 and allow the system to "grow" as requirements become better defined and operational experience increases.

5.0 Aircraft Alternatives

This section presents a summary of the aircraft alternatives evaluated during the study. Several different aircraft types and sizes were considered, including small and medium commuter-type, large twin-engine turboprop, large four-engine turboprop, and turbojet. In addition, specific aircraft such as the Dornier 228 and the Grumman OV-1D were evaluated as special cases. Helicopters were added to the list for this report. All of the aircraft considered are turbine powered. Because of engine failures and increased maintenance demands, piston-powered aircraft would not provide the assured response and dispatch rate needed for the MSRC Surveillance System and were not included in our study. A specific airplane was chosen to represent each class. Each class will be discussed separately.

In addition to evaluating the performance of each aircraft, an analysis was conducted to determine how many aircraft would be required to support a spill 300 nautical miles from a suitable recovery field under Instrument Flight Rules (IFR), weather conditions (worst case), and a spill 100 nautical miles from a suitable field under Visual Flight Rules weather conditions (nominal case). The analysis also considered various basing strategies to assure a timely response and to minimize the number of required aircraft. Mutual support during spill operations was also considered in the basing analysis. The central, east/west, and regional basing options are illustrated in Figures 5.1, 5.2, and 5.3 respectively.

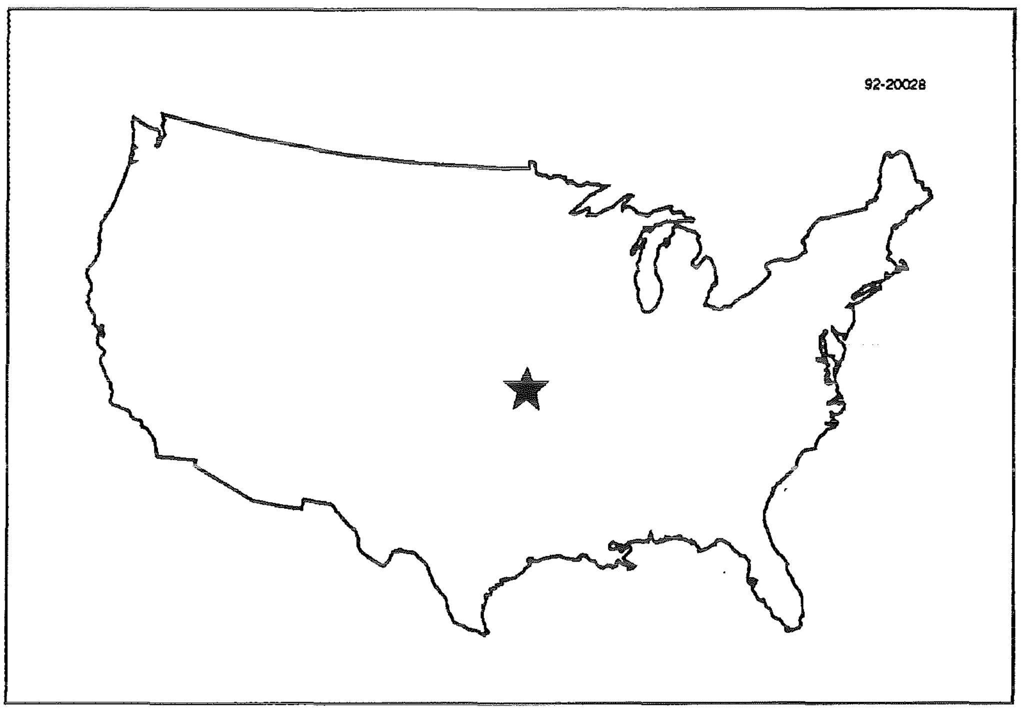


Figure 5.1 *Central Basing*

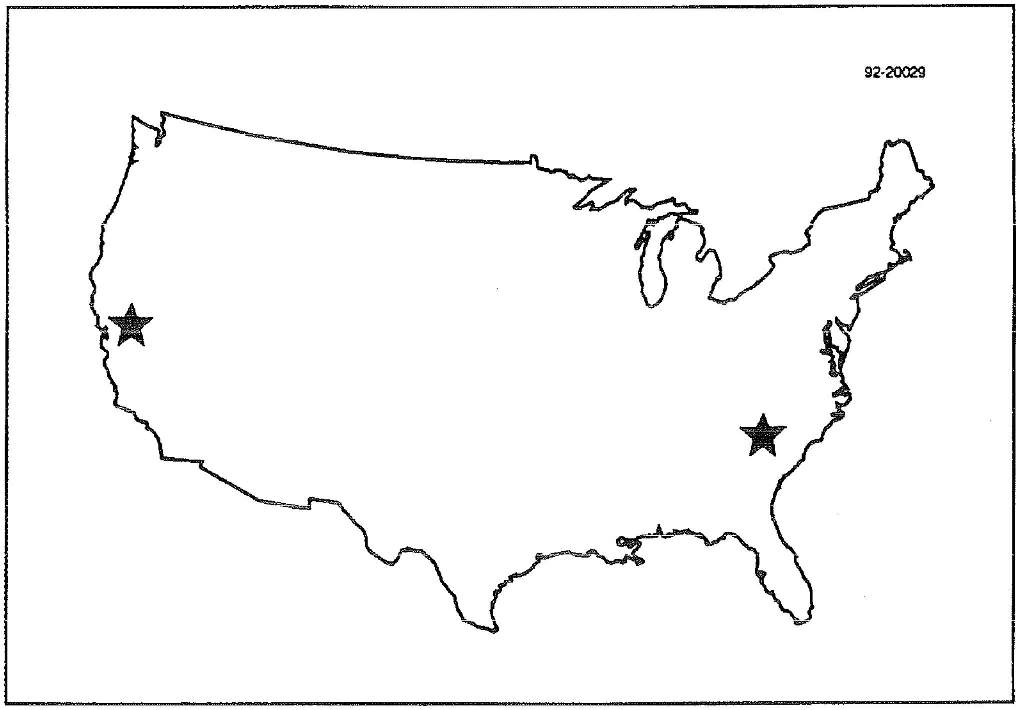


Figure 5.2 *East/West Basing*

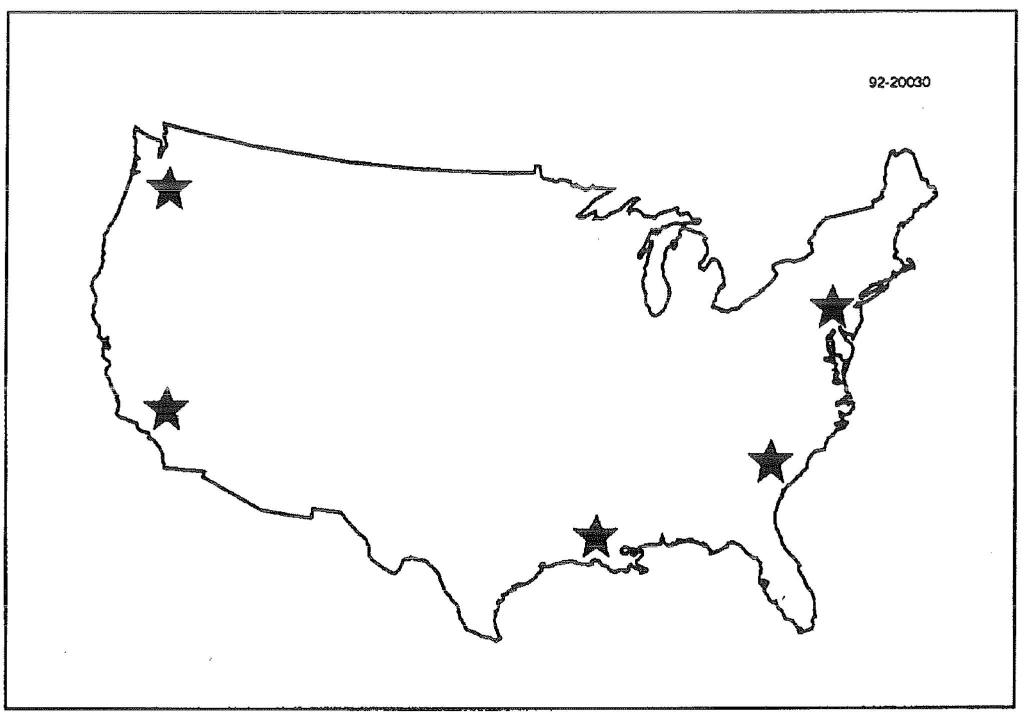


Figure 5.3 *Regional Basing*

Another consideration for selecting the number of aircraft needed is the requirement to perform periodic maintenance on the airplanes during extended spill operations. Most aircraft require inspections based on the number of hours flown, generally around 100 hours. During high usage time, the aircraft may need weekly inspections. This would require an additional airplane to cover the downtime on the other airplanes.

5.1 Assumptions

To evaluate the aircraft alternatives, the following assumptions were made:

- Surveillance coverage will be required 24 hours per day.
- Spill recovery operations will last more than a week.
- Approximately 100 hours of flying time will be required each year to support regional exercises.
- The surveillance system will respond to spills of 50,000 gallons or more.
- The maximum offshore response will be 200 nautical miles from shore or 300 nautical miles from the nearest suitable recovery base.
- There must be a capacity to respond to two simultaneous spills.
- A minimum onstation time of four hours will be required when operating 100 nautical miles from the recovery airport.
- A minimum useful payload of 1700 pounds plus two system operators will be provided.

5.2 Helicopter Launched from MSRC Ships (Local Area Patrol)

This alternative would not be intended to fulfill the wide-area surveillance tasks, but would be used to provide detailed coverage and direct support to the recovery force. It would operate from the MSRC command vessel. The aircraft considered for this class is the Bell 212 (Figure 5.4). Table 5.1 provides the performance parameters for the Bell 212.

Helicopter operations will be limited by the range, endurance, and payload of the aircraft. Operating from a platform or a ship near the recovery operations will relieve the range and endurance limitations. The Bell 212 has approximately 1400 pounds of useful payload with auxiliary fuel aboard. This will allow the suite to contain a FLIR, a TV system, processing equipment, and possibly one other sensor. The suite will adequately provide direct support to the recovery operations. Operating from a ship will present other problems. Flight operations will be restricted to visibility and sea conditions that will allow flight operations from the ship's deck. Icing conditions could preclude helicopter operations completely. Wind associated with higher sea states will limit helicopter operations from a ship.

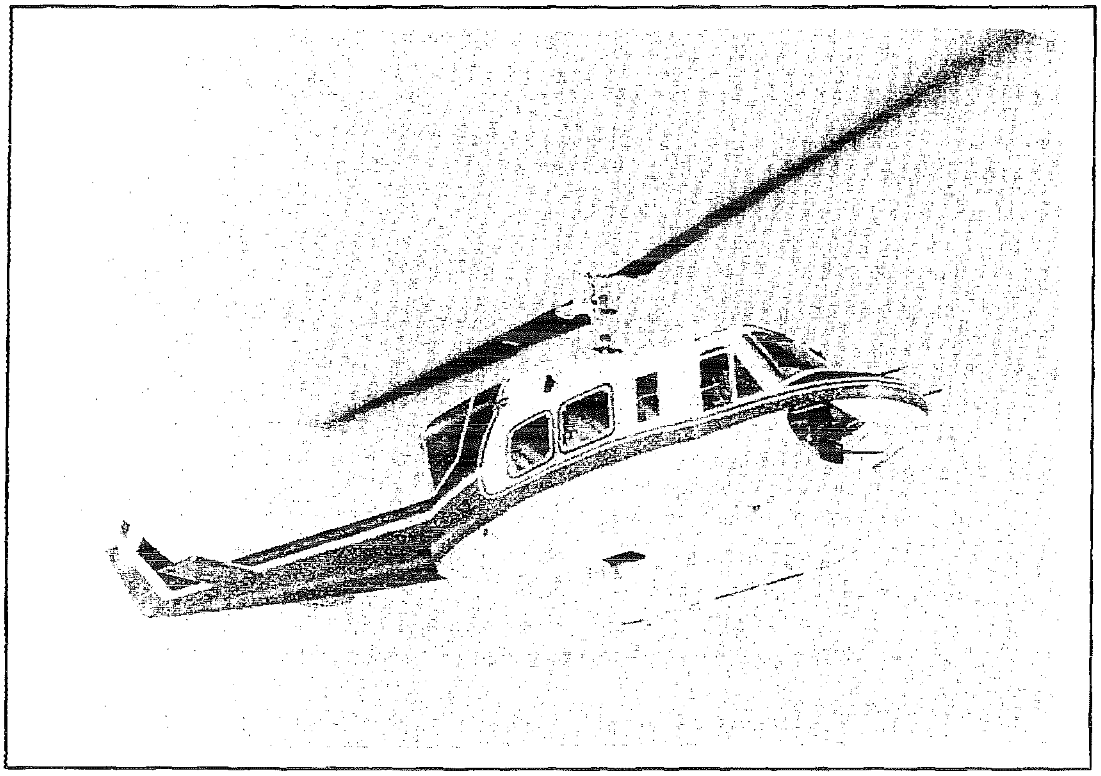


Figure 5.4 *Bell 212*

Petroleum Helicopters of Lafayette, Louisiana, was contacted for information about their operations. They currently provide routine daylight service and nighttime emergency service to oil rigs. They do not currently use ships or oil platforms as alternates during IFR conditions. For example, for offshore IFR operations, the crew would have to maintain fuel reserves to fly to a shore alternate plus 30 minutes of reserve fuel. They do not fly at night. To conduct 24 hours/day weather operations would require MSRC to develop new procedures. One helicopter was found that is U.S. certified to fly in icing conditions. This is the Aerospatiale Super Puma. It would provide approximately 3 hours of on-station time. Aircraft price (new) unmodified is $8.5 million and costs about $1000/hour to operate. Other operating costs were not available.

Table 5.1 Bell-212 Performance Parameters

Performance Parameters	Value
Cruising Speed	90 kn
Response Time (500nmi)*	8.5 h
Time on Station/Mission (100nmi from airport)	2.5 h
Time on Station/Day (100nmi form airport)	10 h
Payload**	1400 lb**
Cost new	$3,825K
Cost used	N/A
Cost Lease/Year	N/A
Cost Crew/Year (salaries, training, exercises)	$336K
Cost Standby (hanger, insurance	$475K
Cost Hourly operating Cost	$400/hr
Availability (with modification and installation)	7-9 mo
Crews required During Recovery Operations	2***

* *Assumes a two-hour alert posture plus fuel stops.*

** *Assumes a response to a spill 200nmi from shore.*

*** *Does not include the additional crew required for extended operations.*

5.3 Beech 300 (Low Cost Regional)

The Beech 300 (Figure 5.5) represents the small commutert-ype aircraft. This aircraft would be regionally based and, because of its lower payload capacity, would not carry a full sensor suite. It could carry any two of the sensors plus the required processing equipment and operators. The general performance parameters for a single aircraft are provided in Table 5.2.

None of the aircraft considered can provide surveillance coverage 24 hours/day using a single aircraft. The Beech 300 meets all other aircraft requirements except the 1700-pound payload requirement. This will restrict the number of sensors and other equipment that could be installed in the aircraft at any one time. The Beech 300 will provide less than two hours of on-station time while operating under Instrument Flight Rules on a spill at the maximum distance from shore. This will either reduce the available surveillance time or require an increased number of aircraft to meet the requirement.

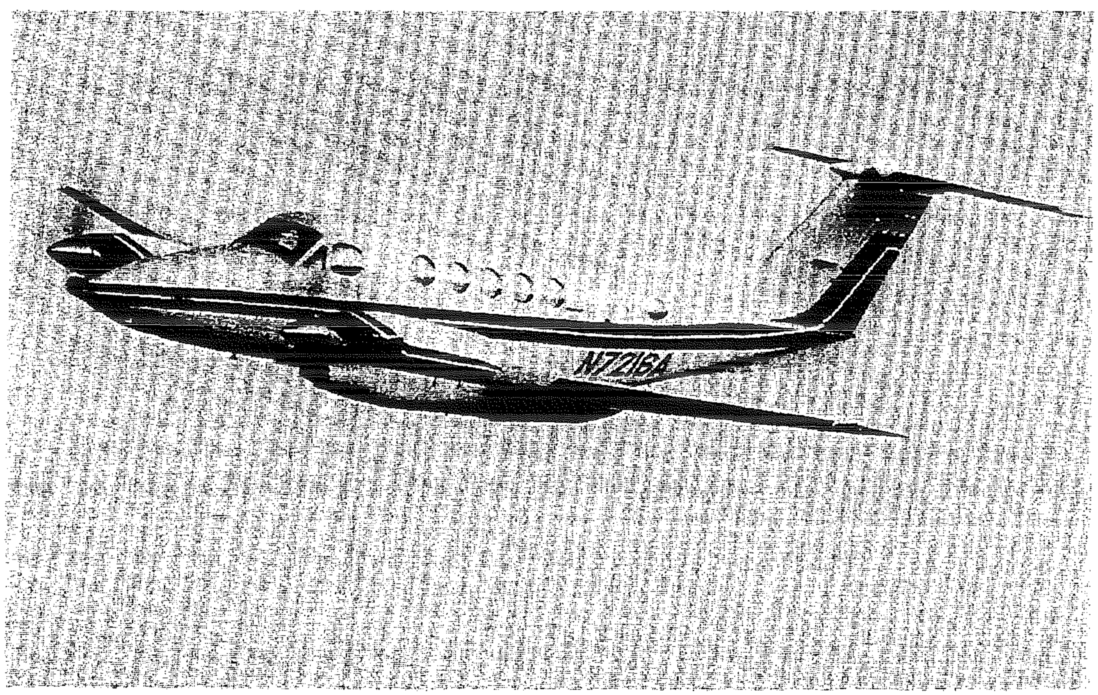


Figure 5.5 Beech 300

Table 5.2 Beech-300 Performance Parameters

Performance Parameters	Value
Cruising Speed	275 kn
Response Time (500nmi)*	3.8 h*
Time on Station/Mission (100nmi from airport)	4:0 h
Time on Station/Day (100nmi form airport)	16.0 h
Payload	1100 lb **
Cost new	$3,500K
Cost used	$2,000K
Cost Lease/Year	$256K***
Cost Crew/Year (salaries, training, exercises)	$345K
Cost Standby (hanger, insurance)	$44K
Cost Hourly operating Cost	$420/hr
Availability (with modification and installation)	15-18 mo
Crews required During Recovery Operations	2****

* *Assumes a twohour alert posture plus fuel stops.*

** *Assumes a response to a spill 200nmi from shore.*

*** *Beech factory leasing cost*

**** *Does not include the additional crew required for extended operations.*

5.4 Beech 1900C (Full Capacity – Regional)

The Beech 1900C (Figure 5.6) represents the medium commuter-type aircraft. This aircraft would be regionally based and could carry a full sensor suite plus the required processing equipment and operators. The general performance parameters for a single aircraft are provided in Table 5.3.

None of the aircraft considered can provide surveillance coverage 24 hours/day using a single aircraft. The Beech 1900C meets all other aircraft requirements. The aircraft will be able to carry a full sensor suite and perform both wide-area surveillance and detailed coverage in support of the recovery operations. The Beech 1900C will provide less than two hours of on-station time while operating under Instrument Flight Rules on a spill at the maximum distance from shore. This will either reduce the available surveillance time or require an increased number of aircraft to meet the requirement.

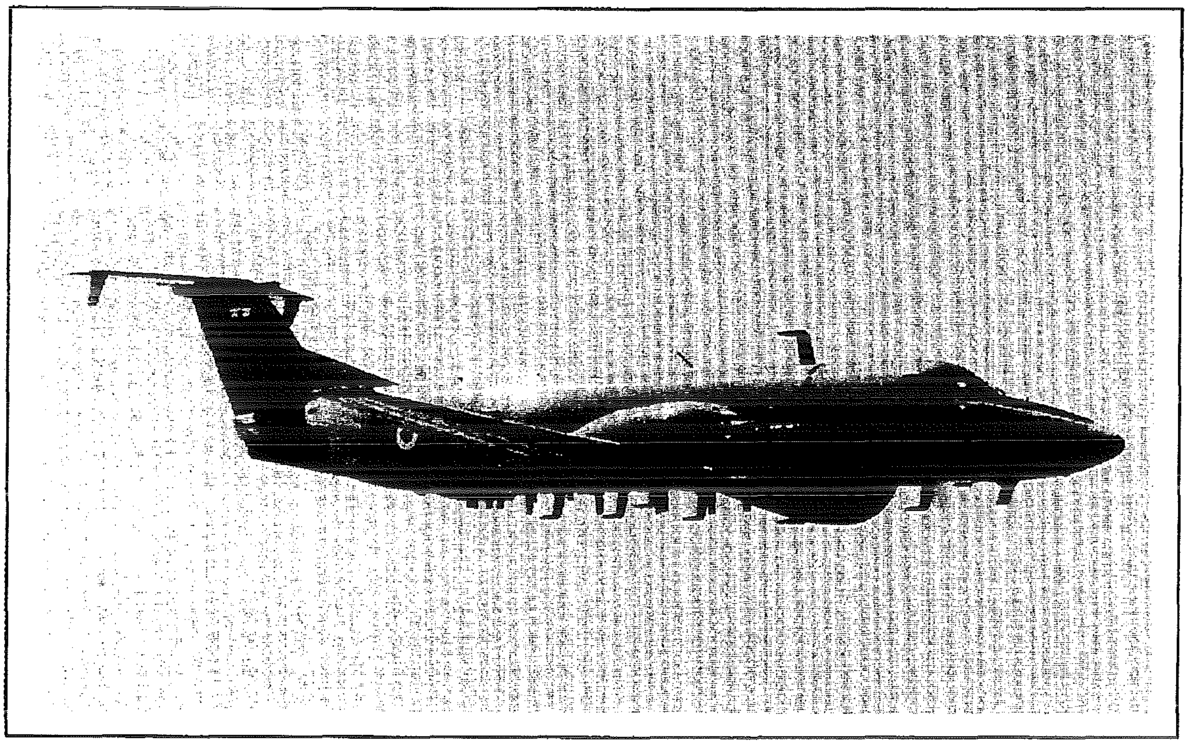


Figure 5.6 *Beech 1900C*

Table 5.3 Beech-1900C Performance Parameters

Performance Parameter	Value
Cruising Speed	262 kn
Response Time (500nmi)*	3.9 h*
Time on Station/Mission (100nmi from airport)	4.6 h
Time on Station/Day (100nmi form airport)	17.0 h
Payload	2400 lb**
Cost new	$4,700K
Cost used	$4,200K
Cost Lease/Year	$408K***
Cost Crew/Year (salaries, training, exercises)	$345K
Cost Standby (hanger, insurance)	$67K
Cost Hourly operating Cost	$405hr
Availability (with modification and installation)	15-18 mo
Crews required During Recovery Operations	2****

* *Assumes a twohour alert posture plus fuel stops.*

** *Assumes a response to a spill 200 nmi from shore.*

*** *Beech factory leasing cost*

**** *Does not include the additional crew required for extended operations.*

5.5 Convair 580 (Test and Validation, Operational Backup)

The CV580 (Figure 5.7) represents the large twin-engine turboprop category. This aircraft would be centrally based and could carry a full sensor suite plus the required processing equipment and operators. The aircraft has the excess capability to carry additional sensors and equipment beyond the required suite. This would allow new suite components (e.g., sensors, processors, communication, and so forth) to be tested and validated under operational conditions before being added to the standard configuration. The general performance parameters for a single aircraft are provided in Table 5.4.

The Convair 580 meets all aircraft requirements except 24 hours/day coverage. The aircraft will be able to carry a full sensor suite with the excess capability to carry new equipment and compare its performance with the standard suite under operational conditions. The aircraft will be able to perform all of the required operational surveillance tasks and could provide backup for the operational aircraft. The CV580 will provide more than six hours of on-station time while operating under Instrument Flight Rules on a spill at the maximum distance from shore. This would greatly increase the available surveillance time for a worst-case spill over the performance of the Beech aircraft.

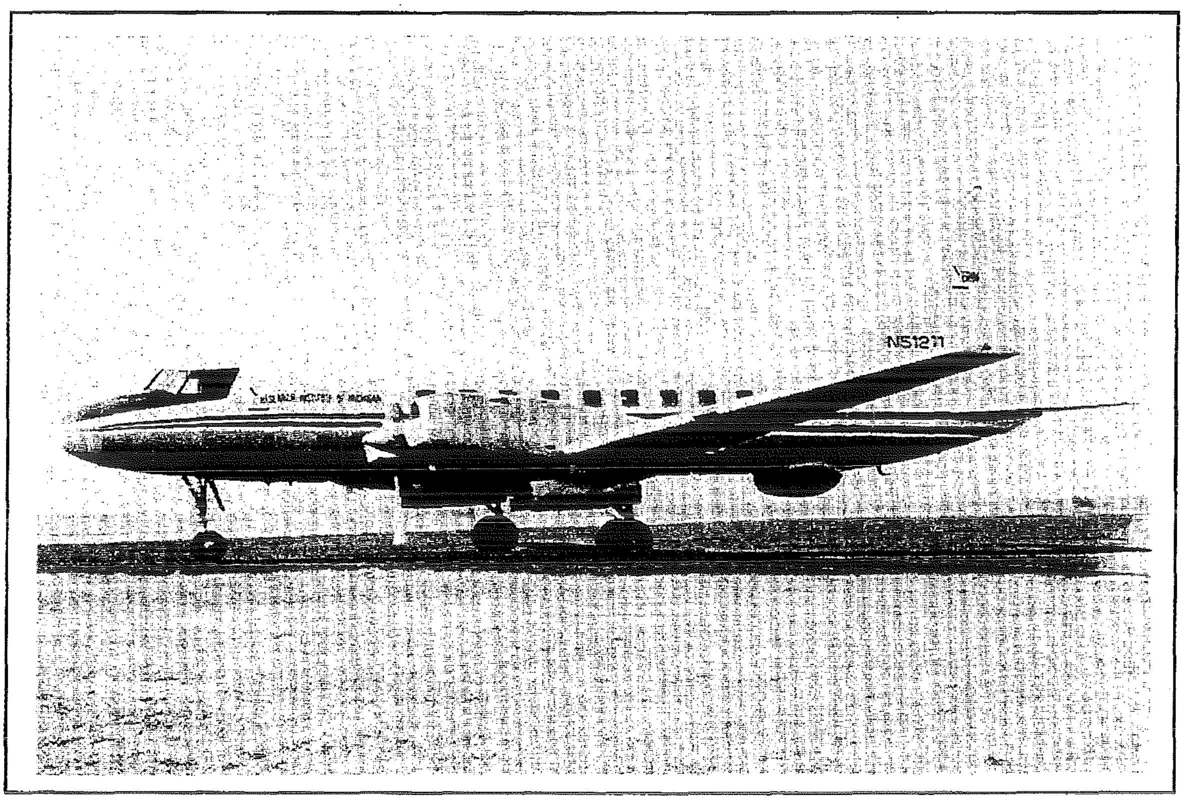


Figure 5.7 *Convair 580*

Table 5.4 Convair-580 Performance Parameters

Performance Parameters	Value
Cruising Speed	280 kn
Response Time (500nmi)*	3.8 h*
Time on Station/Mission (100nmi from airport)	8.6 h
Time on Station/Day (100nmi from airport)	20 h
Payload	8500 lb **
Cost new	N/A
Cost used	$1,000K
Cost Lease/Year	$260K
Cost Crew/Year (salaries, training,exercises)	$450K
Cost Standby (hanger, insurance)	$127K
Cost Hourly operating Cost	$1,500hr
Availability (with modification and installation)	15-18 mo
Crews required During Recovery Operations	3***

* *Assumes a two-hour alert posture plus fuel stops.*
** *Assumes a response to a spill 200nmi from shore.*
*** *Does not include the additional crew required for extended operations.*

5.6 L188/D-C9 (Centralized Support)

The Lockheed 188 Electra (Figure 5.8) represents the large four-engine turboprop category. The DC-9 (Figure 5.9) represents the large turbojet category. These aircraft would be centrally based and could carry a full sensor suite plus the required processing equipment and operators. The general performance parameters for the Lockheed-188 (a single aircraft) are provided in Table 5.5.

None of the aircraft considered can provide surveillance coverage 24 hours/day using a single aircraft. The L188 meets all other aircraft requirements. The L188 would be centrally located. This will require it to respond over greater distances than the regionally based aircraft. The 500 nautical miles in five hours no longer applies. The L188 could respond to a spill 1000 nautical miles from its home base with a two-hour posture. If the alert posture was changed to one hour, the distance would be 1300 nautical miles. To maintain the five-hour response, the aircraft would have to be based on the east and west coasts. The L-188 was designed for long distance operations and provides very long mission times. Its on-station time for a maximum distance offshore spill is over 10 hours. One aircraft flying 11-hour missions could provide almost continuous coverage to a spill within 100 nautical miles of the shore. However, the airplane could maintain this schedule for only a few days due to maintenance requirements. The L-188 had the highest operating cost of any evaluated.

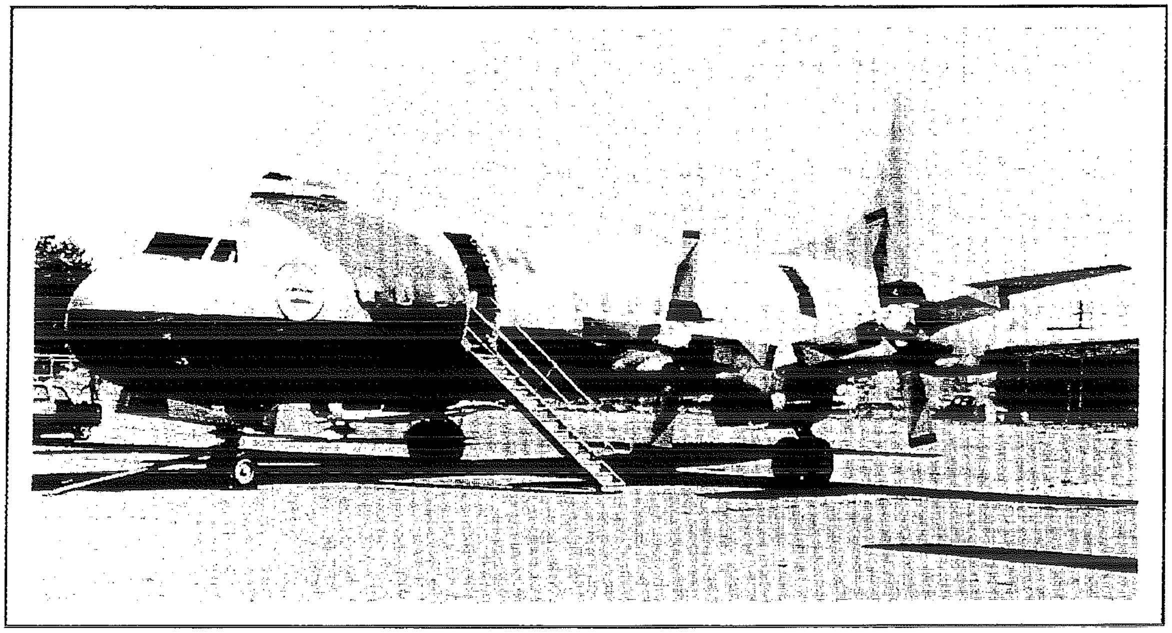


Figure 5.8 Lockheed 188

Table 5.5 Lockheed188 Performance Parameters

Performance Parameters	Value
Cruising Speed	320 kn
Response Time (500nmi)*	3.6 h *
Time on Station/Mission (100nmi from airport)	11 h
Time on Station/Day (100nmi from airport)	21 h
Payload	20,000 lb**
Cost new	N/A
Cost used	$1,250K
Cost Lease/Year	$324K
Cost Crew/Year (salaries, training, exercises)	$700K
Cost Standby (hanger, insurance)	$160K
Cost Hourly operating Cost	$3000/hr
Availability (with modification and installation)	15-18 mo
Crews required During Recovery Operations	2***

* *Assumes a two-hour alert posture plus fuel stops.*
** *Assumes a response to a spill 200nmi from shore.*
*** *Does not include the additional crew required for extended operations.*

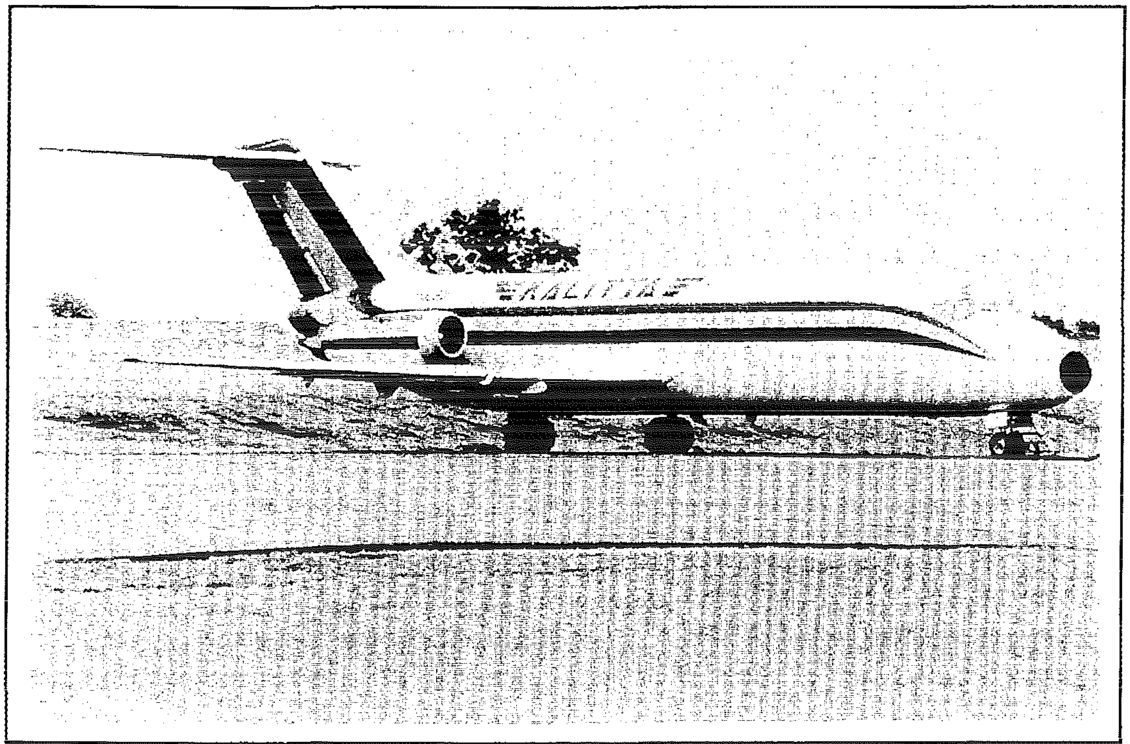


Figure 5.9 Douglas DC-9

The general performance parameters for the DC-9 (a single aircraft) are provided in Table 5.6.

None of the aircraft considered can provide surveillance coverage 24 hours/day using a single aircraft. The DC-9 meets all other aircraft requirements. The DC-9 would be centrally based. This will require it to respond over greater distances than the regionally based aircraft. The 500 nautical miles in five hours no longer applies. The DC-9 could respond to a spill 1200 nautical miles from its home base with a two-hour posture. If the alert posture was changed to one hour, the distance would be 1600 nautical miles. To maintain the five-hour response, the aircraft would have to be based on the east and west coasts. However, allowing six hours to respond would allow for a central base and the resulting cost reductions. The increased speed reduces the impact of distance to the spill and IFR requirements. This allows the DC-9 to perform well on spills out to 200 nautical miles and in all recovery base weather conditions. This aircraft had the lowest standby cost and the highest operating costs of any evaluated.

Table 5.6 DC-9 Performance Parameters

Performance Parameters	Value
Cruising Speed	410 kn
Response Time (500nmi)*	3.2 h *
Time on Station/Mission (100nmi from airport)	6.3 h
Time on Station/Day (100nmi from airport)	19 h
Payload	15,000 lb **
Cost new	N/A
Cost used	$1,400K
Cost Lease/Year	$365K
Cost Crew/Year (salaries, training, exercises)	$670K
Cost Standby (hanger, insurance)	$146K
Cost Hourly operating Cost	$2600/hr
Availability (with modification and installation)	15-18 mo
Crews required During Recovery Operations	3***

** Assumes a twohour alert posture plus fuel stops.*
*** Assumes a response to a spill 200nmi from shore.*
**** Does not include the additional crew required for extended operations.*

5.7 Dornier 228 (Minimum Modification)

The Dornier 228 (Figure 5.10) was included as a special case. This aircraft has already been modified for the Dutch Ministry of Transportation to perform their oil surveillance task. The German government has also installed an oil surveillance system in this aircraft. The sensor suite also includes two prototype sensors, a three-channel radiometer, and a laser fluorosensor. The laser fluorosensor was flight tested in August 1991. The radiometer is due to start flight tests in March 1992. The Dornier 228 would require the least modification of any aircraft evaluated to provide an oil surveillance capability. The general performance parameters for a single aircraft are provided in Table 5.7.

None of the aircraft considered can provide surveillance coverage 24 hours/day using a single aircraft. The Dornier 228 meets all other aircraft requirements. Because of its speed, the Dornier 228 would be regionally based. It is the slowest of the aircraft evaluated, but does provide good station times with 3.5 hours for the 200 mile spill. The apparent purchase or lease costs are high, but include the sensor suite. The aircraft has the lowest operating costs. The lease price quoted is for a seven-year lease. The Dutch aircraft is to be delivered in the spring of 1992; the German aircraft is flying.

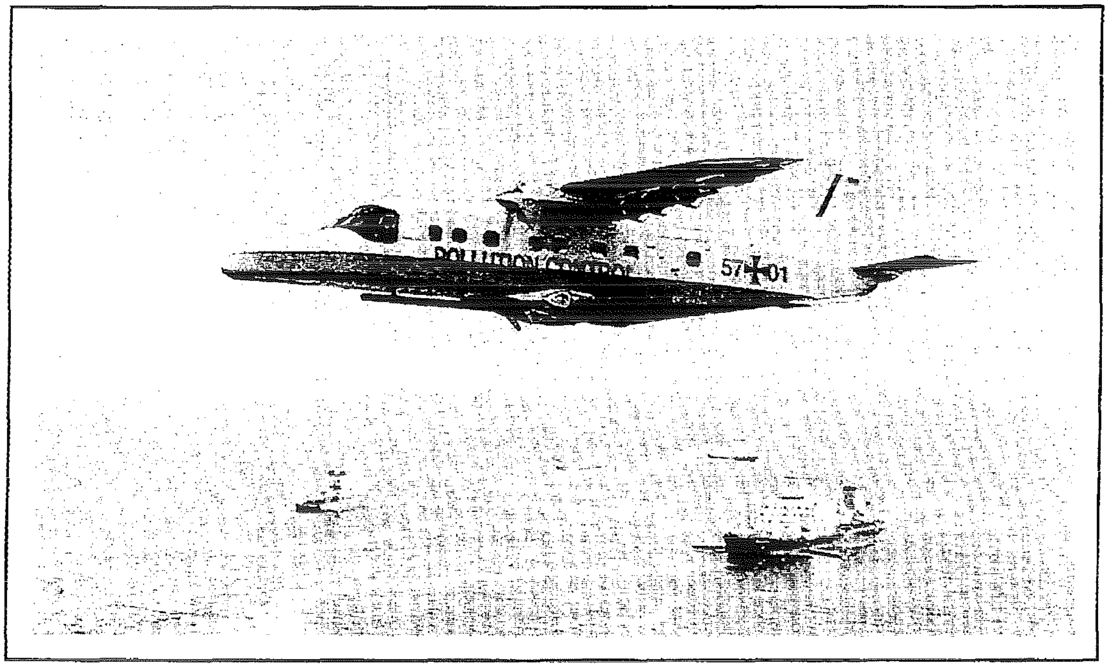


Figure 5.10 Dornier 228

5.8 Grumman OV1D Mohawk (Surplus Aircraft)

The OV-1D was included in the study as a special case because these aircraft are being retired by the US Army and might be available at little cost. The OV-1D is a two-place, twin-engine turboprop military observation aircraft. With the standard 150-gallon drop tanks, the OV-1D is not capable of providing the four-hour station time needed. Larger drop tanks are available, but are not normally carried by the Army during peacetime operations. The tanks are restricted to combat operations because engine loss during takeoff requires the tanks to be jettisoned. Jettisoning the tanks in a civilian location would not be a good practice. Attempts to obtain a resolution of the problem from Grumman were unsuccessful. The aircraft was not analyzed further due to the safety issue.

Table 5.7 Dornier-228 Performance Parameters

Performance Parameters	**Value**
Cruising Speed	234 kn
Response Time (500 nmi)*	4.1 h*
Time on Station/Mission (100nmi from airport)	6.1 h
Time on Station/Day (100nmi form airport)	17.0 h
Payload	0 lb**
Cost new	$8,000K***
Cost used	N/A
Cost Lease/Year	$864K****
Cost Crew/Year (salaries, training, exercises)	$342K
Cost Standby (hanger, insurance)	$50K
Cost Hourly operating Cost	$400/hr
Availability (with modification and installation)	15 mo
Crews required During Recovery Operations	3*****

* *Assumes two-hour alert posture*
** *Assumes a response to a spill 200nmi from shore*
*** *Price Includes the sensor suite (i.e., SLAR, UV/IR scanner, and data downlink).*
**** *Dornier Aviation (North America) Quote*
***** *Does not include the additional crew required for extended operation*

6.0 MSS System Options

6.1 Introduction

This section examines combinations of sensor options for a surveillance system because no one sensor has all the desired attributes determined from the needs assessment. The performance characteristics of individual sensors is summarized in Table 6.1

Table 6.1 Sensor Capabilities and Limitations

	Day	Night	Haze	Clouds Fog	Rain	Thickness	Wide Area	Sufficient Resolution
FLIR or IR Scanner	X	X	X			R		X
TV	X							X
UV Scanner	X					R		X
Microwave Radiometer	X	X	X	X X		R		X
SLAR	X	X	X	X	X		X	
Laser Fluorosensor	X	X	X			A		X

R = Relative thickness measurement potential, emissivity
A = Actual thickness measurement potential, narrow-pulse UV laser

No single sensor will meet the range of requirements included in searching for oil in all weather, monitoring oil movement and thickness, and supporting cleanup operations. Combinations of sensors increase cost, integration complexity, and the aircraft capacity needed. This section provides some options that range in capability, cost, and risk that can be used in a comparative decision process.

Thermal FLIR and IR scanners will not detect oil and water during the twiceaday thermal crossover and they may confuse thermal wakes from ships or drilling platform water discharges with oil. TV and UV scanners may confuse other surfactants (e.g., acids, fish oil) with oil on water. The microwave radiometer must operate at about a 1000-foot altitude or less to have sufficient resolution to detect oil windrows; reliable relative thickness indication requires multiple frequency bands. Multifrequency microwave radiometers are in the prototype stage and are not a proven commercial product. SLAR requires wind conditions to provide good detection and it may confuse other surfactants or surface disturbances with oil. Laser fluorosensors are not fully engineered in size, weight, or ease of operation, and, therefore, are not available as a commercial product.

6.2 MSS System Option 1 – Spotting Capability

A gimballed or handheld FLIR/TV camera could be used on a rented helicopter to provide a day/night capability to spot oil near beaches and near the MSRC cleanup vessels (see Figure 6.1). A stabilized 360° gimbal containing color TV and FLIR cameras could be mounted on a removable pallet that would attach to the helicopter seat attachment points. The cameras could be interfaced to both a display and a commercial computer with a frame grabber to transmit freezeframe imagery down to the ships and the MSRC SOS. As a backup, the operator could provide voice reports and instructions via radio.

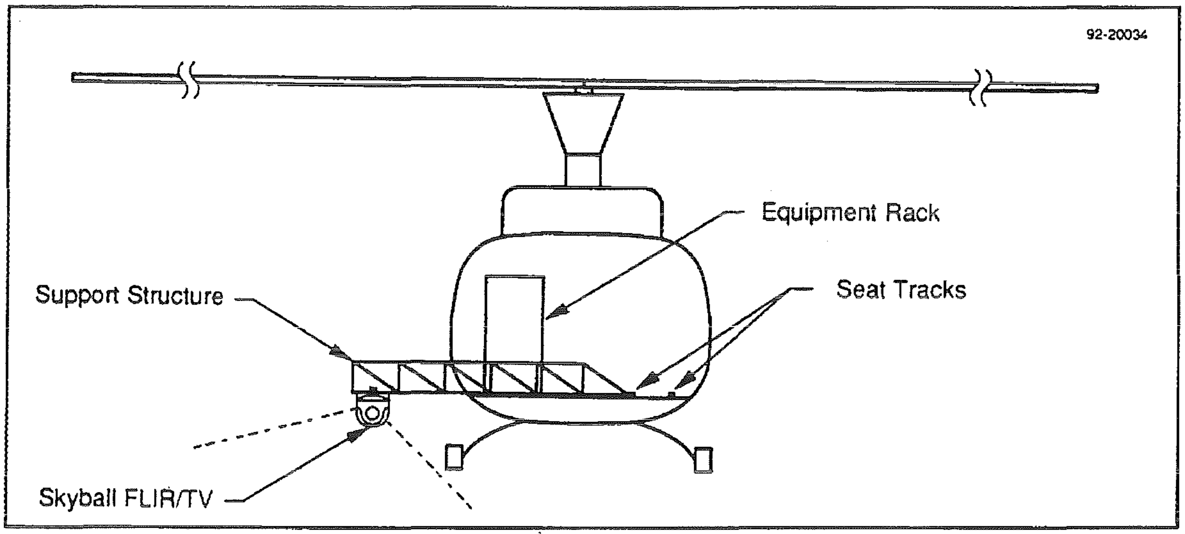


Figure 6.1 Option 1 - Spotting Capability

The specific interface to MSRC ships and SOS is undefined at present, but should not be a problem if standard communication channels are used. As an alternative, completely integrated standalone air-to-ground systems are commercially available. The cameras may be used to spot thick oil that may be about to wash up on beaches and to reposition cleanup ships to the thick oil by their relative position within the frame. This option offers a relatively low-cost, near-term approach to acquire a portable oil spotting capability.

PROS	CONS
All commercial equipment--minimum integration	No adverse weather capability minimum development
Standard commercial interfaces	Poor area coverage
Non dedicated aircraft--low cost	Not useful during search operation for oil
Easy to operate	May not meet fivehour response time
Day/night capability to detect thick oil	Limited onstation time offshore unless supported by landing on ships or platforms

6.3 MSS System Option 2 – Direct Support Capability

A combination of a FLIR and a radiometer could be used to provide day/night limited-weather direct support to skimmers (see Figure 6.2). A stabilized FLIR in a 360° gimbal and a belly-mounted microwave radiometer could be installed on a Beech-300 type aircraft. The equipment could be interfaced to a common commercial display/processor combination with a frame grabber for either fax or video relay to the MSRC ships and SOS. As a backup, the operator could provide voice reports and instructions via radio. This option adds increased weather (e.g., clouds, fog) capability and increased area coverage (~100 nmi^2/hr) relative to Option 1. It also meets the fivehour response time needed and increases the on-station time. With a GPS interface, absolute position information can be included with the image. This option offers a relatively good regionally based capability in one of the four activities listed in the draft MSS Concept of Operations"Direct Support to Skimming."

PROS	CONS
Night and limited weather operation	Could miss (not find) oil in initial spill assessment
Supports skimming recovery	Limited onstation time under IFR conditions (i.e., 2 hours at 200 nmi from shore)
Combined sensors may be used to remove some ambiguity and false detections	Poor utility in recovery area surveillance and wide-area detection and monitoring

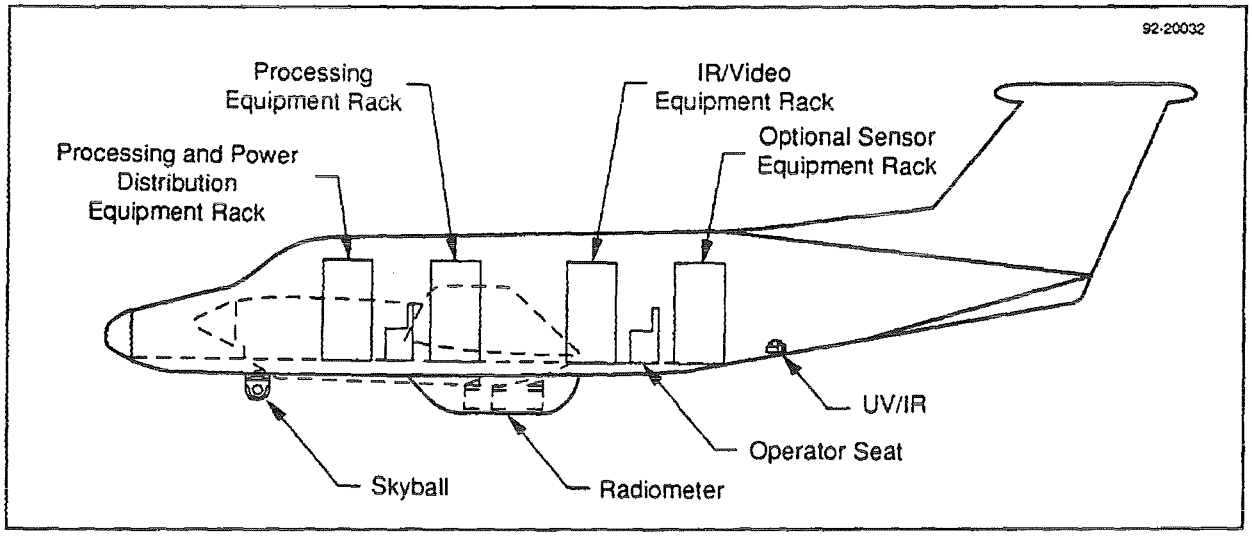


Figure 6.2 *Option 2 - Direct Support Capability*

6.4 MSS System Option 3 – All Weather Capability

A SLAR and radiometer could be bellymounted in a Beech-300 type aircraft and provide an all-weather capability to search and monitor oil (see Figure 6.3). The radiometer coverage would be directly below the aircraft and would detect the thick oil. The SLAR coverage would extend on both sides of the aircraft, starting approximately where the radiometer coverage ended. In this manner, an all-weather oil surveillance capability of a few to a few tens of miles to both sides would exist.

The SLAR would provide a capability to locate the oil and the radiometer would detect areas of relative thickness. A shared display would be used with a frame grabber with fax or video relay to the MSRC ships and SOS. With a GPS interface, absolute position information can be added. As a backup, the operator could provide voice reports and instructions via radio. This option adds an adverse weather capability (e.g., clouds, fog, rain) and a capability to meet wide-area monitoring requirements ($\geq$ 3000 nmi^2/h) and to find thicker oil. However, it does not provide the high definition/resolution image needed to determine the condition of the spiller and to observe the effectiveness of the cleanup operation that is provided by Options 1 and 2. Option 3 offers a relatively good regionally based capability in all four activities in the draft MSS Concept of Operations.

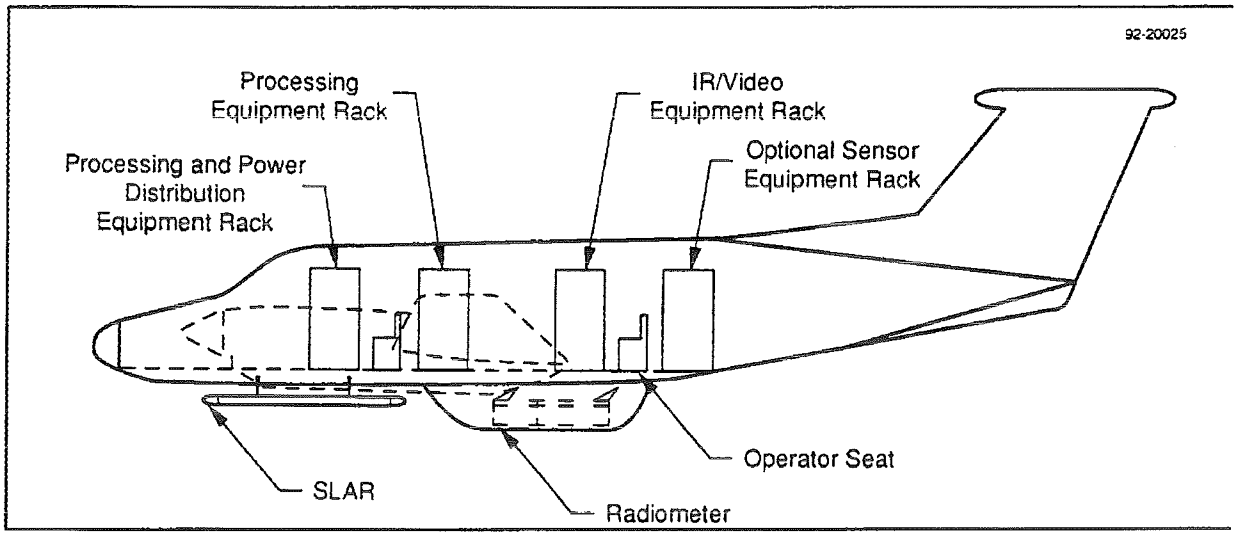


Figure 6.3 *Option 3 - All-Weather Capability*

PROS	CONS
All weather operation	Lack of high resolution
Ability to locate the spill--initial spill assessment	Limited on-station time under IFR conditions (i.e., 2 h at 200 nmi from shore)
Ability for widearea monitoring	
Direct support operations	

6.5 MSS System Option 4 – High Detection Capability

The combined use of a SLAR with a UV/IR scanner provides high combined oil deductibility via (1) area coverage, (2) sheen detection, and (3) thick oil detection (see Figure 6.4). This equipment could be mounted on a Beech 300-type aircraft to provide surface coverage similar to Option 3. The SLAR would be used for both initial location and area surveillance; the UV would locate the thinner portions of the slick and the IR would locate the thicker oil. The configuration of the processor, display, and link is the same as in Options 2 and 3.

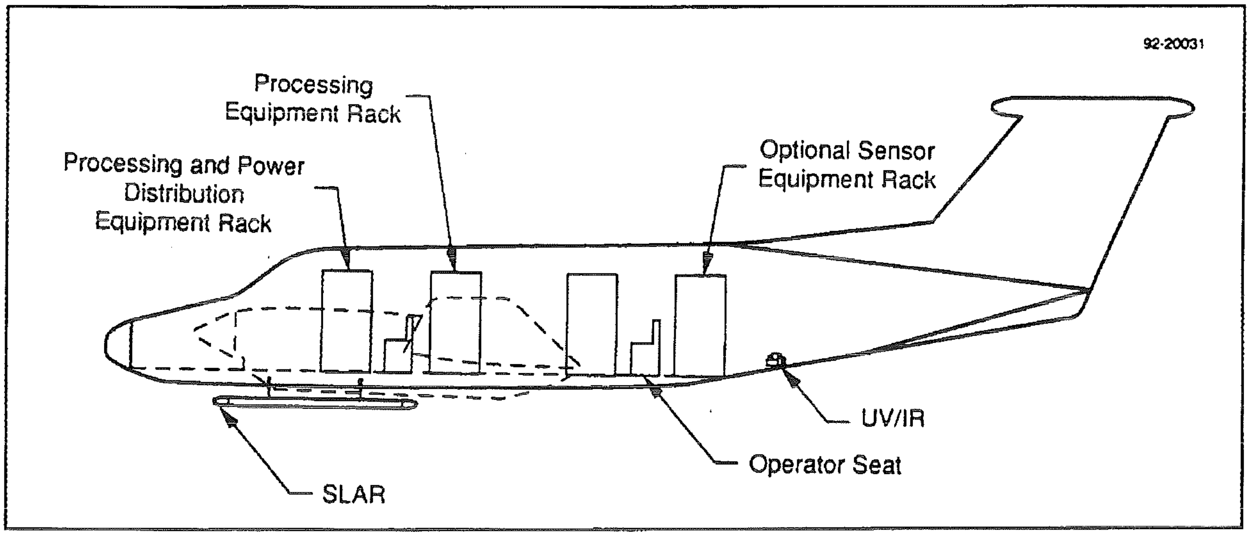


Figure 6.4 *Option 4 High Detection Capability*

Option 4 provides a more robust capability to detect any type of oil because of the three rather than two sensor combinations of the previous options. This imposes a larger workload on the operator both in terms of real-time sensor control/frame selection and in terms of what the operator must learn to effectively use these sensors. Thorough training is essential. However, in adverse weather, only an area detection capability will be provided. The SLAR does not discriminate between sheen and thick oil; it only detects large areas of oil.

Option 4 will provide a regionally based capability for clear weather operation in all surveillance activities.

PROS

Good deductibility of oil

Supports all ConOps activities

Combined sensors may be used to remove some ambiguity and false detections

CONS

Requires a higher degree of training and knowledge to use effectively

Severely limited in clouds and fog

6.6 MSS System Option 5 – Full System Capability

Unlike the previous options, which were tailored to emphasize a particular function or feature, this option assembles everything to meet as many derived requirements as possible. Accordingly, the increased amount of equipment requires a larger aircraft such as the Beech 1900C or Dornier 228. It also requires increased integration and multiple controls and displays (see Figure 6.5).

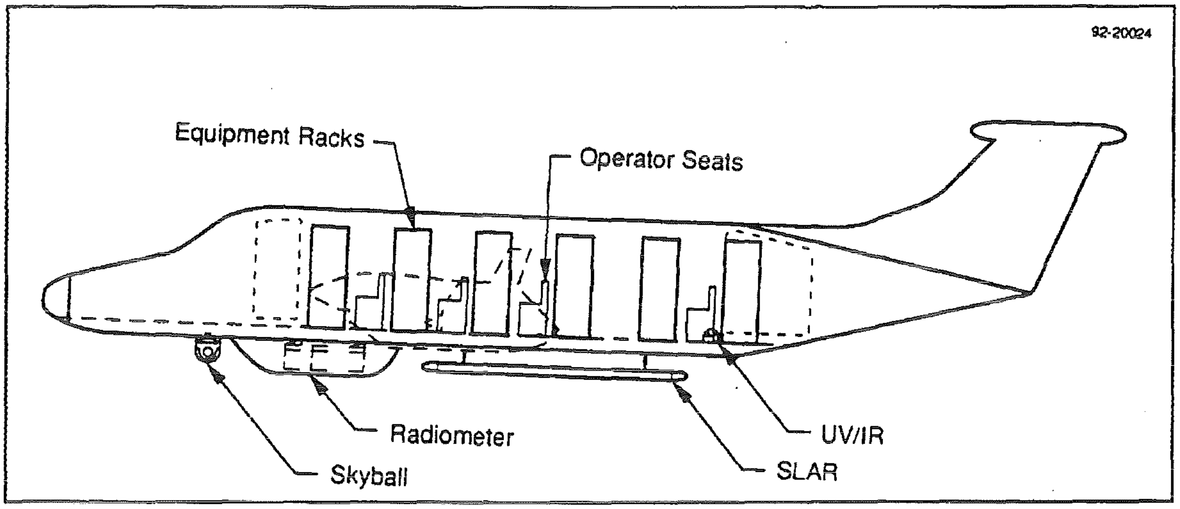


***Figure 6.5** Option 5 - Full System Capability*

Such a system would be similar to or could be a modification of those currently produced by Dornier Industries and the Swedish Space Corporation. The differences relative to the existing packages are (1) the addition of a 3-5 μm FLIR/TV camera combination in a stabilized gimbal, (2) an interface to GPS, and (3) georegistration and feature extraction processing for GIS integration with the MSRC SOS. The cameras are for day/night monitoring and recording of spill cleanup operations, the condition of the spiller, and for spot coverage near ships or along the shoreline. The GPS interface to the processor is needed for georeference accuracy and to aid in georegistration. Processing is needed to provide effective and flexible surveillance output to be used and overlayed with other stored data in the MSRC SOS.

Option 5 provides a complete, regionally based surveillance capability to best meet all known derived requirements within existing technology for oil surveillance.

PROS	CONS
Commercial equipment within today's technology limits	Requires some development--is not yet available commercially
Maximizes requirements satisfaction	Most costly option

6.7 MSS System Option 6 –Tailored Capability

This option could be exercised by MSRC if MSRC decided to limit its investment to a tailored capability (Options 1-4), initially, but planned to increase to a full capability by adding or replacing equipment. The larger aircraft has more capacity than would be needed initially, but should be cost advantageous over deinstallation, new modification, and installation for growth. Another use of this option would be if MSRC decided to buy a configuration of the current Swedish Space Corporation system (Beech 1900C) or the Dornier Industries (Dornier 228) system. This would allow "hands-on" multisensor experience by MSRC to (1) focus its future investment in surveillance equipment, (2) refine its operational concept and requirements, and (3) prioritize its research and development (R&D) investment in surveillance technology.

The capability provided by this option is to be determined upon selection of an initial tailored capability or existing (integrated) system.

6.8 MSS System Option 7 – Research Test Bed on CV580 Aircraft

As was found during the trade study, large centrally based aircraft were not cost-effective for a high frequency of spills at multiple locations, although they were cost-effective with lower spill/suspected spill frequency. However, they do offer significantly longer onstation time and have a significantly larger carrying capacity for people and equipment than the types of aircraft represented in other options.

The selection of the "right" surveillance option for MSRC is not obvious because uncertain requirements of future MSRC operations, evolving technical capability, and "inflated" claims of vendors wanting MSRC business distort the reality of which sensor systems best meet MSRC needs. Thus, the research test bed concept evolved during this study and is presented as Option 7 (see Figure 6.6).

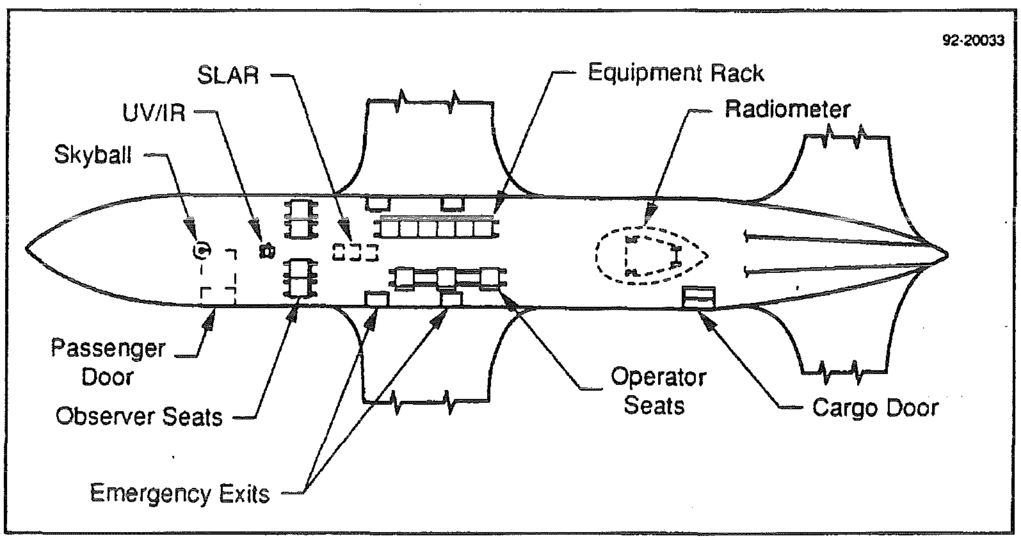


Figure 6.6 Option 7 - Research Test Bed Concept

The use of the research test bed would involve sensors and measurements to quantify and define performance in those areas not within today's technology. For example, those areas in Options 1-6 that are either poorly or partially satisfied will be addressed by the test bed.

Option 7 provides a capability to test equipment being considered before a purchase or an upgrade directly alongside the operational baseline in the same aircraft. In conjunction with other operational MSRC assets, this option could be used during spill operations. Option 7 provides a capability to (1) provide an additional operational backup for large spills or training, (2) test and validate surveillance vendor claims before investment, or (3) both of the above.

Figure 6.7 shows how each option presented meets the derived requirements. Note that several requirements are beyond today's technical capability.

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MSS System Option	Detect Oil	Reject False Targets	Locate the Spill	Determine Spill Boundaries	Determine Oil Thickness	Estimate Oil Quantity	Determine Oil State	Determine Oil Type	Determine Trajectory and Fate	Determine Recovery Effectiveness	Operate During Day and Night	Operate During Adverse Weather	Operate During Heavy Seas	Operate in Shallow or Deep Water	4-hr on Station, 200 nmi Offshore	5-hr Response, 500 nmi Distance	Process Info in 15 min	Meet Various Area Coverages	Interface to MSRC SOS
1. FLIR/TV Camera on Bell-212 Helicopter (Spotting Capability)	○	—	○	—	○	—	—	—	—	○	●	—	—	●	—	—	●	—	?
2. FLIR/Radiometer on Beech 300 (Direct Support Capability)	○	○	○	○	○	—	—	—	○	○	●	○	●	●	○	●	●	○	?
3. SLAR/Radiometer on Beech 300 (All-Weather Capability)	○	○	●	●	○	—	—	—	—	—	●	●	●	●	○	●	●	●	?
4. SLAR/UV/IR on Beech 300 (High Detection Capability)	●	○	●	●	○	—	—	—	—	●	●	—	●	●	○	●	●	●	?
5. SLAR/UV/IR/Radiometer/ FLIR/TV on Beech 1900C or Dornier 228 (Full System Capability)	●	○	●	●	○	—	—	—	—	●	●	●	●	●	○	●	●	●	?
6. Tailored Capability on Beech 1900C or Dornier 228	← TBD →																		
7. Operational Test Bed on CV-580	TBD	●	TBD	TBD	●	●	●	●	●	TBD	TBD	TBD	TBD	TBD	●	TBD	TBD	TBD	?

● Fully or Principally Meets Derived Requirement

○ Partially Meets Derived Requirement

— Poorly Meets or Does Not Meet Derived Requirement

TBD To Be Determined

Figure 6.7 Requirements Satisfaction

7.0 System Engineering and Acquisition

This section outlines the engineering activities needed to acquire each of the options discussed in Section 6. Candidate equipment, alternatives, costs, availability, schedule, and risks are discussed. It is important to reiterate that there is no single or combined set of equipment existing today that meets all of the derived MSRC requirements for surveillance. Requirement priorities will likely evolve after MSRC operations and initial use of surveillance equipment begin.

7.1 Option 1 - Helicopter with FLIR/TV

This option could be purchased as a complete system less any palletization and aircraft modification costs. At least one company (i.e., Intertechnique) is known to offer fully integrated FLIR/TV cameras with stand-alone display systems. Another approach is to assemble a system based on commercial components and interface it directly with the MSRC SOS and vessel equipments. Necessary components and costs for a direct interface system are shown in Table 7.1.

The sizes and weights of handheld camera video equipment are important because this equipment needs to be carried on a small aircraft with limited cabin space and cargo capacity. The use of low-power consumption equipment results in smaller and lighter batteries. Estimates of the equipment sizes, weights, and power consumption are provided in Table 7.2.

All equipment used in Option 1 is off the shelf and built to commercial video interface standards. The equipment is mounted on a removable pallet and could be packaged and transported to any MSRC region. The total pallet and equipment weight is about 700 pounds, more than 75 percent of which will be inside the helicopter. The pallet will be installed through the helicopter door and will be mounted to the seat tracks. Federal Aviation Administration (FAA) certification of this installation, by helicopter type, is required. There is a moderate risk that some delays could occur in obtaining approval for a removable installation.

Each helicopter to be used with this pallet must have a 35-ampere electrical service modification. This includes wiring, circuit breaker, and poweroff provisions that must also be FAA certified and approved. A low risk is foreseen on any delays in electrical certification.

There is very little that needs to be designed for this option. The pallet must be designed; however, it can be designed and fabricated while the equipment is being procured because existing components are used. A small amount of image formatting and control software needs to be designed to be compatible with MSRC vessels and SOS.

Table 7.1 Gimbal Mounted Cameras and Associated Video Equipment

Item	Manufacturer	Model	Comments
Gimbal	Versatron	Skyball	With joystick control
Color Camera	COHU	6800	With remote zoom lens
IR Camera	Kodak	KIR 0310	With dualfocal length lens
Waveform Monitor	Tektronix	1480R	Overlay graphics
8" Color Monitor	Sony	PVM-8220	TV
9" B&W Monitor	Sony	PVM-9115	IR
Video Switch	TBD	TBD	Video select/graphics
VCR	Panasonic	AG-7300	SVHS
Overlay	RP Industries	2503TVOS-9003	With color/IR MUX
GPS Receiver	Trimble	TIGR	With dual I/O ports
Power Converter	Lambda	LRS 53-12	12.5V at 11.5A
Invertor	KGS Electronics	SPS 306B-3	117VAC at 375 VA
80486 Ruggedized Computer and Modem			Frame grabber, image formatting
UHF/VHF radio			Link to MSRC vessels/SOS

Table 7.2 Camera Size, Weight, and Power Requirements

Item	Size, l x w x h (in)	Weight (lb)	Power Consumption (W at 12 VDC)
UV Camera*	TBD	2.0	10.0
Color Camera*	8.6 x 2.5 x 2.6	2.5	4.5
IR Camera Head*	8.1 x 4.9 x 4.8	7.0	
IR Control Unit	9.3 x 5.4 x 10.3	8.0	10.0
Overlay	TBD	3.0	6.0
VCR		21.0	
Totals		51.5 (Max.)	40.0

* *Without lens*

The schedule estimate for all procurement, design, and modification is six months. An additional 2-3 months is needed for final assembly and flight testing. This is judged as a low risk option. The first unit cost is about $.67 million and the recurring units costs are about $.51 million. The "wet lease" operations costs are $1,000/hour for helicopter rental plus $35,000/year for equipment maintenance. Table 7.3 summarizes the cost estimates for Option 1.

7.2 Option 2 - FLIR with Radiometer on Beech-300 Type Aircraft

This option's combination of sensors is not available as an existing integrated system and, therefore, would have to be integrated as a new system.

Candidate equipment for the FLIR portion is as exemplified in Option 1, deleting the TV. Delivery time is six months or less. The Ericsson radiometer and potentially the DLR radiometer will be commercially available. Both require about a 12-month delivery time. The total first unit cost (exclusive of aircraft operations) is about $2.2 million with recurring unit costs of $1.7 million.

Table 7.3 Option 1 Cost Estimates

Item	Initial	Recurring	Maintenance
Sensors (Purchase)			
FLIR, TV, Gimbal and Related Equipment	$400K Comm. Purchase	$400K	
Software and SOS Interface	$60K		
Aircraft Modification			
Power	$20K Per Helicopter	$20K Per Helicopter	
Pallet Integration			
Pallet Design and Fabrication	$90K	$45K	
Assembly and Test	$90K	$45K	
Maintenance/Year			$35K
Total	$660K Helicopter Rental/Hour	$510K 1K/Hour	$35K

TRW reported having a radiometer that is commercially available. However, technical data sheets, mechanical drawings, and cost data are not available for analysis. Only one TRW unit is believed to have been constructed, and a production design is uncertain. There are several companies who have built or could build a radiometer as a special order. However, maintenance, field reliability, and sparing are unknowns with such orders.

This option will require a new interface design to a common processor, an interface to a GPS receiver, and an interface to the MSRC vessels and SOS. All aircraft installation design and modification can be concurrent with equipment procurement because equipment drawing packages exist. Equipment integration should be completed four weeks after delivery and installation; system testing and certification requires three months. The total schedule for operational availability is 16 months after order.

FAA aircraft certification will likely be required in the restricted category. Given the new interfaces of sensors and processors and the new integration, there is some schedule risk. Option 2 is judged as a low to moderate risk. Table 7.4 summarizes the cost estimates for Option 2.

Table 7.4 Option 2 Cost Estimates

Item	**Initial**	**Recurring**	**Maintenance**
Sensor (Purchase)			
FLIR,TV,Gimbal and Related Equipment	$300K	$300K	
GPS/INS and Ruggedized Equipment and GPS	$193K	$193K	
Radiometer	$450K	$450K	
UHF/VHF Radio	$ 9K	$ 9K	
Documentation and Training	$200K	$200K	
Sensor Control and MSRC Interface	$ 200	$ 50K	
Aircraft Modification			
Gimbal	$140K	$ 70K	
Radiometer	$255K	$130K	
Communication/navigation	$85K	$25K	
Processor	$60K	$20K	
Power	$65K	$20K	
Maintenance/Year			$50K
Installation, Integration, and Test			
Installation and Cables	$ 140K	$ 100K	
Integration and Test	$ 140K	$ 100K	
	$2,237K	$1.667K	$50K
Total			
Aircraft Purchase New	$ 3.2M		
Aircraft Purchase Used	$ 2.0M		
Annual Lease	$ 926K		
Operating Costs/Hour	$ 1.15K		

7.3 Option 3 – SLAR and Radiometer on Beech-300 Type Aircraft

This option could be purchased as a complete system from either Swedish Spacecraft Corporation (SSC) or Dornier Industries with modification for a GPS interface and an MSRC interface. Because this is not a standard configuration, system purchase cost data were estimated by ERIM based on SSC- and Dornier-provided cost information. The aircraft modification, installation, and integration costs are the result of a mechanical design analysis using the specific equipment and aircraft drawings.

The first unit cost (exclusive of aircraft operations) was estimated at $2.6 million.* The delivery time for the equipment is about 13 months. This will be concurrent with installation design and aircraft modification. Another four months will be required for aircraft installation, testing, and certification. The schedule risk is foreseen as low to moderate because most of the equipment has been integrated before. FAA certification in a restricted category is likely. Table 7.5 summarizes the cost estimates for Option 3.

7.4 Option 4 – Beech-300 Type Aircraft with SLAR and UV/IR Scanner

This option could be purchased commercially from either SSC or Dornier Industries as an integrated system with stand-alone displays. Both SSC and Dornier use the Daedalus UV/IR scanner, the only commercially available UV/IR scanner. SSC uses the Ericsson SLAR and Dornier uses the TERMA SLAR. These are the only two commercial low-cost SLARs available today.

Because the interfaces of these sensors are complex and nonstandard, a purchase from either one of these system vendors will save appreciable nonrecurring interface design and integration costs of sensors, common processor, controls, and displays. Table 7.6 summarizes the cost estimates for Option 4.

Table 7.5 Option 3 Cost Estimates

Item	Initial	Recurring	Maintenance
SLAR	$400K	$400K	
Radiometer	$450K	$450K	
Communications/Navigation	$280K	$280K	
Documentation and training	$200K	$200K	
Sensor Control and MSRC Interface	$300K	$100K	
Aircraft Modification			
SLAR	$168K	$ 83K	
Radiometer	$255K	$127K	
Communication/Navigation	$ 85K	$ 40K	
Power	$ 62K	$ 22K	
Maintenance/Year	$ 65K	$ 23K	$50K
Installation, Integration, and Test			
Installation and Cables	$ 140K	$ 100K	
Integration and Test	$ 140K	$ 100K	
Total	$2,543K	$1,925K	$50K
Aircraft Purchase New	$ 3.2M		
Aircraft Purchase Used	$ 2.0M		
Annual Lease	$ 926K		
Cost/Hour	$ 1.15K		

Table 7.6 Option 4 Cost Estimates

	Swedish Space Corporation		Dornier Industries	
Item	**Initial Unit**	**Recurring**	**Initial Unit**	**Recurring**
SLAR, UV/IR Processor and Controls, Documentation and Training, Image Link				
System Purchase	$1,765K	$1,765K	$2,575K	$2,575K
First Unit Aircraft Modification, Installation Design, Installation, Integration and Test	$ 925K		$ 925K	
Recurring Modification, Installation, Integration, and Test		$ 560K		$ 560K
Design GPS Interface to Processor (RS 422)GPS Receiver	$ 50K		$ 50K	
GPS Receiver	$ 5K	$ 5K	$ 5K	$ 5K
GPS Interface Card	$ 2K	$ 2K	$ 2K	$ 2K
Software Design for Processor Interface to MSRC Vessels/SOS	$ 100K		$ 100K	
Total	$2,847K	$2,332K	$3,657K	$3,142K

All equipment used in this option is commercially available. It will weigh about 950 pounds and can be carried by a Beech-300 type aircraft with a pilot, copilot, and a system operator. It will be fixedmounted, and, therefore, requires a dedicated aircraft. FAA certification in a nonrestricted category will require six months and $0.5 million to obtain. Restricted certification (i.e., no observers or noncrew passengers allowed, nor operation in icing conditions) is likely.

Aircraft installation design and modification can be performed in parallel with equipment delivery, which will take 11-13 months. During this period, the GPS interface and MSRC interface can also be designed and fabricated. An additional five months are necessary for installation, system testing, and FAA certification. There is a moderate risk that schedule delays will occur.

7.5 Option 5 – Complete System on either Beech-1900 Type Aircraft or Dornier-228 Type Aircraft

This option offers the full capability of off-the-shelf sensors. In addition to the basic SLAR, UV/IR, and radiometer sensors for oil surveillance, it adds gimballed FLIR/TV cameras for oil spotting, recording and monitoring the spiller and cleanup ships. Option 5 also adds a GPS capability for improved position accuracy and an image interface to MSRC vessels and SOS. There are two suboptions possible:

1. Use one of two existing integrated systems modified for the additional capability listed above.

2. Integrate a new system and add additional image georegistration/overlay and feature extraction image processing.

This option is estimated to cost $4.1 to $5 million to buy the initial unit installed and ready for operations. Recurring unit costs are estimated at $3.5 to $4.5 million per unit. Table 32 summarizes the cost estimates for Option 5. The schedule is approximately 12 months for equipment delivery with an additional six months for installation, system test, and FAA certification. This certification will likely be in the restricted category.

All of this equipment has already been integrated in a single system except for the FLIR/TV, which uses standard video interfaces. The addition of GPS uses a standard ARINC bus; the MSRC interface will be the standard low-rate radio channels via modem. The Beech-1900C modification, installation, and the addition of the FLIR/TV gimballed system to the Dornier 228 are the majority of the new design. Given that all of the equipment and commercial drawings exist, the risk of an 18-month delivery ready for operations is judged as low to moderate.

This approach will maximize derived requirements satisfaction. It is the most complex, will cost the most, and will require the most training. However, it is the only approach that will provide MSRC hands-on experience with all sensor types. As was mentioned in Section 4, advances in image processing allow an improved capability for georeferencing, georegistration, and feature extraction within today's technology. The systems today can provide an image frame by frame with a latitude/longitude reference point down to the surface. It is possible to improve this by layering different images to a common scale and georeference and provide thresholded or extracted information to the surface for either direct display or integration with a GIS system. While there are many commercial packages which offer "image fusion" potential, a specific design (software) for each sensor would have to be developed, requiring a more powerful computer. This would add an estimated $1.2 million in software design and $0.2 million in commercial hardware.

Table 7.7 Option 5– Cost Estimates

	Swedish Space Corp.		Dornier Industries	
	Initial Unit	Recurring	Initial Unit	Recurring
Basic System				
SLAR, UV/IR, Radiometer Processor and Contrals, Image Link, Documentation and Training	$2,171K	$2,171K	$3,091K	$3,091K
FLIR/TV Purchases	$ 305K	$ 305K	$ 305K	$ 305K
FLIR/TV Integration into Common Processor	$ 50K		$ 50K	
GPS Interface Design and MSRC SOS Interface	$ 5K	$ 5K	$ 5K	$ 5K
GPS Receiver and Interface Card	$ 7K	$ 7K	$ 7K	$ 7K
A/C Modification	$1,063K	$ 993K	$ 1,063K	$ 993K
Installation, Integration, and Test	$ 370K	$ 90K	$ 370K	$ 90K
Totals	$4,116K	$3,556K	$ 5,036K	$ 4,486K
Lease Costs	$1,099K			
Cost. Hour	$1,370			

If a totally new system design (i.e., a new system integrator) were selected as in option 2 , the estimated cost based on this study is $6.9 million for the first unit, ready for operations. This carries a somewhat higher risk (moderate) of implementation on an 18-month schedule. The reason the risk is not higher is because aircraft mechanical installation design can still proceed concurrently with the procurement of equipment. The increased risk is primarily due to the new processing software.

7.6 Option 6 – Beech 1900-Type Aircraft with tailored Systems

Options 1-4 are tailored systems in that they select particular sensor characteristics or types as opposed to maximizing derived requirement satisfaction. If MSRC chooses Option 2, 3, or 4 initially, larger aircraft may be necessary to have room for potential changes later. A Beech-1900 type aircraft would provide the room for these additions and avoid deinstallation or reinstallation on a new aircraft. The aircraft may be derived from Option 5 and the equipment costs from Option 2, 3, or 4. Because installation on a Beech 1900 is essentially the same as on a Beech 300, Option 6 has the same schedule, risk, and availability as Options 2, 3, and 4.

7.7 Option 7– Research Test Bed

The research test bed (RTB) has many possible configurations. ERIM derived an initial architecture based on a corporate-owned CV580 aircraft and corporate-owned radar assets. The test bed could operate on either a dedicated or nondedicated basis for MSRC, using ERIM crews. The cost to MSRC is lowest on a nondedicated basis, because the maintenance, training, and crew standby cost are carried in ERIM overhead costs. ERIM's large amount of developmental flight test activities require an ongoing flight facility. The proposed test equipment is largely owned by ERIM.

Additional detailed cost data have been provided in briefing packages to MSRC. The costs presented in Table 7.8 represent the MSRC portion of a shared cost with ERIM and, potentially, with other customers to provide the following capability:

Gimballed FLIR/TV	For day and nighttime oil spotting, and monitoring spiller and cleanup operations (Option 1).
Synthetic Aperture Radar	3 m x 3 m all-weather resolution for wide-area (10-nmi wide swath) surveillance.
CV580 Aircraft	Six-hour mission, deployable to any region.
UHF/VHF Radio	Relay of FLIR/TV/radar image frames to MSRC surface vessels.

The operations availability of the FLIR/TV is eight months after start. The radar is being integrated by another project and pending its completion by November 1992, a second integrated radar system could be available for operations by March 1993. All equipment either exists at ERIM or is commercially available. A CV-580 aircraft is available for either dedicated or shared operations. The schedule risk is low for the FLIR/TV and low to moderate for the radar.

Table 7.8 Option 7 Cost Estimates

Cost	Item
$400K	Purchase of gimballed FLIR/TV, monitors, GPS receiver, UHF/VHF radio and modem, ruggedized 80486 computer with frame grabber (Option 1)
$60K	Software for interface to MSRC
$250K	UPD8 synthetic aperture radar with processor/display/interface
$350K	Aircraft modifications
$300K	Installation and test
$1,360K	Initial capability
$1.6K/h	Nondedicated flight hour cost (does not include equipment operator cost or per diem and remote basing costs)

Additionally, one set of the chosen operational equipment could be included in the RTB configuration or additional test sensors could be added.

8.0 Conclusions and Recommendations

There are several conclusions derived by this study. The major ones are presented in Section 8.1; the minor ones are listed in Section 8.2. Recommendations are also provided in this section.

8.1 Primary Conclusions

- There are no off-the-shelf (non-developmental) sensors or combinations of sensors that adequately meet the derived MSRC surveillance requirements.
- Given approximately one year to field the capability, only Option 1 (i.e., FLIR/TV camera) appears practical as an initial surveillance capability for MSRC.
- The requirements used in this study were derived from an information needs analysis based on past spills and discussions with MSRC operations managers. These initial derived requirements will change with MSRC experience in surveillance support.
- It is very likely that MSRC will need a multisensor regional capability such as Option 5 and improvements not currently available commercially.

The introduction of sensors and surveillance systems into MSRC use should follow an evolutionary path. There is little practical U.S. experience with advanced oil surveillance. The USCG Aireye System, for example, suffers from some bad press, which may cause both proper and undue criticism of oil surveillance. The Europeans report success with existing equipment, but not under the type of diverse conditions MSRC will face. There are vendors who offer a range of "solutions." However, it is prudent for MSRC to be cautious in what it selects.

Similarly, based on the significant advantage of extended operations into night and foggy/cloudy weather, MSRC must be willing to explore what each sensor offers. The fact is, there has been very little investment in the application of remote sensing to oil and the development of commercially applicable systems. As found by this study, very little exists "to buy," either in sensors, processors, or integrated systems. Although DoD technology and systems help in a few cases, they tend to either be classified, too expensive, or overdesigned for the need.

The wrong reaction, it would appear, is either (1) do nothing or (2) invest in a "solution." There is no "solution" when one carefully examines the scope of derived requirements and the realities of assets that can be brought to bear. The concept that seems appropriate is an expansion of the "buy a little, try a little" idea.

8.2 Secondary Conclusions

- TV and FLIR cameras will aid in day/clear night confirmation of surface vessel activity and should be used by MSRC. They may also be used for area spotting of oil.

- Dual-frequency radiometers should eventually be used by MSRC for day/night and limited-weather location of thicker oil.

- UV/IR scanners will show both thin and thick oil and should be used to complement the radiometer for day/night operations.

- Except on clear days, locating the oil with the above sensors can be very ineffective unless aided by a SLAR with wide-area surveillance.

- A SLAR can be very ineffective (false alarms) unless used by a trained operator who controls the sensor and display.

- All of the sensors (i.e., radiometer, UV/IR scanner, SLAR) have individual limitations; as a group, they are much more effective.

- Advanced sensor technologies (e.g., laser acoustics, IR polarimetry, laser fluorosensing, SAR) require additional R&D before conclusions can be drawn.

- The numbers of aircraft and surveillance systems needed are highly dependent on the number of simultaneous operations, mission duration, size of spill, coverage per day, and response time required. These parameters will be better defined after MSRC begins operations.

- Five systems in a regionally deployed twin-engine aircraft (e.g., Beech 1900-type) can support two simultaneous operations or one large operation 18 hours/day with a five-hour response time.

- A smaller aircraft (e.g., Beech-300 type) can carry only two of the sensors studied.

- Larger aircraft shared between regions are not cost-effective for a high frequency of operations required by 50,000-gallon spills. However, they can be cost-effective for a lower frequency of operations.

- It is not possible to adequately define MSRC requirements for surveillance until after proof of value and experience in operations.

- The largest cost/schedule risk is new integration. The best way to ensure early capability with minimum investment is to avoid new integration.

- MSRC is best served by initially limiting surveillance system acquisition to what has already been integrated and flown.
- The value of georegistration and multisensor overlay (to reduce ambiguity) is unproven, but potentially high for UV/IR/radiometer.
- The need for image georeferencing is implicit, accuracy required is uncertain.
- Color and contour highlighting can be helpful, but can also be misleading.
- Little has been done to integrate surveillance systems and spill operation management. Eventually, this will be a high payoff area.
- Copies of existing integrated surveillance systems are estimated to cost between $2.2 and $3.1 million. It takes at least 10-12 months for equipment delivery. An additional 2-6 months and $1.4 million for aircraft modification, equipment installation, and testing is estimated.
- For initial MSRC operations, processor interfaces to both GPS and the MSRC SOS/vessels should be implemented. These have additional cost impact, and are costed in all the system options presented.
- In the longer term, processor capability to add georegistration, georeferencing, GIS interface, and integration with spill operations system should be incrementally added. The processor development cost for this capability is estimated at $1.85 million. Units added after the first unit are estimated to cost $0.35 million. There would be some additional cost to retrofit this into an existing system.
- Vendors who may advertise part of a surveillance capability (at a part of its cost) have not been forthcoming with either cost or technical data for this trade study.
- There is a need for an operational test bed aircraft to support operations and test new capabilities for MSRC.

8.3 Recommendations

Given that:

- MSRC is looking toward a surveillance capability after 1993;
- MSRC wants to limit risk in achieving initial capability;
- MSRC wants to gain "hands-on" experience using surveillance in direct support of spill operations decision making;

- MSRC is not sure of its spill frequency, duration, and response time to absolutely define how many surveillance systems to buy; and
- MSRC wants to use surveillance capability fully,

It is recommended that:

- MSRC lease or purchase a limited number of existing integrated systems and use them to gain experience,
- MSRC lease or share in the investment of a test bed that it can use to "shake out" promising new equipment/upgrades and new concepts.

9.0 References

Barber, M.C., S.M. Merther, G.F. Ireland and L. Breslau. 1992. An Analysis of Historical Oil Spills and Current Cleanup Requirements to Aid in Selecting New Technology for Spill Cleanup Operations. Marine Spill Response Corporation, Washington D.C. MSRC Technical Report Series 92-001, 57 p.

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