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SATELLITES AND SOVEREIGNTY

Report of the Interdepartmental Task Force on Surveillance Satellites

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FOREWORD

New technology is generally oversold by its enthusiasts and underestimated or discounted by its critics. That was, and still is true, of LANDSAT, the picture-transmitting satellite, the first version of which (ERTS) was launched in July 1972. It was surprising how close the resolution of the LANDSAT pictures (80 metres) actually was to the predictions made by the scientists directly concerned. (The ability of the sensor in the satellite to discern small objects on the ground is called its "resolution" or "resolving power").

As a surveillance satellite, however, LANDSAT neither has the necessary resolution to detect many man-made objects nor can it penetrate cloud and fog whose occurrence off the East Coast and in the Arctic averages about five days out of seven. LANDSAT, because of these known limitations, never was intended as a surveillance satellite. In July 1972, at the time of ERTS launch, satellites which could penetrate cloud and fog were not considered because of the complexity and greater power requirements of radar sensors.

With the advances in the use of "synthetic aperture radar", which requires only a fraction of the power needed by conventional radars and whose resolution is independent of range, it is theoretically possible from orbital altitudes to discern objects on the earth's surface whose maximum dimensions are a few metres. Such a satellite would not be recommended at present because of the enormous cost of handling so much data. There must be a trade-off between resolution and cost of data handling.

And so, the real possibility now exists of having radar surveillance satellites with ground resolutions of about 20 metres produce radar pictures showing the location of ships, the distribution of sea-ice, the sea state and the temperature of the ocean surface - all through cloud, fog and darkness. The studies indicate that potential benefits to Canada could exceed $200 million per year. The risk is large, but it will be greatly reduced after the experience of NASA's SEASAT "A", particularly if Canada decides to participate in that experiment. The problems reduce to the simpler ones - do we need satellites and are they worth it? The opinion of the Task Force is "yes" to both these questions.

In leading the Interdepartmental Task Force, Dr. Philip A. Lapp, in spite of the fact that he is a remote sensing and satellite enthusiast, has, in my opinion, done an honest and exhaustive job in trying to ensure that false claims were not made for the proposed systems. The members of the Task Force, all of whom were well-qualified representatives of their departments, were equally scrupulous in this regard. Their intense interest and degree of participation were a joy to behold.

I was particularly pleased to observe a complete absence of inter-departmental bickering and departmental 'position-taking' by them, in an effort to win as much for their respective departments as possible. Perhaps this was helped by the fact that this requirement was written into the terms of reference. The matter of departmental jurisdiction, however. still has to be decided by higher authority.

It is with great pleasure and satisfaction that I endorse and recommend this report for submission to Cabinet in response to its instructions.

L.W. Morley,
Director-General,
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August, 1977

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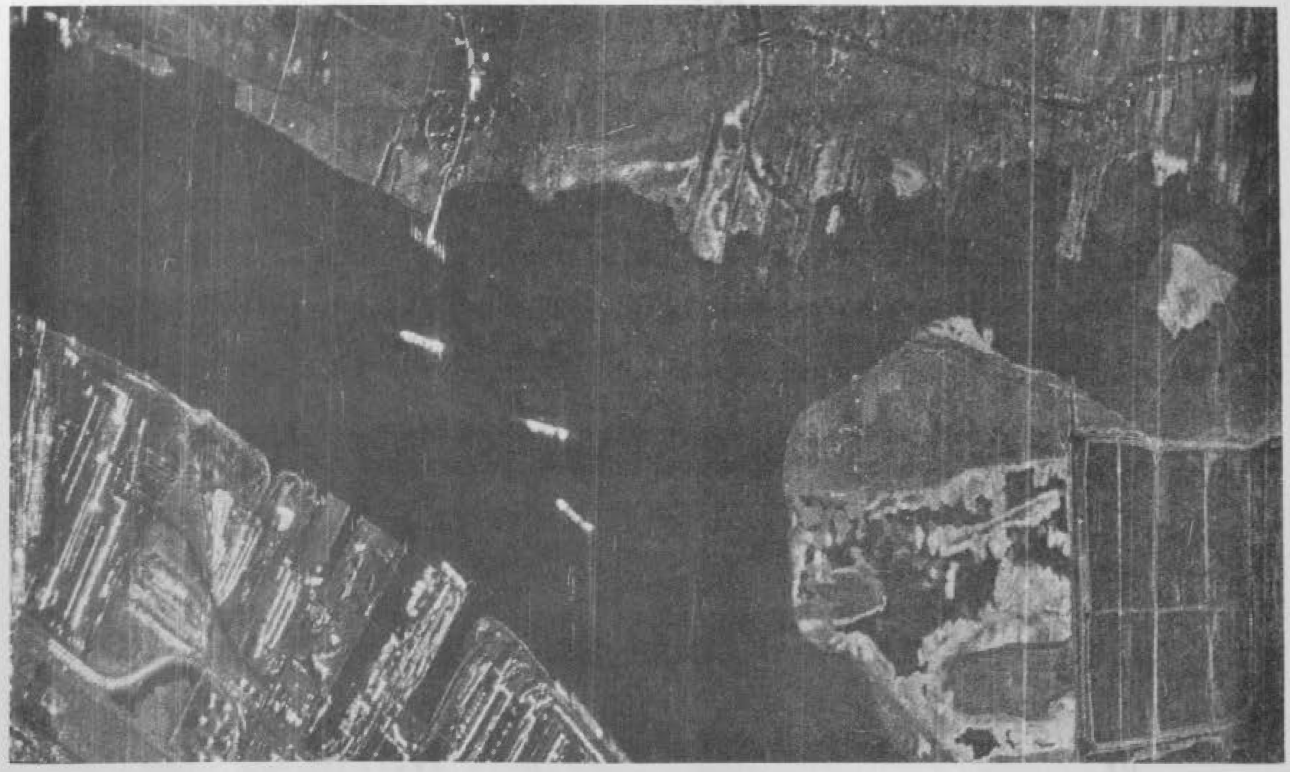
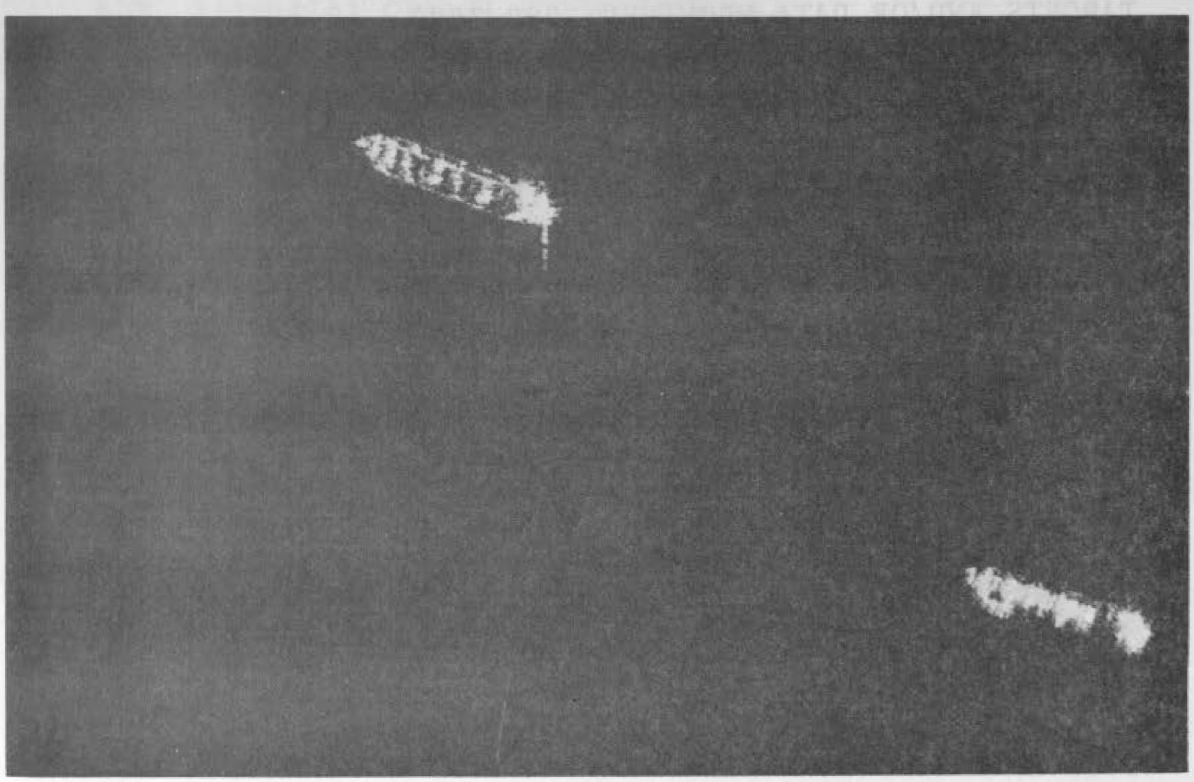


ABOVE: AIRBORNE SYNTHETIC APERTURE RADAR IMAGE OF SHIPS IN THE DETROIT RIVER, PROCESSED TO 3 METRE RESOLUTION

BELOW: PHOTOGRAPHIC ENLARGEMENT OF PART OF FIRST IMAGE. NOTE STRUCTURAL DETAILS OF SHIPS

(Images Courtesy of the Environmental Research Institute of Michigan)



1. INTRODUCTION

Following an interdepartmental study that examined capabilities and various levels of response to non-military challenges to Canadian sovereignty, the Government directed.

that the Canada Centre for Remote Sensing, in consultation with interested departments, conduct a feasibility study of a Canadian surveillance satellite to be operational in the early 1980's to assist in meeting forecast surveillance needs in the 1980-2000 time frame.

Accordingly, it was agreed to create an interdepartmental surveillance satellite task force at a meeting of representatives* from appropriate government departments, held in Ottawa on April 23, 1976 and chaired by the Department of Energy, Mines and Resources. The following terms of reference for the task force were established at the meeting:

1. Identify Canadian total satellite surveillance needs as perceived by departments and agencies.

2. Identify present and projected surveillance satellite capabilities.

3. Identify potential applications with particular reference to:

   a) Management of the Canadian Coastal Economic Zone,

   b) Management of the Arctic Coastal Area and Archipelago,

   c) Other surveillance needs as perceived by departments.

4. Identify the technical evaluation program that will provide information upon which a decision in respect of Canadian surveillance satellite needs can be taken, including the options of a Canadian surveillance satellite and of a cooperative program with one or more countries.

* See Annex to Appendix 1

5. Highlight the need for ground data handling, analysis and dissemination.

6. Prepare a report which is to be the basis for drafting a cabinet document in response to the cabinet decision that CCRS carry out a surveillance satellite feasibility study in cooperation with other departments.

7. Air space surveillance is to be excluded since the means of archiving this are being addressed separately.

Prior to the formation of the task force, CCRS and several departments already had conducted studies related to surveillance satellites. They included a concept definition study for a remote sensing satellite mission (Ref. 1) completed for CCRS in February, 1976, in partial response to the cabinet decision, an evaluation of a Canadian involvement in the NASA Seasat program including the preparation of a draft memorandum to cabinet considered by both the Interagency Committee on Remote Sensing and the Interdepartmental Committee on Space, and a technology assessment of microwave remote sensing satellite systems using Seasat as a prototype (Ref. 2). In addition, Canadian industry is conducting studies on a data collection and fisheries surveillance satellite, and a search and rescue satellite, both the result of unsolicited proposals through funding mechanisms of DSS, with DOE and DND as the "sponsoring departments" respectively. Thus the task force could draw upon a wealth of materials already available from earlier work.

The task force was formed in late April, 1976; the names of members and their affiliations appear in Appendix 1. During the period May-August, 1976, twelve meetings were held which included three sessions where specialists from interested departments appeared before the task force to make presentations, respond to questions and join in discussions related to their particular interests and areas of expertise. A two-day field trip to Halifax also was included where DND, DOT and DOE establishments were visited, during which the task force had an opportunity to hear from operations personnel, see their facilities and question them on surveillance requirements. In this way, the task force was able to gain an insight and understanding of the factors involved in surveillance operations which could not be achieved solely by interviewing persons at headquarters in Ottawa.

In order to meet the requirements laid down in the terms of reference, the task force divided into five groups dealing with:

1. Capabilities,
2. Requirements,
3. Cost effectiveness studies,
4. Research and development, and
5. International implications.

The capabilities group dealt with all matters related to surveillance satellite technology including the ability of existing and future sensors to meet user requirements, the related support systems in the satellite and on the ground, as well as problems expected in data handling, analysis and dissemination. The requirements group, consisting of representatives from each user department, was charged with the responsibility of collecting, assembling and organizing the surveillance needs of user departments and agencies in ways that could be interpreted by the capabilities group in terms of sensor performance, and in a fashion that is meaningful to non-technical managers. Both the capabilities and the requirements groups participated in the selection of those applications which appear to be best suited for surveillance satellites.

Operating in parallel with the work of the task force was a small group from CCRS conducting surveillance cost effectiveness studies, and drawing comparisons between various sensor platforms which included satellites, aircraft, ships and automatic stations located at fixed points. While the group is preparing a separate report (Ref. 3), the results of their work have been made available to the task force and are included herein.

For any activity involving advanced surveillance techniques, there are research and development implications. One group was assigned the task of determining the minimum necessary R and D program needed to support varying levels of Canadian surveillance satellite efforts, working in close cooperation with the capabilities group. The fifth group examined the international implications of a Canadian surveillance satellite, and provided advice on the factors involved in mounting a joint surveillance satellite program with other nations.

Arising from a concern about the science and technology implications of the impending increase in ocean management responsibilities associated with the establishment of a

200-mile exclusive economic zone, a Panel on Ocean Management was created at about the same time as the task force. Composed of representatives at the assistant deputy minister level from twelve concerned departments and chaired by MOSST, the panel conducted an overview study which:

i) identified and described the ocean management functions which Canada will have to carry out over the next decade, particularly as a result of the establishment of a 200-mile zone, and

ii) provided an overview description of the systems needed to carry out these functions, in light of changing priorities and new technologies projected over the next decade.

The study (Ref. 4) was completed in early July. The panel is "to keep informed about other ocean-related programs and proposals originating with departments or other study groups, and be prepared to give advice on them in light of the developing overview on oceans management". It is expected that the panel will be asked to provide an opinion and advice on this report, which draws upon some aspects of the overview report.

The task force terms of reference form the basis for the structure of this report. Following a definition and discussion of surveillance including the role and place of satellites among alternative sensor platforms, departmental surveillance requirements are described and listed by department and management function, and by target type for use in matching with the technical performance of satellite sensors. Capabilities of satellite systems are covered next, which leads to a selection of those applications best suited for satellites including both technical and cost considerations.

In the following section, international implications are considered and alternatives for cooperative programs with other nations are examined.

Next, the basic options open to Canada are described and examined in detail in terms of research and development implications, cost and schedule impact, industrial involvement and benefits, and international participation. The results of the cost effectiveness studies than provide a framework for drawing conclusions.

2. SURVEILLANCE

2.1 Definition

From the beginning, the task force was faced with the need for a consistent definition of the term surveillance, Within the narrowest concept of sovereignty control, surveillance can be defined as the detection and observation of human intervention in whatever form it might take within the region of concern. Such a definition excludes environmental phenomena, and begs the question as to whether or not the effects of human intervention resulting from such actions as vessel source pollution and ocean dumping should be included. It was decided that environmental phenomena also should be included not only because certain forms of human activity can be detected by their impact on the environment as in the case of pollution, but also because environmental surveillance is an essential element which, as an expression of sovereignty, supports a total ocean management and services activity that must attain international visibility. Moreover, the same technology applies to either form of surveillance. The task force adopted a definition of surveillance that embraces both human activities and environmental phenomena.

2.2 Stages of Surveillance

Surveillance in its broadest sense is "the act of maintaining a watch", according to the dictionary meaning. It has been interpreted as a multi-stage process involving detection, location, classification, identification and inspection of human activity and environmental phenomena - for example, vessels at sea or ice formations. Each subsequent stage in the process demands increasing performance from the surveillance system. The first step is to detect the presence of a target against its background; but this in itself is of little use without, as a minimum, establishing its location. The third stage requires more information such as shape, speed, direction, etc. so as to distinguish, for example, a ship from an iceberg or drifting debris. Identification such as the name of the ship, the type of ice or the nature of the debris requires even greater resolution and performance. Finally, inspection such as the amount and species of fish in a net requires extremely close surveillance, possibly involving the need to board the vessel.

2.3 Platforms

The five stages of surveillance defined above can be linked to the sensor platforms available for surveillance - satellites, aircraft, ships and automatic stations. Surveillance satellites with typical altitudes in the order of 800 km will cover wide swaths but be limited in their ability to discern detail; conversely, aircraft operating in the 0-20 km altitude range will provide less coverage, but more detail. Ships can operate under most weather conditions, conduct inspections and make in situ measurements, but their coverage is extremely limited. Automatic stations such as buoys and shore-based radar can operate in all weather and provide essential time-series data at fixed locations, but even shore-based radar has limited coverage and its ability to detect falls off rapidly with range. Thus no one platform is ideal for surveillance; each has limitations and there are overlaps in performance. The best system will be a cost effective mix of platforms meeting minimum requirements.

2.4 Need for Radar

While the main Canadian landmass was not excluded, the focus of the study was directed to the coastal 200-mile zone including the ice-covered waters of the arctic and the archipelago, a total area of approximately 2.0 million square nautical miles (Ref. 3). At any time in this vast region, there will be large sections covered with cloud or fog, preventing visibility from aloft. Also, roughly half of the total area is covered in darkness for substantial periods of the year. Thus for sovereignty control, the surveillance system cannot rely on visual contact exclusively. The only known technique for penetrating both darkness and cloud cover from above is through radio wave propagation, which includes radar and radio receiving-type sensors. Such sensors have been proven on surface and airborne platforms, but there is no known experience with surveillance radar in space. Radio receiving-type sensors are capable of discerning temperature differences on the surface and in the atmosphere, including certain atmospheric constituents such as water vapour, but they lack the high resolution capability and sensitivity of radar to detect small targets and physical features that do not differ in temperature from their background. The task force concluded that radar should be an essential component of any surveillance system used for sovereignty control by Canada.

2.5 Role and Place of Satellites

The most distinguishing feature of a satellite compared with other sensor platforms is the extent and frequency of coverage. A single satellite as described in Section 4 is capable of observing with radar every square mile of Canada, including the 200-mile zone and arctic regions, twice in five days in southern latitudes and more frequently in the arctic. For completeness of coverage, the satellite is preeminent in its ability to cover large areas frequently.

There are six positive features of surveillance satellites that aid in establishing the role and place of such platforms among the alternatives:

1. Completeness - in continuity of coverage at synoptic scales.

2. Accuracy - in location of detected targets in the vicinity of ground control points.

3. Reliability - operates in all weather, day or night with anticipated low failure rates based on current satellite technology and practice.

4. Timeliness - data can be received and processed in close to real time.

5. Repeatability- fixed radar beam geometry relative to the earth's surface, and satellite passes that repeat over any point at constant sun angle, ensure repeatability not only for radar sensors, but also for optical sensors.

6. Cost - using systems dedicated solely to simple detection and location of relatively large targets and to monitoring environmental factors, the total cost of satellites over 15 years would be only one-tenth that of aircraft for the same frequency of wide-area coverage. (Ref. 3). Also, costs could be shared with other nations.

Two other positive features of a satellite worth noting are the absence of continuing hydrocarbon fuel burnup (as opposed to aircraft and ships), and the fact that the spacecraft can be designed and built by Canadian industry, in contrast with certain of the aircraft alternatives.

The negative features can be listed as follows:

1. Resolution - an altitude of 800 km. places stringent limits on the ability of any sensor compared with typical aircraft altitudes, with the exception of synthetic aperture radars where resolution is independent of range.

2. Signal Processing - covering a large area, even with moderate resolution places severe demands on recording and processing technologies. Typical data rates for a satellite radar are in the order of 240 million bits per second.

3. Data Handling, Analysis and Dissemination - the high data rates for satellites will place strains on man's ability to analyse and interpret the data, and place large demands on broadband communications facilities for dissemination.

4. Satellite Launch - Canada must rely on another nation to launch its satellites.

Another negative feature of surveillance satellites at the present time is the lack of experience with satellite radar which thus far makes it impossible to confirm any performance figures. Nevertheless, calculations show that it should be possible to detect on calm seas a target whose dimensions exceed 20 metres[1], for example, a steel ship 20 metres long. With such a sensor, a radar satellite should be able to perform the first three stages of surveillance as defined earlier - detection and location of targets that exceed 20 metres in dimension, and classification for targets larger than 200 metres. It would be unreasonable to expect satellite sensors alone to perform the identification function for all but the largest of targets, such as a drilling platform or an ice island.

As in all detection systems, the satellite will miss some targets completely. Moreover, the satellites will create some false alarms - indications of targets that do not exist, caused by noise and spurious radar returns. There is no experience yet as to how to evaluate these factors until Seasat-A is launched in 1978.

It is evident then that the satellite lies at the strategic end of the surveillance spectrum. It is capable of providing wide-area coverage at relatively low resolution. Thus, it can be used to alert other platforms such as aircraft or ships, where necessary, to perform the more tactical role using their higher resolution sensors for identification and inspection.

In addition to the satellite's role as a strategic surveillance tool, it can perform a number of environmental monitoring missions that form part of the oceans management support and service activities. They include the support of such missions as weather, ice and sea state observation and forecasting, search and rescue, and thermal mapping.

One final issue in considering the role and place of satellites in surveillance is that other nations are developing a

(1) In theory, the dimensions can be as small as a metre or so. Practical considerations, discussed in section 4.3.1 (page 33) and, in more detail in Appendix 4, lead to a choice of 20 metres as a nominal design baseline.

satellite surveillance capability. Because of the extent of the country and the physics of orbits, it would be impossible for another nation's surveillance satellites to avoid passing over Canada, if they are in polar or near-polar orbits. Without a comparable capability and an understanding of how such spacecraft perform, we may never learn what other nations know about us - which must be viewed as a serious non-military threat to Canadian sovereignty.

2.6 Summary

In summary, the task force adopted a definition of surveillance that embraces both human activities and environmental phenomena. It recognized five stages in the surveillance mission - detection, location, classification, identification and inspection. In evaluating alternative platforms, satellites were seen to be complementary to aircraft and ships, providing strategic information that could be used to direct the other platforms to specific locations. It was concluded that radar was an essential component of any surveillance system used for sovereignty control by Canada.

Satellites provide completeness of coverage, accuracy, reliability, timeliness and repeatability. For the same frequency of wide-area coverage, using systems dedicated solely to this purpose, the amortized costs of a satellite are an order-or-magnitude less than those of aircraft. On the other hand, because of their distance from the earth's surface, satellite sensors are limited to the detection, location and classification end of the surveillance mission. Satellite sensors produce extremely high data rates which create challenges in signal processing, data handling, analysis and dissemination. There is yet no known experience with satellite radars to permit a thorough performance evaluation.

In comparison with ships and aircraft, they are energy conserving in that they do not burn hydro-carbon fuel continuously; and they can be built by Canadian industry. However, Canada must rely on other nations to launch her satellites.

For complete coverage of Canadian sovereign territory, the arctic and the 200-mile zone, satellites are an attractive option. Moreover, in order to protect Canadian sovereignty over all of these regions, particularly the northern and seaward reaches, Canada may feel obliged to establish a surveillance satellite program, if other nations do likewise.

We turn now to an examination of surveillance requirements as expressed to the task force by the user departments of the federal government.

3. CANADIAN SURVEILLANCE REQUIREMENTS

3.1 The Requirements Group

In the context of sovereignty control, there are seven functions performed by government which require surveillance. They align also with those listed in the Panel on Ocean Management Overview Report (Ref. 4). They are:

1. Renewable resource management - principally fisheries.
2. Non-renewable resource management - oil, gas and minerals.
3. Protection of the marine environment - oil-spills, vessel source and ocean pollution.
4. Development and control of navigation - vessel traffic management, ice routing, navigation, port and other facilities.
5. Defence
6. International Ocean Management - extension of domestic ocean management functions.
7. Ocean service activities - weather, ice, sea state forecasting, icebreaking, search and rescue, etc.

In some cases, the function is performed by more than one department, depending on geographical or other subdivision of responsibilities. Activities performed in support of the functions often are distributed, in order to maximize the utilization of departmental resources through multiple tasking.

A requirements group was formed representing departments with responsibilities embracing all of the above functions.

The group was given the responsibility of determining forecast surveillance needs of the concerned departments and agencies in the 1980-2000 time frame.
Their names are listed in Appendix 1.

3.2 Method of Approach

The point of departure was to compile a census of departmental surveillance requirements. Since there were some which clearly could not be met by satellite surveillance (e.g. on-board inspection of fishing vessels), the census focussed only on those for which remote sensing, not necessarily from a satellite was considered feasible. This approach served two purposes: first, it was a useful preliminary filter; second, it provided useful data on possible trade-offs for the cost effectiveness study.

The census gathered information on:

1. Targets or phenomena to be observed,
2. Data required,
3. Purpose for which data is needed,
4. Range of data (maximum and minimum values),
5. Precision and accuracy required,

6. Characteristics of targets or phenomena (type of material, size, shape, distribution, etc.),

7. Geographical areas to be covered,

8. Frequency of observation,

9. Data handling requirements (allowable time lag between collection and delivery to user, formats required, security and other requirements).

These data were supplemented by comments supplied by respondents. While the census was being compiled, several technical briefings on sensor capabilities were arranged for members of the requirements group and other persons from their departments. Also, a number of colloquia were held at which the members of the Task Force were briefed by technical experts from the user departments. Three such sessions were held in Ottawa:

1. <u>May 27, 1976</u> (½ day)

   Ocean traffic
   Fisheries surveillance
   Marine search and rescue
   Offshore non-renewable resources management

2. <u>June 4, 1976</u> (all day)

   Ice reconnaissance
   Weather and sea state data
   Physical oceanography
   Biological oceanography
   Pollution (both vessel source and ocean)

3. <u>June 11, 1976</u> (½ day)

Land, coastal zone and on-ice activities including:

- Enforcement of land-use regulations
- Resource management
- Aircraft and other non-marine search and rescue
- Enforcement of law and order
- Other defence requirements

In addition to the colloquia, the Task Force made a field trip to Halifax, N.S. area on June 17th and 18th. It consisted of visits to DND and DOT installations, and the regional office of the Atmospheric Environment Service of DOE. Detailed briefings and discussions were held at each place visited.

For purposes of matching requirements to probable satellite capabilities, the departmental missions are irrelevant. What is important is a description of the characteristics of each target or phenomenon to be observed and the frequency of observation. However, departmental managers need to know how effectively a particular surveillance requirement might be met in the context of the mission, so that trade-off decisions between various surveillance methods can be made.

In an attempt to satisfy both needs, the requirements are presented in two ways. First, Appendix 2 lists them by departments, functions and specific missions. They are presented in a generalized way, without quantitative detail as to the characteristics of targets or specific phenomena, frequency of observation, resolution, etc. Secondly, the data were grouped according to target types and characteristics, and tabulated in a standardized two-page format, which lists quantitative details on data required, target characteristics, accuracies, areas, frequencies of observation, data handling and other aspects. The census sheets are presented as Appendix 3.

3.3 Surveillance Targets

Fourteen distinct surveillance requirements by targets and/or data required have been identified. The following paragraphs are an attempt to bring forth some of their subtleties, which a simple listing of the quantitative aspects fails to do.

3.3.1 Ocean Traffic

In general, the data required are the location, course, speed, classification, identification, status and activity of all ships and other vessels in waters under differing Canadian jurisdictions or areas of responsibility. The specific data, vessels of interest or geographical areas depend on individual departmental responsibilities. The application areas are vessel traffic management (DOT), fisheries surveillance (DOE with DOT and DND support), management of offshore non-renewable resources (DINA, EMR), search and rescue (DND, DOT) and military surveillance (DND). The targets include fishing vessels, cargo ships, tankers, naval vessels, drilling ships and platforms, survey vessels of various types, civilian patrol vessels, ice breakers, barges, tugs, lifeboats and life rafts. Many of these vessels will be "co-operative", that is, it is in their interest to have their position, course, speed and identification known. To this end, they will be willing to carry a "black box" which will transmit some or all of this information to a satellite in such a way that they can be identified unambiguously on an image. If such a device were coupled to the output of an electronic navigation system, precise positioning data could be passed to the satellite. The location of other targets on the image could then be derived by direct measurement on the image.

There are aspects of nearly all of these requirements which obviously cannot be met by satellite. For example, fisheries surveillance and management of non-renewable resources both require occasional on-board inspections; some targets, such as ships in distress, require continuous or near-continuous monitoring once detected and identified.

Currently, such surveillance requirements are being met using ships, aircraft, shore-based radar and voluntary radio reporting.

Developments planned or being implemented to meet future requirements include DOT's:Vessel Traffic Management System, which involves voluntary and mandatory reporting by radio as well as radar surveillance of high traffic density inshore areas; the acquisition by DND of a fleet of long range patrol aircraft (LRPA); studies on the use of emergency locator transmitters (ELT) with a polar-orbiting satellite carrying a VHF repeater for search and rescue (SARSAT); and an investigation on the use of transponders and a communications satellite for some aspects of fisheries surveillance.

3.3.2 Navigation Aids and Hazards

These are grouped together because of similarity of target sizes, characteristics and application.

Two classes of navigation aids are of interest - inshore buoys and markers in high traffic density areas (such as the St. Lawrence Seaway) and offshore buoys.

For the first group, the targets are very numerous and close together; their positions need to be known with very high accuracy and precision and they require nearly constant monitoring for positioning and functioning of lights and acoustic signals, since there are many legal implications. Satellite surveillance, it would appear, is not likely to satisfy these needs. Fortunately, in many cases, positioning can be monitored by existing or planned shore-based radar installations. Studies are under way to assess the feasibility of automated monitoring of the functioning of lights and sound signals.

Monitoring the positions of offshore buoys, however, poses less stringent constraints. There are at present over one hundred of them, from 7 to 20 nautical miles offshore. Their positions need not be determined so precisely or checked as frequently. Approximately 15 of these go adrift each year, and since they cost $10,000 to $15,000 each, significant savings may be realized if, when one does break loose from its mooring, the situation is detected rapidly.

The navigation hazards of interest are floating objects of various sorts, such as icebergs, bergy bits and growlers, loose navigation or mooring buoys, oil tanks and drums, containers washed off the decks of ships and other flotsam. Even though many ships employ radar which is capable of detecting many of these hazards, the high speeds (25 kt) and large mass (often over 200,000 tons) of modern tankers and container ships result in relatively low manoeuvrability, making advance knowledge of the existence and location of navigation hazards very desirable.

3.3.3 Ice Reconnaissance

As might be expected, all users of Canadian eastern and northern waters wish accurate, up-to-date ice information and forecasts. Of particular interest to users is the ability of a satellite-borne radar system to provide frequent, repetitive, high-resolution, all weather coverage of all ice-infested Canadian waters, thus overcoming one of the limitations of airborne and shipborne surveillance. Reservations were expressed by departments about the capability to determine the age, type and thickness of ice and its snow cover and to resolve narrow leads, small polynias and other structures of interest, using satellite-borne sensors. One interesting point brought out by AES personnel is that, at present, only limited observations are made in the Arctic during the freeze-up and early break-up periods, and that such information would be useful for long-term predictions of ice conditions.

Another type of ice surveillance is monitoring of rivers during break-up for purposes of flood control. In densely settled areas, this requires very frequent, high-resolution surveillance, currently done by low-level aerial photography and on-site inspection. With the prospects of increased industrial development in remote areas, early prediction of possible flooding during spring break-up will be needed and might be done in a cost-effective manner by satellite sensors.

3.3.4 Pollution

Most of the interest was in water-borne pollutants, their sources and clean-up problems. The main types of pollutant are oil (of which 60% to 70% comes from small spills), ocean dumping, chemical spills and near-shore suspended solids. Oil spills appeared to be the problem of most concern. Major spills are infrequent (though serious when they occur) and are usually reported. When a major or moderate oil spill occurs at sea or in a remote region (especially the Arctic), it is essential to map it frequently, so as to make and implement decisions regarding containment and clean-up operations.

Minor oil spills (such as those resulting from the illegal pumping of bilges) are a persistent problem. The difficulty with them is not so much surveillance as the positive identification of the source in such a way as to obtain adequate evidence to lay a charge and obtain a conviction. This usually involves acquiring samples of the pollutant and other data which could not be obtained from a satellite.

Two potential applications are the detection and monitoring of shore-derived marine pollution and the incremental build-up of multiple-source pollution through the use of sequential imagery over periods of time, an application for which satellites are well suited.

3.3.5 Siltation

The problem of monitoring the build-up of silt in ports and waterways is analogous to that of monitoring pollution. In established high-density ports and waterways, both horizontal and vertical growth and growth rates are needed to high precision - an application for which a satellite may not be useful. However, for preliminary investigation of possible port sites and waterway routes, sequential images obtained over time would be most useful if the siltation can be detected on the images. Another relevant application would be observing the plumes of water-borne solid particles associated with dredging operations, in order to ensure that the resulting silt build-up is not in an undesirable place.

3.3.6 Selected Human Activities

Certain human activities, often in remote areas, are of interest. The targets have similar characteristics and, in Canada, are found in the same general area, so they are grouped together for convenience.

The applications are:

- Monitoring seismic survey parties, on land or ice
- Detecting and monitoring drift stations on ice islands
- Detecting and monitoring lodgments and encampments for military purposes

In each case, the targets of interest comprise groups of men with vehicles and equipment, usually in a remote, uninhabited area. Some targets show a distinctive pattern, for example, seismic survey parties are strung out in columnar form, and on land, work in long cuts made through trees or brush. New trails or roads, aircraft runways or aircraft on the ground or ice are also distinctive markings.

In the case of seismic survey crews and other resource exploration parties, the requirements of DINA for resource management north of 60°N are such that their geographic position must be known with high precision. Identification of survey parties should not be difficult as it is expected that they would co-operate by carrying electronic identification devices.

3.3.7 Cartography

Cartography is another application for which the precision, accuracy and type of data required are such that satellite observations, with present and forecast sensor technology, will probably be of limited usefulness. However, high resolution (30 m or better) radar and optical imagery should be most useful for updating maps and charts, for detection and correction of errors and for rapid preparation of large-scale working maps to satisfy immediate operational needs. It should be noted that at a scale of 1:25,000 a distance of 30 m on the ground corresponds to only 1.2 mm on the map; such accuracy should be adequate for many purposes.

3.3.8 Weather and Sea State Data

One of the more important requirements, mentioned by all responding departments, is the need for better weather and sea state forecasts. The difficulty in specifying this requirement in terms of satellite data is that such data will not satisfy user demands directly, requiring, as it does, assimilation into complex weather prediction systems. Weather reports and forecasts are provided by the Atmospheric Environment Service (AES) of DOE. In addition to central and regional offices, AES has specialized offices such as those serving aviation and the Meteorological and Oceanographic Centres (METOC), operated in cooperation with DND.

As indicated in Appendix 3, Application 9, AES can and does accept a very wide variety of input data, much of it not unique but with many alternatives. Because of the global nature of weather phenomena, there are many arrangements for international co-operation in data exchange and the development of data standards and forecasting methods through the World Meteorological Organization, the World Weather Watch and international experiments such as the Global Atmospheric Research Project (GARP). At present, for some applications such as long-term forecasts, AES has access to more data than can conveniently be used within budgetary constraints. The most useful data for their purpose would be sea state, wind velocity and sea surface temperature distribution, especially in regions where data are currently sparse, such as the North Pacific Ocean.

At the regional level, it appears that satellite data, especially sea state and temperature data, would be more useful. It should be mentioned, however, that the cost of obtaining such data is a significant factor in AES's considerations. At present, they obtain a great deal of satellite data, at little or no cost, from a variety of U.S. satellites; planned future satellites will provide even more. Consequently, it should not be expected that AES would be enthusiastic about data from a Canadian satellite if there were a significant price tag attached.

3.3.9 Other Applications

The following applications are not covered in Appendix 3.

Search and rescue operations on land, especially as they apply to downed aircraft, also were investigated. As mentioned in Appendix 3, Application 12, referring to marine search and rescue, the orbital parameters of a surveillance satellite would be such that it could easily serve the role envisaged for SARSAT[(1)] if it carried an ELT detector/repeater. Such a device would, of course, apply to all cases where ELTs are used. The low price and ready availability of these devices are such that they are now starting to be used by pleasure-boat operators and persons using snowmobiles and all-terrain vehicles for hunting and other purposes. Indeed, the number of such devices coming into use, and the resulting high "false alarm" rate is such that serious consideration is being given to providing an additional frequency assignment for uses other than aviation. This increase in usage and false alarm rate increases the need to determine quickly the location of active devices so as to avoid needless searches. Satellite monitoring should achieve this quite effectively.

The sensors which a surveillance satellite would carry are such that data acquired by them could serve a number of useful purposes other than surveillance. No detailed investigation of these has been carried out, nor were departments consulted about them, as they are not surveillance tasks. Nevertheless, they are listed here since it is possible that significant benefits could be derived from them. The list is incomplete and to some extent speculative.

Forest mapping
Agricultural crop assessment
Soil moisture monitoring
Land use mapping

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(1) Search And Rescue SATellite. The European Space Agency uses the same acronym for Synthetic Aperture Radar SATellite; in this report the letters SAR alone means Synthetic Aperture Radar, described in section 4.3.1, page 33.

Snow mapping for run-off forecasts (hydro power and flood control)

Surficial geology mapping for major engineering work

Geological structure mapping for mineral exploration

Updating aeronautical charts and topographic maps

Damage assessment after natural disasters

The user needs listed in Appendices 2 and 3 provide the basis for establishing the surveillance regime best suited for a satellite. In the following section the capabilities of satellite technology are examined through the conceptual design of a spacecraft focussed on the requirements that now have been identified.

mentioned in Appendix 3, Application ID, referring to marine search and rescue. The [illegible] of a surveillance satellite would be such that it could easily serve the role envisaged for SARSAT (1) [illegible] ELT detection/[illegible] apply to all cases where ELTs are used. The low price and ready availability of these devices are such that they are now starting to be used by pleasure-boat operators and persons using snowmobiles and all-terrain vehicles for hunting and other purposes. Indeed, the number of such devices coming into use, and the resulting high "false alarm" rate is such that serious consideration is being given to providing an additional frequency assignment for uses other than aviation. This increase in usage and false alarm rate increases the need to determine quickly the location of active devices so as to avoid needless searches. Satellite monitoring should achieve this quite effectively.

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(1) Search And Rescue SATellite. The European Space Agency uses the same acronym for Synthetic Aperture Radar SATellite; in this report the letters SAR alone means Synthetic Aperture Radar, described in section 4.5.1, page 53.

4. SURVEILLANCE SATELLITE CAPABILITIES

4.1 Approach

In establishing the capabilities of surveillance satellites, the group responsible, listed in Appendix 1, conducted a brief conceptual study of a Canadian satellite that might be launched in the early 1980's time frame. Appearing as Appendix 4, the study draws upon contemporary sensor and satellite system technology of the type that has or will emerge following the Landsat, CTS and early Seasat missions. The capabilities of such a satellite then are compared with the requirements described in the previous Section, and listed in Appendices 2 and 3. The result is a tabular listing of departmental requirements that can be met, in whole or in part, by a surveillance satellite.

The high data rates associated with satellite surveillance create special challenges and opportunities in signal processing and in ground data handling and distribution. They are described in Appendix 4. Signal processing, data handling and distribution are common to all surveillance platforms including aircraft, ships and fixed stations. However, satellites produce the largest flow of data and therefore could dictate the form and extent of the total future surveillance system. For these reasons, signal processing and data handling have been given special emphasis.

4.2 A Canadian Surveillance Satellite

Appendix 4 describes a satellite system designed to meet as closely as possible Canadian requirements with sensor technology that will emerge, mainly from the Seasat and Landsat programs. The basic sensor complement consists of:

1. Two synthetic-aperture radars (SARs) looking out to the sides of the satellites.

2. A high resolution multispectral scanner.

3. A scanning microwave multi-frequency radiometer.

4. A search and rescue beacon transponder.

The pre-operational system will consist of two long-life satellites (one active, one spare), as a minimum space segment, and three ground stations, located at Shoe Cove, Nfld., Prince Albert, Saskatchewan, and Resolute, N.W.T., for controlling the spacecraft and receiving and processing satellite data. The stations will have digital processing equipment to produce imagery, and will be linked to users via communication satellites.

Each spacecraft will be designed to have a 70% chance of lasting 5 years in orbit. A single satellite in a sun-synchronous, 700 km. circular orbit provides almost complete Canadian coverage (including the landmass, 200-mile coastal zone and the arctic) by the radar twice in 5 days (one in daylight, one at night) below 57^{o}N, and increasing in frequency between 57^{o}N and 350 km. below the north pole. The vehicle would be launched either by a Delta rocket or the space shuttle, when the latter becomes available. An operational system may contain more than one active satellite, depending on the necessary frequency of coverage and requirements for continuity.

Technical details of the spacecraft are described in Appendix 4. Much of the technology was developed in Canada for the CTS satellite.

The ground stations each contain a conventional auto-tracking 10 metre antenna. The signal processing portion of the radars is contained in the ground stations which, because of the complexities associated with deriving images from synthetic aperture radar signals, will involve computing equipment of advanced design. Each station is equipped with a data processing capability for producing images and computer tapes.

4.3 Sensors

4.3.1 Synthetic-Aperture Radar (SAR)

The ability of ordinary radar to detect small targets depends on the antenna size, among other things. For the given requirements, a satellite radar would need an antenna many kilometers long, which is not realizable. Modern signal processing techniques, using equipment on the ground, give the ability to synthesize the required length, hence the name "synthetic-aperture radar". Theoretically, such methods can achieve resolution of the order of one metre; in practice, it is limited by such factors as the speed at which signals can be recorded and/or processed. These and other factors discussed in Appendix 4, are such that a compromise figure of 20 metres was chosen for baseline design purposes.

The desired frequency of coverage leads to specifying two radars, one to each side of the satellite, scanning a 200 km. swath. At the receiving stations, digital recorders, capable of recording 240 million pulses per second are required - a technology that should be available within 5 years.

The lower frequency L-band chosen for the radars is based on currently-available technology and anticipated Seasat-A experience. The effects of the Canadian ionosphere could be a problem at this frequency, and the severity of sea clutter is not known. Both of these problems might be alleviated at the higher X-band frequencies, if sufficient satellite power and space qualified solid-state transmitter components were available. Also X-band provides improved textural information for such functions as the classification of sea ice.

4.3.2 Multi-Spectral Scanner (MSS)

The radiometric and spectral characteristics of a multi-spectral scanner make it a desirable sensor as a backup for the radar in clear weather, and for environmental surveillance and mapping over the landmass as well as the ocean regions. It produces images on a line-by-line basis using optical detectors responsive to selected spectral bands. The MSS selected covers a swath 200 km wide directly below the spacrcraft, and produces registered digital data with a resolution of 40 m x 40 m for 4 spectral bands in the visible region, and a resolution of 120 x 120 m. for a thermal infrared band. Such a scanner uses optics similar to Landsat, but with detectors that double its resolution performance. A similar scanner is being developed in the United States as the present time.

4.3.3 Scanning Microwave Multifrequency Radiometer (SMMR)

All physical objects emit electromagnetic radiation; the amount and characteristics depend on their temperature. For the range of temperatures encountered at the earth's surface, emitted radiation in the microwave region of the spectrum provides a measurement of temperature. SMMRs are radio receivers that can be scanned so as to form a temperature image or map of the earth's surface. The Seasat-A SMMR will be used to record absolute sea-surface temperatures to within 2°C, and relative temperatures to within 1C° under all weather conditions. The resolution is established by antenna size, and for the Canadian design the size is twice that of Seasat-A to achieve a resolution of 50 km. The swath width is 920 km which provides global coverage every 40 hours. The SMMR can be used to measure surface winds and map ice areas. Atmospheric water vapour and liquid water also can be inferred from SMMR data.

4.3.4 Search and Rescue Beacon Transponder

An electronic locator transmitter (ELT) transponder for search and rescue applications can be included in the satellite payload because of its light weight and low power requirements. One satellite provides complete coverage of southern Canada every 24 hours; the frequency increases with latitude.

4.4 Satellite System Capabilities

The satellite system design described in Appendix 4 and summarized above provides a basis for matching capabilities with requirements as listed in Appendix 3. The result is Table 4.1 which abbreviates the target descriptions and designates which of the four sensors selected for the satellite are the most likely to meet the requirement in terms of the first two stages of surveillance - detection and location. Feasibility of achieving further stages in the surveillance process is covered in the remarks column and in the footnotes.

Radar, the lead sensor in the spacecraft, has not been proven at orbital altitudes, so that all of the performance claimed for it is speculative, which accounts for many of the 'probables' and 'possibles' listed in the table. In examining the table it is important to bear in mind that targets at the threshold level in size for detection cannot be classified or distinguished one from the other. Thus a ship, piece of flotsam or an iceberg, for example, all look more or less alike as a single spot or resolution element on the image. When the target is large enough for the radar to outline its shape - roughly when the target dimensions exceed 200 metres - then target classification becomes possible. The Seasat-A experiment will provide the opportunity to establish such target size limits for detection, classification and identification under actual operating conditions.

There are two major environmental factors that will affect the radar - the ionosphere in Canada's auroral zone and the radar properties of the sea surface. Ionospheric effects in regions near the magnetic pole could cause some performance degradation of the radar, particularly during the periods of severe ionospheric disturbances that occur at Canadian latitudes. Sea surface roughness creates radar backscatter or "clutter" that reduces the ability to detect small targets. While synthetic aperture radars inherently have a resolution performance independent of altitude, backscatter from a rough sea tends to mask the image - an effect that increases with the width of the swath covered by the radar, and thus with altitude. The impact on radar performance of these two environmental factors, one peculiar to Canada, will not be known or understood until a synthetic aperture radar is flown over Canada at satellite altitudes, as planned for Seasat-A.

The MSS already has been proven in space through the Landsat program. The instrument selected is the same, except that it has been designed for twice the resolution performance of Landsat. There is every reason to believe the MSS will perform as predicted.

Successful experience in the Nimbus-5 program with an electrically scanning microwave radiometer has encouraged NASA to proceed with a SMMR for Nimbus G and Seasat-A, both of which will be launched in 1978. Thus, the technical risks associated with the SMMR should be minimal by the early 1980s time frame. As a secondary sensor associated mainly with environmental parameters, it could be eliminated without major prejudice to the primary mission.

The ELT transponder also is a low technical risk sensor that has been added to meet Application No. 15 related to search and rescue.

The locational accuracy of satellite sensors without surface control points depends on the accuracy of knowledge of the orbital parameters and viewing geometry. It is expected that under such circumstances, targets could be located to within 3 km.; but when ground control points are available on the imagery, it should be possible to locate targets to within 30 metres.

Frequency of coverage with one satellite (as proposed for a pre-operational system) is twice every 5 days in southern Canada, and increases with latitude. While such coverage does not meet the majority of requirements which call for 24 hour periods between observations, a three-satellite operational system would provide coverage approximately every 20 hours, in the south, 10 hours in the north, and thus be sufficient for most of the applications listed in Appendix 3.

An examination of Table 4.1 leads to the conclusion that satellite surveillance is feasible for the majority of applications <u>if</u> the radar performance is verified and proven on Seasat-A. However, it must be realized that vessels shorter than 20 metres likely will not be detected; and that icebergs and ships may not be distinguished from each other until their dimensions are considerably larger. For environmental targets such as ice in open water, the radar, MSS and SMMR should meet most requirements.

From the foregoing, it can be concluded that the feasibility of a satellite meeting Canadian surveillance requirements will not be known until the synthetic aperture radar on Seasat-A has been tested and proven following its launch in 1978.

It should be noted that the requirements listed in Appendices 2 and 3, which form the basis for Table 4.1, are those needs as perceived by departments today for the period 1980-2000. Many respondents expressed concern as to their ability to foresee their requirements even 5 years ahead, let alone 20-25 years! Thus the requirements stated to the task force should be regarded with a degree of caution, and the conclusions that can be drawn from Table 4.1 do not take into account changes in the technology over the 1980-2000 time period which will alter both the requirements for surveillance and the capability of satellite sensors to meet them.

4.5 Signal Processing

Processing the radar signals from the satellite involves a special technique known as correlation which, for the high data rates associated with satellite radars, can impose a substantial time delay between the recording of real-time signals from the satellite and the production of imagery ready for interpretation. Current state of the art in correlation is such that it takes 20 to 60 times longer to process the data than to acquire it.*

Appendix 3 lists response times required for each application, ranging from an hour to a week. A system capable of providing imagery ready for interpretation within 3 hours would meet all but two of the requirements (forest fires and military needs in times of emergency). For a single correlation processor whose rate is 1/60 of real-time recording rate, only 3 minutes of recording could be processed within the required response time of 3 hours. At a processing speed 1/20 of real-time recording rates, 9 minutes of data could be processed within 3 hours, which is approaching the recording interval for a single pass. In order to complete the processing before

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* One orbit requires approximately 100 minutes of which roughly 1/8 is over Canadian areas of interest. The recording interval on a single pass is typically 8-12 minutes.

the next pass 100 minutes later, the processor speed would have to exceed 1/8 real-time recording rates.

At present, most airborne synthetic aperture radars use optical correlators, and the U.S. are developing such a processor for Seasat-A capable of processing 10 minutes of real-time data in 4 hours (1/24 of real-time recording rate). With modern solid-state circuit techniques, it is possible to perform the correlation task electronically using digital methods. The digital approach eliminates some of the uncertainties associated with optical methods and can produce consistent, high-quality imagery. However, current estimates for processing Seasat-A data digitally are 1/64 of real-time recording rate. The Seasat-A radar covers a 100 km swath, whereas the system herein described covers a 400 km. swath. A correlation processor capable of processing at 1/8 real-time recording rates would have to enlarge its throughput by a factor of 32 greater than current digital processor performance estimates. New Canadian approaches to the design of digital correlators show promise, and a processor could be developed within 2 years. It is anticipated that with continuing support through involvement with Seasat-A processor development, the required throughput to meet the Canadian requirement could be met in the early 1980's time frame. Otherwise, there is no assurance that an adequate processor would be available to Canada within the time scale required.

4.6 Data Handling and Distribution

The high rate of production of imagery by the satellite creates new challenges in data handling and distribution. The radar produces 160 images per day, the MSS 80 images per day in each of 5 bands. Each image from these sensors covers an area of 200 x 200 km., and contains roughly 100 million picture elements or pixels. The SMMR adds another 50 images per day, each covering a 920 x 920 km. area and containing 20 thousand pixels. Approximately a third of these images cover the ocean and arctic areas of direct interest; the balance relate to the main Canadian landmass.

The ground stations (two in the south, one in the arctic) either must contain facilities to create and screen the images, or they must be linked by wide-band communications to central or regional facilities for screening, analysis and filtering before onward distribution to the appropriate responsibility centres. Only a detailed trade-off study will reveal the best alternative.

Appendix 4 outlines a technique for the automatic extraction of targets from the radar data to facilitate the screening and filtering task. Coupled with human interpreters, it should be possible with such a scheme to optimize the man/machine combination by maximizing interpreted data throughput per unit of total cost. Other forms of automatic interpretation present themselves once the radar images are stored on high-density tapes. For example, it will be possible to extract wave information during the target extraction process. including wave direction and wavelength.

Multi-spectral scanner data can be handled in the same fashion as in the Landsat program using standard image tape formats, but digital facsimile transmissions could be used by agencies needing a fast response time. The lower data rates of the SMMR should pose no problem; and it may be possible to use spare capacity on the radar target system to produce the thermal maps derived from this sensor. Detailed SMMR data processing procedures will be developed in the Seasat-A and Nimbus-G satellite programs.

The Ocean Management Panel Overview Report outlines a flow process in which data from various platforms including satellites become integrated and filtered before onward transmission to the activity responsibility centres. It is evident that some satellite data should pass directly to the user with little if any integrating and filtering; for example, certain types of environmental data such as forest fire maps, or major forms of defence-related human intervention where integration and filtering is done by the user, and response time is most critical. Most satellite data, however, will be integrated with the output of other sensors; or it will be used as a strategic tool for tasking other platforms such as aircraft or ships.

It can be concluded that in whatever way the satellite data is to be used, there will be a need for extensive wide-band communications, linking ground stations, data processing centres, integrating and filtering facilities, activity responsibility centres and users. In some instances, the data flows will be enormous, and for a country the size of Canada, it is possible that communication facilities could become saturated, or spectrum allocations exceeded. Thus it will be necessary to design the total surveillance system with spectrum conservation and communication constraints as major design conditions.

The examination of surveillance satellite capabilities has shown that experience with synthetic aperture radars in space is needed before the feasibility of an operational Canadian satellite that meets Canadian surveillance requirements can be established. The U.S. Seasat-A satellite to be launched in 1978 will test such a sensor, and therefore, provides an opportunity to gain the necessary experience. For this reason and others associated with future cost-sharing cooperative space programs with other countries, international considerations are dealt with in the following sections.

TABLE 4.1 (Page 1 of 4)

SATELLITE CAPABILITY

TO MEET SURVEILLANCE REQUIREMENTS

(see footnotes)

APPLICATION NUMBER (1)	TARGET (2)	SENSOR(3)	FEASIBILITY OF DETECTION & LOCATION (4)	REMARKS
1	Clusters of Ships	Radar	Probable	
2	Drilling Platforms	Radar	Probable	Identification possible for platforms larger than 200 m.
3	a) Seismic Lines b) Lodgments, Camps	Radar, MSS Radar, MSS	Yes Yes	Classification possible for targets larger than 200 m.
4	Oilspills	Radar	Possible	Difficult in calm or very rough seas, thickness measurement doubtful.
5	Flotsam	Radar	Doubtful	Only for objects larger than 20 m in calm sea, 50 m in rough sea.
6	All Ships	Radar	Possible (5)	Only for vessels larger than 20 m in calm sea, 50 m in rough sea.
7	Navigation Aids	-	No	Targets too small, locational accuracy needed too high
8	Siltation	MSS	Partial	Horizontal extent only.

TABLE 4.1 (Page 2 of 4)

SATELLITE CAPABILITY

TO MEET SURVEILLANCE REQUIREMENTS

(see footnotes)

APPLICATION NUMBER (1)	TARGET (2)	SENSOR (3)	FEASIBILITY OF DETECTION & LOCATION (4)	REMARKS
9	**Weather and Sea State:**			
	a) Surface Temperatures	SMMR	Yes	Absolute to 2^{o}C, relative to 1C^{o}, 50 km. resolution
	b) Water Vapour & Liquid Column	SMMR		20% accuracy.
	c) Surface Winds	SMMR	Yes	7-50 m/sec.
	d) Waves	Radar	Probable	Lengths 50-1000m, direction to 15^{o}.
10	Ice-Open Water	Radar, MSS	Yes[5]	Meets most requirements but not snow cover or growlers, ice classification may be possible. Sensor resolution limits detail and texture variations under 20 m.
		SMMR	Yes	Extent within 10-15 km.
11	Ice-River	Radar, MSS	Possible	Where river exceeds 20 m in width. Locational accuracy needed is too high

TABLE 4.1 (Page 3 of 4)

SATELLITE CAPABILITY

TO MEET SURVEILLANCE REQUIREMENTS

(see footnotes)

APPLICATION NUMBER (1)	TARGET (2)	SENSOR (3)	FEASIBILITY OF DETECTION & LOCATION (4)	REMARKS
12	Search and Rescue	ELT Transponder	Yes	Complete southern Canada coverage every 24 hours, and at frequencies increasing with latitude.
		Radar, MSS	Yes	For targets larger than 20 m.
13	Cartography	Radar, MSS	Doubtful	Resolution inadequate.
14	a) Forest Inventory	MSS	Yes	Crude classification only
	b) Forest Fires	MSS	Yes	Clear weather only
15	Non-Surveillance Tasks: Forest Mapping Agricultural Crop Assessment Land-Use Mapping Snow Mapping Geological Mapping Damage Assessment	Radar, MSS	Partial	Current experience with Landsat shows applications and benefits for all requirements listed; all-weather capability of radar may add further, as yet unknown, value.

TABLE 4-1 (Page 4 of 4)

SATELLITE CAPABILITY

TO MEET SURVEILLANCE REQUIREMENTS

Footnotes:

1. Application numbers refer to Appendix 3.

2. Frequency of coverage: Most applications in Appendix 3 required coverage every 24 hours, some more frequently. One satellite provides complete coverage twice (day and night) every five days from 40-57°N, and at increasing frequencies further north. Extra satellites would be needed for more frequent coverage.

3. Detection capability of the radar sensor is subject to Seasat-A confirmation.

4. Locational accuracy of satellite is ± 3 km. without and ± 30 m. with ground control points. Latter accuracy meets most requirements except where noted.

5. It is unlikely that proposed radar sensors will be able to distinguish small ships from icebergs.

5. INTERNATIONAL IMPLICATIONS

5.1 Cooperative Programs

Canada, through the Atmospheric Environment Service, already makes extensive use of U.S. meteorological satellites such as the earlier ESSA series, the NOAA series and the SMS/GOES geostationary weather satellites. Also, AES plans to use the future TIROS-N satellites and their successors including the operational versions of Seasat. The Canada Centre for Remote Sensing (CCRS) collects, processes and distributes data from the Landsat satellites. While international cooperation make good economic sense for a surveillance satellite that could be employed by many other nations without affecting Canada's use of the spacecraft, the satellite must meet Canadian requirements. This includes consideration of the sensors on board, the orbit selection, the number of spacecraft, etc. The design and definition phase of the project could be a Canadian responsibility, and the operational phase could be cooperative with another nation or nations.

Since Canada and the U.S.A. share some common problems in ocean management, a Canada/U.S.A. program would be reasonable. Moreover, Canada must rely on the results of the U.S. Seasat-A experiment before mounting its own surveillance satellite program, or bear the awesome burden of developing its own radar technology satellite before committing to an operational satellite system. On the other hand, Europe needs an all-weather surveillance satellite for reasons similar to those of Canada; consequently, ESA is interested in some form of cooperative program with Canada.

5.2 Surveillance of Other Nations

The U.N. Outer Space Committee has been examining the question of satellite surveillance and has agreed that countries should have access to data on their own territories. The Canadian policy is to support this principle. Since the Canadian satellite described herein does not carry on-board data storage, the problem should be reasonably tractable. Moreover, there are no plans to observe other nations' territories, unless requested by those nations to do so. Canada will continue to cooperate with the U.N. Outer Space Committee to resolve such problems, and assure that remote sensing can benefit all nations.

5.3 Restriction of High Resolution Data

It is understood that the military authorities of some countries are attempting to place image resolution limits on unclassified satellite remotely-sensed data to prevent unauthorized dissemination of high-resolution imagery which may contain sensitive military information. Current indications are that the incorporation of any sensors providing spatial resolution significantly less than 25 metres on the earth's surface would not be acceptable if Canadian or neighbouring U.S. military targets were covered in routine surveillance. Such data would require the use of one or more appropriate security control measures such as on-board recording capability, down-link data encoding, processing and screening of data by security-cleared personnel, selective and controlled data dissemination, etc. The resolution limits are likely to diminish with time, and so the matter may not be relevant by the time a Canadian satellite could be launched.

If this does not happen, then either the image resolution capability of a Canadian satellite may have to be constrained to an acceptable level, or adequate assurance may have to be given that appropriate security measures will be taken.

The security or screening controls on a high-resolution system must, however, be such as to have the confidence of all users that all data of potential operational and scientific value will be provided promptly to authorized users, and that no such data will be suppressed without good reasons. The Ocean Management Panel Overview Report noted that there was a trend toward separation of the user of data from the data collection system, and suggested that security-controlled receiving and initial processing stations probably will be acceptable to users. A precise set of rules for vetting data, drawn up and reviewed at frequent intervals by a standing inter-departmental security committee, might likewise find acceptance. The day-to-day implementation of such rules could be done in an acceptable manner through the use of integrated information centres of the type suggested in the Overview Report.

6. THE CANADIAN ALTERNATIVES

Among the alternative surveillance platforms, satellites are unique in their ability to cover vast areas completely and frequently. In the interests of sovereignty control, it is assumed that Canada must be seen to be keeping watch over her northward and seaward reaches, including the 200-mile zone and the high arctic. In addition, it is assumed that Canada must be seen to be able to manage these regions, which includes the provision of management support functions and ocean service activities. A surveillance satellite provides such an international visibility. Moreover, other nations will be operating surveillance satellites of their own which, without a Canadian involvement, creates the undesirable situation where other nations could know more about Canadian resources, the environment and human activity within the outer boundaries, than Canada herself.

Because of the large amount of cloud cover over the regions of interest, and the long periods of arctic darkness, it is essential that a surveillance satellite carry radar. The first tests of a surveillance radar from space, from which technical data will be readily available, will be from the Seasat-A satellite, to be launched in 1978. While the satellite radar provides the necessary coverage, it likely cannot detect targets such as ships shorter than 20 metres. The satellite is a strategic tool complementary to other platforms such as aircraft and ships which will be needed to perform the identification and inspection functions, and to collect the finer detail required for tactical purposes.

Since the results of the space radar tests will not be known until 1978, a strong argument can be made to postpone the decision to mount a Canadian surveillance satellite program until the Seasat-A radar has been proven. If the radar does not come up to performance expectations, there may be insufficient incentive to proceed.

There would appear to be five principal surveillance-satellite options open to Canada which would necessitate varying degrees of Canadian participation in the Seasat-A program:

1. An all-Canadian satellite without international participation.
2. A Canadian satellite with international participation.
3. Other nations' satellite program, influenced to meet Canadian requirements,
4. Buy surveillance satellite data from the U.S.,
5. No surveillance satellite activity.

The above options need to be evaluated in the light of the possible roles Canada could play in the Seasat-A experiment.

6.1 Potential Canadian Roles in the Seasat-A Program

The Seasat-A spacecraft is tentatively scheduled for launch in the second half of 1978, into a nearly circular orbit with an altitude of 800 km. and a period of 100 minutes 45 seconds (14 - 1/3 orbits per day).

The spacecraft carries five sensors:

1. Radar Altimeter - to measure altitude to within ± 20 cm., which can be used to measure wave height and shape of the sea surface (for estimating currents, tides, wind pile-up, storm surges, etc.)

2. Synthetic Aperture Imaging Radar (SAR) - to yield images of waves (wavelength of 50-1000 metres) and images of sea ice with a 25 m resolution. It covers a 100 km swath, displaced 200 km to one side.

3. Microwave Scatterometer - a type of radar capable of measuring near-surface winds.

4. Scanning Visible and Infrared Radiometer (SVIR) - to provide images of visible and thermal emissions from oceans, coastal and atmospheric features.

5. Scanning Microwave Multifrequency Radiometer (SMMR) - to measure global, all-weather (through clouds) surface temperatures, atmospheric moisture and sea ice extent.

In the northern hemisphere, the orbits reach a maximum latitude of 72°N. Therefore only the lower Canadian region will be covered, including the mainland coastal part of the Beaufort Sea, Gulf of Boothia, Foxe Basin and Davis Strait; but it will not cover the major portion of the northwest passage through Melville Sound, Lancaster Sound and Baffin Bay, and most of the Canadian high-arctic archipelago. However, future Seasat orbits, including those for the planned 6-satellite operational system, could be chosen to cover the high arctic regions at the request of Canadian and other international users of Seasat, provided that such potential participants made some form of contribution to the program.

Five Seasat ground receiving stations are planned with locations in Alaska, Goldstone near the U.S. west coast, Rosman near the U.S. east coast, Madrid (Spain) and Orroral (Australia). These stations do not provide for real-time, line-of-sight data transmission over the entire globe. For example, there is a significant gap in the coverage of Canada's northeastern region - Foxe Basin, Hudson Strait and Davis Strait, and the Atlantic region south of Greenland - an area that could be covered from a Seasat readout station at Shoe Cove, Newfoundland.

There have been extensive discussions with NASA officials as to the form of Canadian involvement in Seasat-A. They have centered on the provision of a ground receiving station and data processing facilities in Canada. Specifically, Canada proposes to:

- Modify the CCRS Shoe Cove receiving station near St. John's, Newfoundland to receive and record Seasat-A data.
- Develop a digital synthetic aperture radar (SAR) signal processing facility,
- Conduct assessment studies and carry out verification experiments to prove system performance.

While detailed negotiations with NASA have not been concluded as to the tradeoffs between the degree of Canadian participation and the amount of Canadian contribution, the principle has been made clear that appropriate modifications to the Shoe Cove station are a minimum contribution, and that long delays in receiving processed imagery from the U.S. could be avoided if a SAR processor were available in Canada.

The five surveillance-satellite options listed above call for differing forms of involvement in Seasat-A as listed in Table 6.1. They are described in the following paragraphs which amplify the different options open to Canada, and Table 6.2 is a summary of the relative merits of each option.

TABLE 6.1

SUMMARY OF REASONS FOR CANADIAN INVOLVEMENT IN SEASAT-A

Option	Canadian Contribution to Seasat-A	Derive from Seasat-A Program
1. Canadian Satellite Without International Participation	1. Modify Shoe Cove Station 2. SAR processor 3. Verification experiments[1]	1. Knowledge of radar performance in orbit. 2. Space radar experience 3. Design and engineering experience.
2. Canadian Satellite With International Participation	1. Modify Shoe Cove Station 2. SAR processor 3. Verification experiments[1]	1. Knowledge of radar performance in orbit. 2. Space radar experience 3. Design and engineering experience.
3. Other Nations' Satellite (such as Operational Seasat) Modified to Meet Canadian Requirements	1. Modify Shoe Cove Station 2. SAR processor or other major subsystem 3. Verification experiments[1]	1. Knowledge of radar performance in orbit. 2. Space radar experience 3. Minimum experience needed to make necessary Canadian contribution to other nations' program.
4. Buy Surveillance Data from U.S.	1. Modify Shoe Cove Station 2. Verification experiments[1]	1. Knowledge of radar performance in orbit 2. Space radar experience
5. No Surveillance Satellite Activity	None	None

1. "Verification experiments" are those conducted to evaluate sensor performance in the context of sovereignty control surveillance requirements, as opposed to applications studies, used to determine the feasibility and usefulness of other possible applications.

TABLE 6.2 (Page 1 of 3)

RELATIVE MERITS OF CANADIAN OPTIONS

Factor \ Canadian Options	Canadian Satellite Without International Participation	Canadian Satellite With International Participation	Other Nations' Satellite (such as Operational Seasat) modified to meet Canadian requirements	Buy Surveillance Data from United States	No Surveillance Satellite Activity
Contribution to Seasat-A	1. Modify Shoe Cove Station 2. Develop Digital SAR Processor 3. Perform verification experiments			1. Shoe Cove 2. Verification experiments	No Seasat-A involvement
1. No. of Canadian Options Left Open	Highest	High	Moderate	Low	None
2. Coverage of all Canadian Areas of Interest	Yes	Yes	Possible	Unlikely	None
3. Independence of Canadian Action	High	Moderate	Low	None	None
4. International Visibility of Canadian Sovereignty Control	Highest	High	Moderate	Low	Lowest
5. Canadian Control of Operational System Parameters	Yes	Yes	Yes	No	No
6. Delay in Receipt of Processed Data	None	None	None	Yes	N/A

TABLE 6.2 (Page 2 of 3)

RELATIVE MERITS OF CANADIAN OPTIONS

Factor / Canadian Options	Canadian Satellite Without International Participation	Canadian Satellite With International Participation	Other Nations' Satellite (such as Operational Seasat) modified to meet Canadian requirements	Buy Surveillance Data from United States	No Surveillance Satellite Activity
Contribution to Seasat-A	1. Modify Shoe Cove Station 2. Develop Digital SAR Processor 3. Perform verification experiments			1. Shoe Cove 2. Verification experiments	No Seasat-A involvement
7. Access to All Canadian Data	Yes	Yes	Yes	Uncertain	Unlikely
8. Access to All Radar Technical Data	Yes	Yes	Yes	No	No
9. Access to Necessary Technology	Probable	Yes	Yes	No	No
10. Access to Spacecraft Launch	Probable	Yes	Yes	N/A	N/A
11. Technical and Financial Risk	Highest	High	Moderate	Low	None
12. Industrial Experience Gained and Industrial Loading	Highest	High	Moderate	Low	None

TABLE 6.2 (Page 3 of 3)

RELATIVE MERITS OF CANADIAN OPTIONS

Factor / Canadian Options	Canadian Satellite Without International Participation	Canadian Satellite With International Participation	Other Nations' Satellite (such as Operational Seasat) modified to meet Canadian requirements	Buy Surveillance Data from United States	No Surveillance Satellite Activity
Contribution to Seasat-A	1. Modify Shoe Cove Station 2. Develop Digital SAR Processor 3. Perform verification experiments			1. Shoe Cove 2. Verification experiments	No Seasat-A involvement
13. Potential of Technology Export	Highest	High	High	None	None
14. Cost of Seasat-A involvement	High	High	High	Moderate	None
15. Cost of Operational System	Highest	High	Moderate	Unknown	None

6.2 Canadian Satellite Without International Participation

It could be argued that any vehicle used for sovereignty control, by definition, should be under the control of a single nation. The selection of sensors and orbit characteristics to meet Canadian needs can be accomplished without interference or compromise only if it is solely a Canadian satellite. Absolute control of the operational system is assured. Thus in Table 6.2, the first option scores highest in the first five factors related to sovereignty control and Canadian independence. Also, Canadian industry stands to gain the most from this option, but the technical and financial risk is the highest. On the negative side is the need for Canada to bear the total cost of the satellite system, including research and development and any royalty payments associated with proprietary sensor technology. Also, there is the question as to whether or not Canada could have access to such technology, and to a launch facility.

Access to the necessary sensor technology and launch facilities is more likely to be assured if Canada were a partner in the Seasat-A experiment. Since the key sensor is the synthetic aperture radar, and since the SAR processor is as much a part of the sensor as the portion on board the spacecraft, Canadian involvement in the processor would provide total access to the radar technology - a knowledge that is essential for possible future surveillance systems. Thus in Table 6.1, the SAR processor is listed as a Canadian contribution to Seasat-A along with modifications to the Shoe Cove station and verification experiments.

The critical research and development areas associated with the first option are examined in Appendix 5. It also describes the technical performance problems associated with the radar. With the exception of the radar, the required technology already exists. It is pointed out that cost savings, of course, will result from international cooperation in all phases of a Canadian surveillance satellite program. The unknown factor is the amount of such cooperation Canada could permit before losing influence over the direction of the program.

A major consideration in weighing the Canadian-only alternative is that each satellite in the system spends approximately 87% of its time over other countries, many of which could use surveillance data to the same advantage as Canada. With no data-storage facilities on board, user nations would be able to obtain the data in real time when the satellite is near their sovereign territory. Thus because of the cost savings involved, there are strong arguments for Canada to seek international participation.

6.3 Canadian Satellite With International Participation

If Canada could take the lead in designing and specifying her own surveillance satellite system, it may be possible to achieve international participation without serious compromises in sensor payload, orbit or system performance, and thus obtain some relief in the total costs of such a system. Moreover, such participation may ease access to the technology and to a launch facility.

The small loss of independence should not compromise sovereignty control significantly, nor should Canada's credibility in managing her ocean regions be adversely affected.

Since the U.S. has invited Canada to participate in Seasat-A, it is logical that Canada should look to the U.S. as a major participant in any international surveillance program. Further, until the radar performance is proven on Seasat-A, there is little need for Canada to proceed at all with a surveillance satellite program. An exception would be if Canada were to undertake the total development of its own operational satellite surveillance radar - a costly alternative that was rejected by the task force as being too expensive, as the U.S. already is well advanced in its program.

In order to be in a position to design and specify the satellite, Canada must have access to SAR radar technology, and so the arguments for Canada to contribute a SAR processor to the Seasat-A program used in the first option apply equally well to the second, as listed in Table 6.1.

6.4 Canadian Participation in Other Nations' Satellite Program

Canada might be able to meet her requirements by negotiating a role in the surveillance satellite program of another nation in much the same way as other nations might join a Canadian program as in the previous option (Section 6.3). An example would be the six-satellite operational Seasat program of the U.S.; but a European surveillance satellite or a Japanese system also might be possibilities. If the program were to be influenced sufficiently to meet Canadian requirements - for example, orbital coverage and sensor combinations - a contribution from Canada will be expected. In the case of Seasat, the most likely candidate program at present, the SAR processor should be a contribution. For other nations' programs, there may be other major subsystems which could be contributed where Canada has developed special skills on such programs as CTS and the Telesat Dual-Band satellites. For the purposes of Table 6.2, the SAR processor has been chosen as Canada's contribution.

The attraction of this third option is the anticipated moderate cost of being involved with the operational system, as compared with the first two options. Also the technical and financial risks are lower, being mainly those associated with the development of the SAR processor. The higher cost of the first two options over the third can be thought of as the price to be paid for international visibility of sovereignty control and Canadian independence of action.

6.5 Buy Surveillance Satellite Data from the U.S.

If Canada were to rely entirely on the purchase of satellite data from the U.S., it would not be necessary to develop a Canadian SAR processor, and thus the cost of Seasat-A involvement for this option would be relatively lower than for the first three options. On the negative side, it would not permit Canada to assess fully the technical performance of the radar, although eventually Canada would receive processed imagery from which a superficial performance evaluation would be possible.

The loss of any significant control of the Seasat program associated with this fourth option could result in a loss of coverage of all Canadian areas of interest. (As described above, the maximum latitude for planned operational Seasat is 72°N, which does not cover all the northwest passage). Moreover, there would be no assurance that Canadian users would receive data with any priority, and without some screening beforehand. Also, it is uncertain whether or not there will be timely access to all Canadian data, and, the magnitude of U.S. charges for processed Seasat data is unknown.

6.6 No Surveillance Satellite Activity

It already has been stated that the consequence of opting out of any surveillance satellite activity is that other nations would have greater knowledge than Canada of her seaward and northward reaches through their own satellites. Even if the performance of such satellites were very much inferior to that expected for Seasat-A, Canada's credibility in managing its oceans and arctic regions could be questioned unless there were some apparent and visible form of wide-area, regular coverage at a time when technology makes it economically feasible. With the qualifications given in Ref. 3, the same area and frequency of coverage by a fleet of aircraft would cost ten times more than a satellite system. Nevertheless, before concluding that Canada should undertake some form of surveillance satellite activity, cost factors should be considered. They are examined in the following section.

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7. COST IMPLICATIONS

This section presents cost estimates for the options presented in Section 6, together with an appraisal of the degree to which satellites are expected to augment or replace current programs. Then, the results of related cost effectiveness and cost-benefit studies are summarized and conclusions drawn as to the relative value of satellites compared with other sensor platforms.

7.1 Cost Estimates for a Canadian Surveillance Satellite

Table 7.1 summarizes rough order of magnitude cost estimates for the five options described in Section 6. Together with the footnotes, the table is reasonably self-explanatory. Appendix 5 describes the research and development implications of a Canadian surveillance satellite program, and outlines in more detail the activities that make up the basic system studies, project definition and development phases of the program.

The figures listed in Table 7.1 should be used with caution. The information and background available at the present time does not permit a more precise estimate without extensive study beyond the efforts that were possible by the task force. However, the estimates do provide rough orders-of-magnitude which can be used for comparative purposes.

The estimates are based on a 1983 launch date for the first satellite. Seasat-A experience will provide the necessary information as to whether or not the program should proceed. The project definition phase defines the spacecraft in broad terms, and results in a Request for Proposal to Canadian industry for the development phase based on system performance specifications. Basic systems studies will be required throughout the program mainly related to the performance of the spacecraft sensors. They are listed in Appendix 5, Table A. The development phase extends over 2 years, and results in final hardware design and drawings for the final construction phase.

Two years will be needed to build the hardware, assemble, integrate and test the spacecraft. The following recurring

TABLE 7.1

ORDER OF MAGNITUDE COST ESTIMATES FOR CANADIAN SURVEILLANCE SATELLITE OPTIONS[1]

$ millions

Option / Program Activity	1. Canadian Satellite Without International Participation	2. Canadian Satellite With International Participation	3. Other Nations' Satellite (such as Seasat) Modified to meet Canadian Requirements	4. Buy Surveillance Data From U.S.	5. No Surveillance Satellite Activity
Seasat-A	4.1[2]	4.1[2]	4.1[2]	2.3[3]	-
Basic Systems Studies[4]	9.2	9.2	9.2	-	-
Project Definition	4.2	4.2	-	-	-
Development[5]	78.0	78.0	-	-	-
Construction					
a) Satellites @ $24M	96.0[6]	48.0[7]	-	-	-
b) Ground stations, processing and distribution @ $6M	18.0	18.0	18.0	9.0	
Launch (Delta 3910) @ $18M[9]	54.0	18.0	-	-	-
Total Capital Costs	263	180	31.3	11.3	-
Annual Operating Costs[10] @ $2.2M per ground station	6.6	6.6	6.6	UNKNOWN[11]	-

Footnotes to Table 7.1

1. In 1976 dollars; includes in-house man years @ $30,000 per man year.
2. Includes Shoe Cove station modifications ($1.55M), SAR processor development ($1.8M) and those verification experiments needed to prove radar performance for sovereignty control ($0.75M), both capital and operating costs.
3. Includes Shoe Cove station modifications and verification experiments only.
4. Basic systems studies as listed in Appendix 5, Table A, include general radar studies now in progress or which may be initiated whether or not Canada proceeds with a surveillance satellite program.
5. Includes $41M for sensor development (radar, MSS, SMMR and ELT Transponder) which could be reduced by sharing in developments underway in U.S., or by inviting other nations to participate.
6. A complete operational system includes 3 satellites in orbit to provide needed frequency of coverage, and one spare spacecraft in reserve.
7. It is assumed that Canada contributes 1 operational satellite and 1 reserve, and that participating nations provide the remaining 2 spacecraft.
8. Ground stations for the fourth option do not contain a SAR processor.
9. Launch costs could be reduced sharply when the U.S. shuttle becomes available.
10. Annual operating costs exclude satellite replacement costs ($42M), assumed to have a life of 5 years.
11. U.S. charges for providing Seasat data to Canada are not known.

construction costs have been estimated as:

- $24 million for each satellite
- $6 million for each ground station and its share of the data processing and communications systems.

A single Delta launch now costs $18 million, but when the Shuttle becomes available, launch cost should reduce significantly.

The yearly operating cost of $2.2 million per ground station is assumed to cover the readout, recording, processing and distribution of data from a multi-satellite system, whether it be all-Canadian or international in content.

It is difficult to make the assessment as to the degree satellites might replace existing programs. The only specific case that can be identified directly is ice reconnaissance where it has been stated* that satellites with suitable all-weather sensors are "the only foreseen development which could ease the requirement for long-range ice reconnaissance aircraft". By the mid-1980's, ice reconnaissance aircraft costs are expected to exceed $10M annually. In other cases, the satellite will augment current programs. Cost effectiveness and cost benefit studies have shown the advantages to be gained through surveillance satellites. They are summarized below.

7.2 Cost Effectiveness and Cost Benefit Studies

In a parallel study with the work of the task force (Ref. 3), cost effectiveness assessments were attempted for various

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* AES submission to the Task Force on Surveillance Satellites.

surveillance systems including satellites and aircraft. The study concluded that:

> It is not possible to make a complete cost effectiveness comparison of various remote sensing platforms such as satellites and aircraft. However, a partial comparison is possible on the assumption that the alternative platforms perform almost identical tasks. On this strictly limited basis, a satellite system can be compared with an aircraft surveillance system relative to
>
> a) simple detection and location of objects such as ships (no identification or courtroom evidence).
>
> b) monitoring of atmospheric and surface environmental factors such as winds, sea ice, and state of land vegetation.
>
> (Conclusion 27, Ref 3)

Satellite costs of a one satellite system (1 operational, 1 reserve) were derived from Table 7.1, and a 5-year life was assumed for each operational satellite. Total satellite data acquisition costs over a 15-year period were estimated at $263.5 million, or $17.6 million per year. The cost of operating 3 ground stations including data distribution adds $6 million per year, for a total of $23.6 million per year for a one-satellite system.

Aircraft costs are based on an assumed capital cost of $17.2 million per aircraft including side-looking airborne radar (SLAR), amortized on a straight line over 15 years. Operating costs of $2,241 per flying hour have been estimated for 1380 hours per year. This figure includes spares, repair and overhaul, fuel, flight crew, observers and equipment operator costs. Administrative overhead costs, hanger rental and other ground support facility costs (ramp charges, landing fees, etc.), make up 22.5% of the total operating cost. The study concluded that:

> Considering only Canada's arctic areas and coastal and ocean areas of responsibility, and using a comparison most favourable to aircraft, an operational surveillance system with a single satellite (including ground data handling) would provide almost 10 times as much areal coverage as an aircraft system having the same annual cost. The average annual cost of the satellite system would be about the same as that of a fleet of five long-range, SLAR-equipped aircraft. For the cost of one complete satellite coverage of the total area (3,776,000 square nautical miles), one could buy only three aircraft sorties (378,000 square nautical miles). (Conclusion 28, Ref. 3).

A detailed cost-benefit analysis was carried out for four major applications. The potential incremental gross economic benefits of improved environmental surveillance were computed as follows:

TABLE 7.2

Four Economic Applications, Potential Gross Benefits

$ million

	1976-80	1981-85	1986-90	1991-2000
Offshore Oil and Gas	109	349	808	* --
Fisheries	17	29	38	105
Ocean & coastal transport	210	337	589	1,090
Wheat production & export	500	500	500	2,000
	836	1,215	1,935	3,195

* Benefits have not been calculated beyond 1990 but are expected to decrease. According to scenarios presented in Ref. 2, the peak in offshore drilling activity will have passed by 1990. Increasing transportation benefits are included under ocean transport.

The potential gross benefits may be attributed to six surveillance systems as follows:

TABLE 7.3

Assignment of Four-Case Study Potential Gross Benefits

$ million

	1976-80	1981-85	1986-90	1991-2000
Industry Systems	21	70	161	--
Upgrade existing systems	149	299	467	849
Add Ocean Data Buoys	17	36	109	57
Add Operational Seasat (5 satellites)	-	-	707	1,325
Add Operational Landsat (2 satellites)	-	50	150	350
Add Operational Canadian Surveillance Satellite (1 satellite)	-	-	291	615
	187	455	1,885	3,196

This table is based on one of several alternative scenarios.

It should be noted that the total potential incremental gross benefits over the 25-year period are over $7 billion. However, it was estimated that the available six systems could achieve only $5,723 million of this amount.

The estimated costs to government for each of the sensor platforms are as follows:

TABLE 7.4

Incremental Costs of Sensor Platforms

$ million

	1976-80	1981-85	1986-90	1991-2000
Industry Systems	-	-	-	-
Upgrading Existing Systems	75	50	50	100
Canadian Ocean Data Buoys	8	10	12	25
Canadian Seasat Program	10	22	30	60
Canadian Landsat Program	-	5	5	10
Canadian Surveillance Satellite	-	180	40	80

Canada's minimal contributions to an operational Seasat system were assumed to be in ground receiving and data processing facilities, with costs of about $7 million per year from 1985 onward. Participation in the operational Landsat system will require an upgrading of the CCRS facilities, and a capability to handle the output from two satellites at an estimated incremental cost of about $1 million per annum. Cost for the Canadian Surveillance Satellite were derived from Table 7.1 data.

The cost effectiveness studies have shown that satellites are an order of magnitude cheaper than aircraft for the same area and frequency of coverage. In terms of benefits, over the period covered in the task force's terms of reference, 1980-2000, the computed benefit/cost ratio for a single Canadian surveillance satellite is 3:1, for the four selected economic applications. The program, however, also permits Canadian access to Seasat, and so, by adding benefits and costs of operational Seasat participation, the benefit/cost ratio for the two programs is about 7:1.

The figures reveal that satellites are of positive value for environmental surveillance for the four applications studied. Other applications such as ice routing or pollution counter-measures could add to the tangible benefits and improve the ratio further. In addition, the cost effectiveness of satellites for strategic wide-area coverage make them an attractive complement to the available aircraft fleet in the surveillance of human activity. The intangible benefits associated with sovereignty control amplify the value of satellites in the mix of platforms available to Canada for surveillance.

Aside from their direct contribution to the solution of Canada's surveillance problems, satellites can benefit Canadian industry. The following section deals with the industrial implications of a Canadian surveillance satellite program.

8. INDUSTRIAL IMPLICATIONS

Since the early 1960s, Canadian industry has been gaining experience in space technology and now has the capability of managing the design, development and construction phases of a complete satellite system including both space and ground sectors. The next section provides a summary of Canadian capabilities in manufacturing, testing and integrating satellite hardware. There follows an outline timetable of existing and future government space activities, along with their relationship to a possible Canadian surveillance satellite program. Particular attention is paid to the role such a program might play in levelling the industrial loading over the coming decade, in order to sustain a viable space industry in Canada.

8.1 Facilities and Capabilities

Canadian industry competence and experience exists in the following areas. The list is not complete, but gives a measure of overall capabilities.

- spacecraft structures
- thermal and attitude control
- deployable solar arrays
- other mechanical sub-systems
- optical and infrared sensor design and development
- spacecraft transponders
- space qualified power supplies
- space qualified electrical sub-systems
- antennas
- spacecraft communication sub-systems
- space qualified microwave components
- spacecraft software
- ground receiving stations
- ground data-handling systems
- signal and data processing systems

Several government departments also have relevant facilities and/or experience. The David Florida Laboratory of the Communications Research Centre, Department of Communications, has an environmental testing facility where spacecraft components may be tested in a thermal, vacuum and vibration environment similar to that encountered in space. The National Research Council has been heavily involved (with industry) in the design, development and fabrication of the Remote Manipulator System for the U.S. shuttle. The Canada Centre for Remote Sensing has extensive experience in sensor design and development and the acquisition, processing and interpretation of remotely-sensed data from satellites and aircraft. Other departments with experience acquiring and/or using remotely-sensed data include CDA, DFE, DND and DOT.

8.2 Present Government Space Programs

Figure 8.1 presents an outline of present Canadian government space hardware programs. Additional information on each is given below:

a) Communications Technology Satellite (CTS, now called Hermes)

- launched in January, 1976, future activity is related to experimental applications of the satellite.

b) International Aeronautical Satellite (Aerosat)

- Canada will own 6% of the space segment, in partnership with European Space Agency and Comsat General. Procurement of satellite subsystems within Canada will be in proportion to the Canadian share. Contracts will be issued in the fall of 1976. Two spacecraft will be launched: one in 1979, the other in 1980.

c) Telesat Dual-Band Satellite

- RCA Limited will be providing the Canadian content, the spacecraft to be delivered by the RCA parent company to Telesat Canada. Launch is planned for 1978.

d) Shuttle Remote Manipulator System (RMS Program)

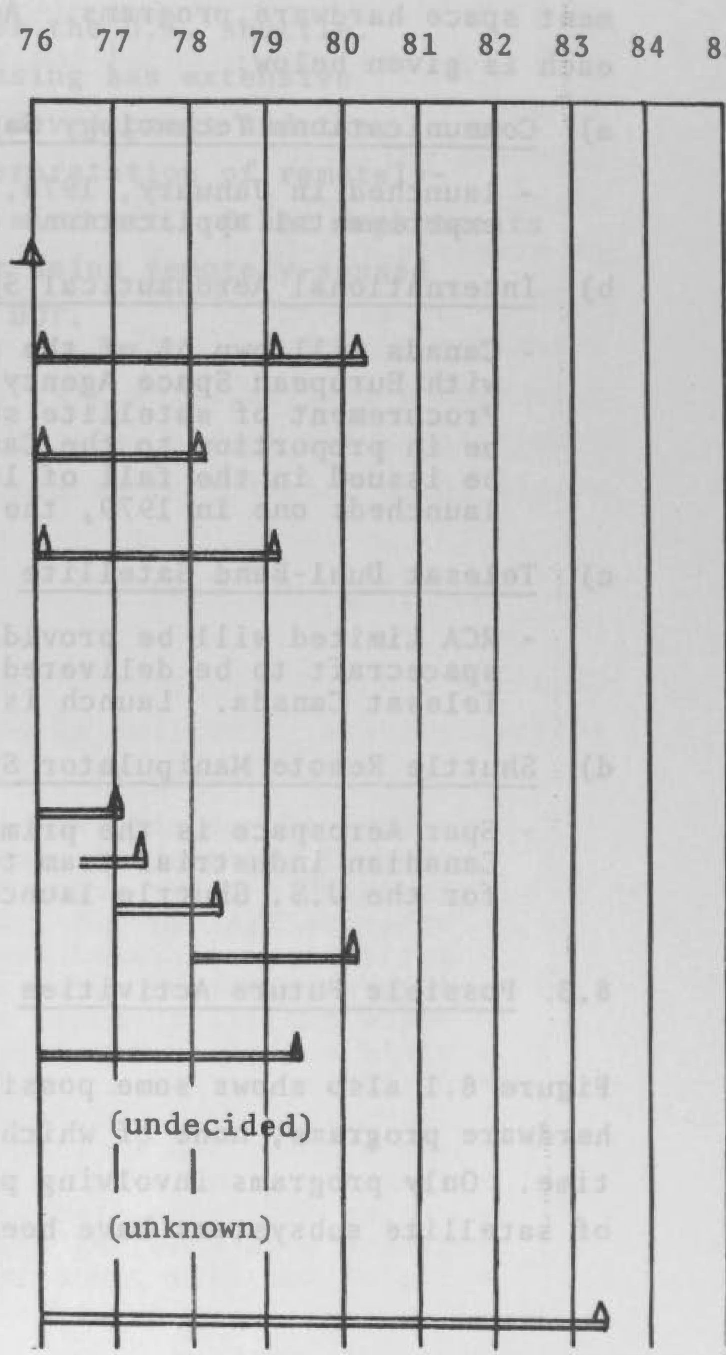
- Spar Aerospace is the prime contractor heading up a Canadian industrial team to provide a manipulator arm for the U.S. Shuttle launcher, to be delivered in 1979.

8.3 Possible Future Activities

Figure 8.1 also shows some possible future Canadian government hardware programs, none of which are approved at the present time. Only programs involving potential Canadian procurement of satellite subsystems have been included. They are:

FIGURE 8.1

CANADIAN GOVERNMENT SPACE PROGRAM SCHEDULE



Present Activities

a) Communications Technology Satellite - launch

b) Aerosat RFP - launch

c) Telesat Dual-Band Procurement - launch

d) Shuttle RMS Procurement - delivery

Possible Future Activities (Not approved)

a) Multipurpose UHF Satellite

Feasibility

Definition

System design & development

System implementation

b) Search and Rescue Satellite launch

c) Data Retransmission and Fisheries Surveillance Satellite

d) Inmarsat

e) Canadian Surveillance Satellite - launch

a) Multipurpose UHF Satellite (Musat)

An interdepartmental study group headed by DOC has been examining the feasibility of Musat - a system intended to meet specific Canadian government communication needs.

b) Search and Rescue Satellite (Sarsat)

This program has been the subject of continuing discussions between DND and NASA. An unsolicited proposal program now is being conducted by Canadian Astronautics Ltd.

c) Data Retransmission and Fisheries Surveillance Satellite (DOESAT)

This program originated as an unsolicited proposal from Canadian Astronautics Ltd. and is investigating data retransmission and fisheries surveillance requirements for DOE.

d) International Maritime Satellite (Inmarsat)

Resulting from a recommendation by a Panel of Experts established by the Intergovernmental Maritime Consultative Organization (IMCO), it is probable that Canada will participate in Inmarsat in both system management and hardware production.

e) Canadian Surveillance Satellite

- the subject of the present task force.

8.4 Possible Schedule for a Canadian Surveillance Satellite

Figure 8.2 shows a possible development scenario for a Canadian surveillance satellite. It should be regarded as preliminary, and is intended only to show how such a program could fit in to the present loading in Canadian industry. The program phases would be:

a) System Feasibility Study - intended to encompass the work of the present task force, and some following interdepartmental activity.

b) Program Definition Phase - to explore sensor capabilities in cooperation with other agencies, and to define a Canadian program in some detail. Canadian participation in Seasat-A likely would be a central activity of this phase.

c) Development Phase - intended to alleviate uncertainties identified during the Program Definition Phase, and would contain substantial hardware R and D in Canadian industry. Some sensor testing may be possible aboard a space laboratory to be carried by the Shuttle.

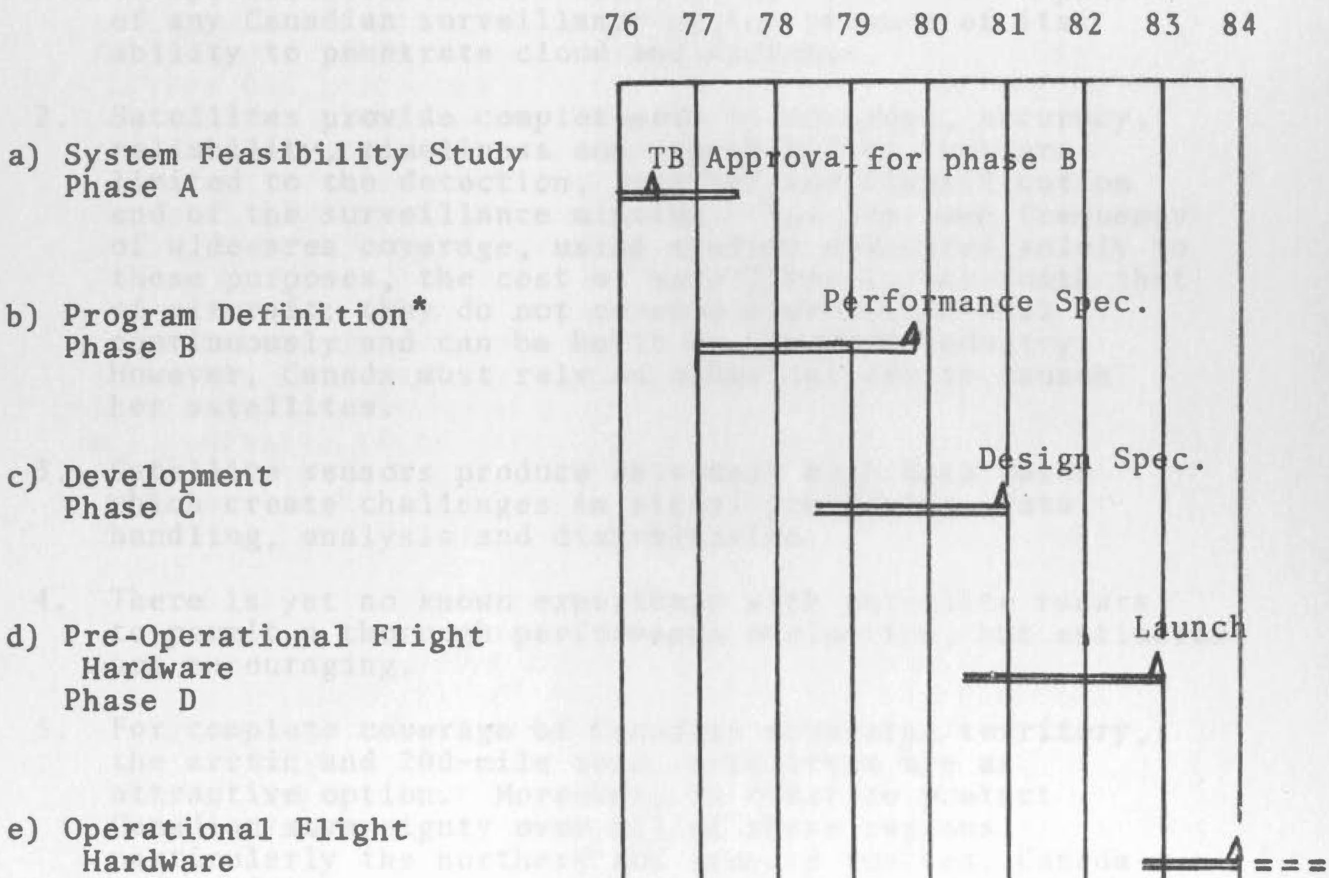
d) Pre-Operational Flight Hardware Phase - the first satellite would be launched in 1983. While serving a test role initially, it could become the first of an operational series if performance meets expectations.

A Canadian surveillance satellite program following the schedule shown in Figure 8.2 would complement existing programs in the sense that hardware expenditures would maintain industrial loading at a time when other approved programs are drawing to a close. Thus a surveillance satellite would appear to be compatible with current and potential future space programs. Moreover, such a program is in line with government policies on space, spacecraft procurement, oceans, and "make or buy".

FIGURE 8.2

CANADIAN SURVEILLANCE SATELLITE

POSSIBLE DEVELOPMENT SCENARIO



* Includes Seasat-A activities.

9. CONCLUSIONS

The conclusions listed below follow the sequence of the text. They are not placed in order of priority.

1. Satellites are complementary to aircraft and ships in the government's surveillance mission*, providing strategic information used to direct the other platforms to specific locations. Radar is an essential component of any Canadian surveillance system because of its ability to penetrate cloud and darkness.

2. Satellites provide completeness of coverage, accuracy, reliability, timeliness and repeatability, but are limited to the detection, location and classification end of the surveillance mission. For the same frequency of wide-area coverage, using systems dedicated solely to these purposes, the cost of satellites is one-tenth that of aircraft; they do not consume hydrocarbon fuel continuously and can be built by Canadian industry. However, Canada must rely on other nations to launch her satellites.

3. Satellite sensors produce extremely high data rates which create challenges in signal processing, data handling, analysis and dissemination.

4. There is yet no known experience with satellite radars to permit a thorough performance evaluation, but estimates are encouraging.

5. For complete coverage of Canadian sovereign territory, the arctic and 200-mile zone, satellites are an attractive option. Moreover, in order to protect Canadian sovereignty over all of these regions, particularly the northern and seaward reaches, Canada may be driven to the establishment of its own satellite program if other nations do likewise.

6. Surveillance requirements from DND, DOT, DINA, DEMR and DOE call for wide-area coverage of a broad range of human activities and environmental phenomena including ships, fishing fleets, offshore resource activity, lodgements and camps, pollution and dumping, siltation, ice and icebergs, meteorological parameters, distressed

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* For purposes of the task force study, surveillance is defined as the detection, location, classification, identification and inspection of human activities and environmental phenomena.

vessels, forestry and mapping. While minimum target sizes and required resolution for many of such applications exceed anticipated radar performance, locational accuracy, response time and frequency of coverage are compatible with satellite system capabilities in most cases.

7. It is expected that the synthetic aperture radar (SAR) as specified for the satellite will detect and locate a target as small as a ship 20 metres in length on calm seas, 50 metres on rough seas. While it is unlikely that the SAR will be able to distinguish small ships from icebergs, it should be possible to classify targets exceeding 200 metres in length such as drill rigs and aircraft carriers. The radar will provide complete coverage of the regions of interest twice in 5 days below 57°N, with increasing frequency between 57°N and 350 km below the pole for a single satellite; higher frequency requires more satellites.

8. It is not known how the ionosphere in the Canadian auroral zone will affect radar performance, and how the radar properties of the ocean surface (sea clutter) will reduce the ability to detect small targets. The answers will not be known until the U.S. orbits its radar - carrying Seasat-A over Canada after its 1978 launch.

9. Other sensors that should be on board a Canadian satellite are a multispectral scanner as a backup for the radar in clear weather and for environmental surveillance and mapping over the landmass, a scanning microwave multifrequency radiometer for measuring surface temperatures and ice mapping, and an ELT (electronic locator transmitter) transponder to meet search and rescue requirements.

10. Processing SAR data requires advanced techniques. A unique Canadian approach to the SAR processor design using digital methods will produce a marketable product capable of producing consistent, high-quality imagery superior to current optical technology being pursued by the U.S. The current design goal is to process SAR imagery at a factor of 8 longer than it takes to record the data.

11. The present evidence suggests that satellite surveillance is feasible for a substantial proportion of the applications specified by government departments. Firm proof of feasibility must await completion of the Seasat-A experiments and the related basic studies.

12. Surveillance satellites will accelerate the need for extensive wide-band communications linking ground stations, data processing centres, integration and filtering facilities, activity responsibility centres and users. Spectrum conservation and communication constraints will be major design conditions for any operational Canadian system.

13. Any international initiatives by Canada in surveillance satellites should take into account current Canadian usage of U.S. meteorological and resource satellites. However, international participation would reduce Canadian surveillance satellites costs, and should be encouraged. The most logical partner for Canada is the U.S., but other nations such as Japan or the European Space Agency (ESA) are possibilities. Concern has been expressed, however, about surveillance satellites examining other nations' territories and the problem is being studied by the U.N. Outer Space Committee.

14. No operational Canadian surveillance satellite program should be initiated until the radar on Seasat-A has been proven.

15. There are five Canadian surveillance satellite options:

    .1 An all-Canadian satellite without international participation,

    .2 A Canadian satellite with international participation,

    .3 Other nations' satellite program, influenced to meet Canadian requirements,

    .4 Purchase of surveillance satellite data from the U.S., and

    .5 No surveillance satellite activity.

16. There are three ways in which Canada could contribute to Seasat-A:

    .1 Modify Shoe Cove station in Newfoundland to receive Seasat-A data,

.2 Develop a digital SAR processor and

.3 Conduct verification experiments related to sovereignty control using Seasat-A data.

For the first three options, in Conclusion 15, Canada would participate in all three Seasat-A contributions in order to gain timely access to the data, an engineering knowledge of the radar and a capability to take the lead or participate in the design and development of an operational system. A Canadian SAR processor is not needed for the fourth option and, of course, no Canadian involvement is needed for the fifth.

17. Canada should make all three contributions to Seasat-A: modifications to Shoe Cove station; development of digital SAR processor; and verification experiments related to sovereignty control, at an estimated total cost of $4.1 million over 3 years.*

18. Simple access only to already-processed satellite SAR data purchased from the U.S. will not provide sufficient information to assess Canadian ionospheric effects and the ability to discern targets among the sea clutter.

19. For an operational system of 3 satellites in orbit and one in reserve, the capital costs are estimated at $260 million, with annual operating costs for ground stations (east coast, west coast and arctic) of approximately $7 million excluding the cost of replacing satellites in orbit; their life expectancy is five years. International participation should reduce capital costs significantly.

20. Separate cost effectiveness and cost-benefit studies show a positive case for employing surveillance satellites in Canada, provided radar operates as expected.

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* Seasat-A would cover part of the Canadian Arctic, and therefore, this course of action would be consistent with the statement issued by the Minister of Indian Affairs and Northern Development in January, 1976 entitled "Guidelines for Scientific Activities in Northern Canada", Item 14(c) which states "there should be Canadian scientific participation in any significant scientific investigation in the Canadian North".

21. Canadian industry has the capability of developing and building the surveillance satellite system, although some sensor technology would have to be licenced or purchased from the U.S. Such a program is compatible with current and planned space programs, and would tend to maintain industrial loading at a time when approved programs are drawing to a close.

22. A Canadian surveillance satellite program is consistent with the government's space, spacecraft procurement, oceans, make or buy and sovereignty control policies.

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1. "Concept Definition Study for a Remote Sensing Satellite Mission", Canadian Astronautics Ltd., a report prepared for CCRS, February 25, 1976.

2. "Preliminary Technology Assessment of Microwave Remote Sensing Satellite Systems Potential for Canada" (with Seasat as a Prototype), Donald J. Clough and A. K. McQuillan, a preliminary report to the Interagency Committee on Remote Sensing, June 6, 1975.

3. "Surveillance Satellites and Complementary Airborne and Seaborne Surveillance Systems for Canada" (A Technology Assessment), Donald J. Clough and A. K. McQuillan, CCRS, 10 August, 1976.

4. Panel on Ocean Management Overview Report, MOSST, July, 1976.

5. "Implications for Canada of Remote Sensing of the Earth by Satellite", Valerie Hood, Legal Operations Division, Department of External Affairs.

APPENDIX 1

COMPOSITION OF THE INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

COMPOSITION OF THE INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

The main task force proper consisted of the Chairman, a group of designated departmental "generalist" representatives and a group of technical experts. These persons are:

Chairman:

Dr. Philip A. Lapp, Consultant

Co-Ordinator:

Mr. A. M. Kelly, EMR (CCRS)

Generalist Members:

Capt. W. Dancer	DOT (CCG)
Mr. S. A. Kanik	DINA (Oil & Minerals Div.)
Mr. J. Koop	DND (DSTSP)
Dr. J. Kruus	DOE (Office of Science Advisor)
Mr. M. V. Patriarche	DOC (HQ Space Programs)
Mr. G. Rejhon	EA
Insp. L. A. Scherlowski	Sol. Gen. (RCMP)
Dr. M. E. Smith	MOSST

Technical Experts:

Dr. J. N. Barry	DOC (CRC)
Prof. D. J. Clough	Consultant
Dr. R. G. Langille	ICS Secretariat
Dr. A. K. McQuillan	EMR (CCRS)
Dr. D. F. Page	DOC (CRC)
Dr. E. Shaw	EMR (CCRS)

A number of other persons made significant contributions, attending some or all of the meetings as alternates or observers. They are:

Mr. P.R. Anderson	DND (DMOR)
Maj. S. K. Dewar	DND (DMA)
Mr. K. R. Greenaway	DINA (Corporate Policy Group)
Dr. E. M. Hassan	MOSST
Mr. J. C. Henein	EMR (CCRS)
Mr. J. A. D. Holbrook	TBS (Programs Branch)
Mr. D. A. Karsgaard	EA
Mr. D. A. McKinnon	DND (CRAD/DTG)
Dr. L. W. Morley	EMR (CCRS)
Mr. D. Smith	DINA (Oil and Minerals Div.)
Dr. R. A. Stacey	DOE (OAS)
Mr. J. Stewart	DOT (CCG)
Mr. R. Thomas	Sol. Gen. (RCMP)

As mentioned in the narrative, five sub-committees were formed to report on various aspects of the work. Because of the need for certain specialized expertise, some persons who were not members of the task force served on sub-committees. The sub-committees and their membership were:

Surveillance Requirements

Mr. A. M. Kelly	EMR (CCRS) (Chairman)
Capt. W. Dancer	DOT (CCG)
Mr. S. A. Kanik	DINA (Oil and Minerals Div.)
Mr. J. Koop	DND (DSTSP)
Dr. J. Kruus	DOE (Office of the Science Advisor)

Satellite and Sensor Capabilities

Dr. E. Shaw	EMR (CCRS) (Chairman)
Dr. S. Ahmed	DOC (CRC)
Mr. R. Gray	DOC (CRC)
Mr. G. Haslam	DOC (CRC)
Dr. D. Page	DOC (CRC)
Mr. V. Werle	DOC (CRC)
Dr. B. Young	DND (DREO

Research and Development Requirements

Dr. D.F. Page	DOC (CRC) (Chairman)
All those stated under Satellite and Sensor Capabilities	

Cost Effectiveness Study

Professor Donald J. Clough	Consultant (Chairman)
Dr. A.K. McQuillan	EMR (CCRS)

International Implications

Dr. R.C. Langille	ICS Secretariat (Chairman)
Mr. M.V. Patriarche	DOC (HQ. Space Group)

The following persons, listed by department, prepared and presented technical or operational briefings to the task force. Their contributions are gratefully acknowledged. Special acknowledgements are made for the contribution of Vice-Admiral Boyle and his staff at Maritime Command, Mr. K. Curran and the staff of Regional Headquarters of the Canadian Coast Guard and Mr. J. McCulloch and his staff of the Regional Office of Atmospheric and Environment Services, Department of the Environment, all of Halifax, N.S.

<u>DINA</u>

Mr. G. Campbell	(Oil and Minerals Division)
Mr. F. Joyce	(Oil and Minerals Division)

<u>DND</u>

Vice-Admiral D. Boyle and Staff	MARCOM
Maj. G. Caffrey	DLP
Maj. S. K. Dewar	DMA
Maj. R. L. Jones	DMETOC
Maj. W. Leslie	DAOT
Lt. Col. J. L. McDougall	DCARTO
Col. L. Skaalen and Staff	DMA

<u>DOE</u>

Ms. M. Adams	EPS
Dr. J. Clodman	AES
Mr. W. F. Ganong	AES
Mr. S. Hart	EPS
Mr. J. McCulloch and Staff	AES
Dr. M. Mercer	FMS
Mr. D. S. Puccini	FMS

DOT

Mr. N. Conroy	CCG
Mr. K. Curran and Staff	CCG
Capt. W. Stewart	CCG
Mr. B. Tepper	CCG

EMR

Mr. M. Bell	RMCB
Mr. G. Hobson	PCSP

ANNEX

The terms of reference for the task force were drawn up at a preliminary meeting of departmental representatives held on April 23, 1976. Present at that meeting were:

Dr. J. D. Keys	ADM (S&T) EMR Chairman
Mr. G. H. Booth	DOC (HQ Space Program)
Prof. D. J. Clough	Consultant, EMR (CCRS)
Mr. K. R. Greenaway	DINA (HQ)
Mr. J. A. D. Holbrook	TBS (Program Planning)
Mr. F. J. Joyce	DINA (NNRE)
Mr. A. M. Kelly	EMR (Planning & Evaluation)
Mr. J. Koop	DND (Policy Planning)
Dr. J. Kruus	DOE (Office of the Science Advisor)
Dr. P. A. Lapp	Consultant, EMR (CCRS)
Dr. D. I. R. Low	MOSST
Mr. D. McKinnon	DND (CRAD/DTG)
Dr. L. W. Morley	EMR (CCRS)
Dr. D. F. Page	DOC (CRC)
Mr. R. A. Quail	DOT (CCG)
Dr. E. Shaw	EMR (CCRS)
Col. L. Skaalen	DND (DCDS/CAO/DMA)
Dr. M. E. Smith	MOSST
Dr. R. A. Stacey	DOE (OAS)
Mr. J. Stewart	DOT (CCG)
Mr. M. A. Turner	DOT (CCG)

APPENDIX 2

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

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SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.N.D.	Support to civil agencies	Search and Rescue	1. Detection, location and estimated status of any vehicle and/or crew in distress, including lifeboats and rafts.
DND (Cont'd)		Regulatory and enforcement support (Fisheries and pollution surveillance)	2. Detection, location, classification and identification of all ships in waters of Canadian jurisdiction. Determination of: course and speed, current activity; description and status of on-deck cargo and equipment(s) especially oil and mineral exploration/extraction equipment.
			3. Detection, location and source of pollutants.
	All sea activities	All sea borne missions	4. Current and forecast sea state, air and sea surface temperatures, wind speed and direction, air pressure, visibility cloud cover and types.
			5. Current and forecast ice information: extent and type, location and dimensions of leads, polynias and potential routes in arctic and Atlantic transportation areas, including Gulf of St. Lawrence and Hudson Bay.

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENTS
DND (Cont'd)	Maintenance of Arctic Sovereignty	Arctic Surveillance	6. Position and size of lodgements, base camps and drift stations; identification of man-made structures, vehicles, aircraft on the ground or ice and estimates of activity (ies)
	Support to Civil Agencies	Surveillance of on-land or on-ice exploration activities.	7. Position, size of area, identification of structures, equipment, air-craft and vehicles and estimate of activity of oil and gas or mineral exploration parties.

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
DND (Cont'd)			
	All	All	8. Cartographic quality imagery of Canadian territory, particularly arctic and coastal regions.
D.O.T.	Marine Transportation Facilities	Maintenance of navigation aids	1. Detect and locate navigation buoys Position of inshore, river and harbour buoys required to high precision; offshore buoys require lower precision. Buoys are 4 m. diameter steel bylinders, surmounted by 4 m angle iron framework. Some carry radar reflectors

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.O.T. (Cont'd)			2. Check functioning of lights and sound signals on navigation buoys.
		Maintenance of waterways and channels.	3. Determine the horizontal and vertical extent and growth rates of siltation which might endanger or restrict marine traffic in all Canadian waters.
	Support to marine transportation	Ice breaking (tactical).	4. Determine the extent and type of ice coverage; movement of ice; ice growth; ice pressure (rafting, ridging and hummocking); amount of snow cover; extent of puddling within floes; location and dimensions of open water leads in all ice-infested Canadian waters.
		Ice breaking (strategic)	5. Information as in (4), together with such weather, tidal and current information as to enable forecasts of ice conditions from 10 to 30 days in advance, for voyage planning purposes.

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SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.O.T. (Cont'd)	Marine Safety	Development and enforcement of regulations for design, building and loading of ships.	6. Statistical data on: ice coverage type, thickness and movement; weather, especially windspeeds and directions, wave heights, lengths and directions.
		Marine Search and Rescue (SAR)	7. Detection and location of incidents requiring SAR operations, location and identification of other shipping which might render assistance; ice, sea state and weather conditions in and forecasts for the area concerned.
	Protection of the marine environment.	Pollution control and clean-up.	8. Detection, location and identification of ocean pollution (usually oil).
			9. Identification of source of pollutant.
			10. Current and forecast weather, sea state sea temperature, air temperature and ocean current conditions in the areas.
			(Nos. 11-19 inclusive apply to all waters in Canadian jurisdiction).

APPENDIX 2 (Page 6 of 10)

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.O.T. (Cont'd)	Marine Transportation	Vessel Traffic Management	11. Detection, location, identification and determination of course and speed of all ships.
			12. Position of all offshore drilling platforms and work boats.
			13. Position of experimental, data gathering, mooring and other buoys.
			14. Locations of fishing fleets.
			15. Location and drift of icebergs and growlers.
			16. Current information on extent and type of ice coverage, leads, etc.
			17. Location and extent of fog banks.
			18. Position and drift of any object posing a hazard to marine transportation.
			19. Current and forecast weather and sea state conditions.
	Public safety and support to marine transportation.	Flood control	20. Extent of ice cover, areas of flowing ice, location of ice jams on all navigable rivers in Canada.

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SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.I.N.A.	Management of non-renewable resources in Canada Lands north of 60^{o} North.	Regulation of oil and gas exploration and development.	1. Location, classification, identification course, speed and activity of research and survey vessels operating in Canadian waters north of 60^{o}N. 2. Location, classification, identification and activity of all offshore drilling platforms and ships. If drilling, position needed to high accuracy. If in motion, course and speed required. 3. Detect and locate seismic survey parties operating on ice. 4. Detect, locate and identify seismic survey lines cut through trees or brush by survey party. 5. Current information on extent and type of ice floes, location and dimensions of leads in ice greater than 5 m wide, location, size, direction and speed of drift of icebergs.

APPENDIX 2 (Page 8 of 10)

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.I.N.A. (Cont'd)		Pollution control	6. Detect, classify and locate oil slicks larger than 200 x 300 m, flotsam larger than 5 x 5 m and turbidity variations (water discoloration) in ocean waters north of 60^{o}N.
	Management of forest resources in NWT and YT.	Forest inventory	7. Location, composition, species, areas and volumes of forest stands.
		Forest fire management	8. Location and sizes of fires; estimate of unburned fuel; estimate of losses.
E.M.R.	Management of offshore non-renewable resources south of 60^{o}N and in Hudson Bay.	Regulation of oil and gas exploration and development.	1. Detect, classify, identify, locate and determine activity of all research and survey vessels, giving course and speed.
			2. Detect, identify, locate and determine activity of all drilling platforms and ships. If in motion, determine course and speed.
			3. Detect, locate, classify, identify and determine activity of all ships in the area of drilling or production rigs.
			4. Provide current and forecast information on weather, ice and sea state conditions up to 400 km. offshore east coast, 250 km offshore west coast for areas south of 60^{o}N and Hudson Bay.

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.O.E.			NOTE: Most, if not all, of the DOE requirements are such that satellite data would be complementary to prime requirements. See text for further explanation.
	Provision of Environmental Services	Preparation and dissemination of weather and sea state reports and forecasts.	1. Direct or indirect measures of: air temperature, pressure and humidity; wind speed, direction and fluctuations; visibility; cloud type, intensity and duration; wave heights and lengths; sea current direction and speed. Data required on global, hemispheric and regional bases.
		Preparation and dissemination of ice reports and forecasts.	2. Data on extent of ice coverage; type, age and thickness of ice; distribution and height of ridges; snow cover on ice; location and dimensions of leads and polynias, location and drift of icebergs, bergy bits and growlers. These data are required for all Canadian waters, including the Great Lakes, St. Lawrence Seaway and Gulf of St. Lawrence.

SURVEILLANCE REQUIREMENTS BY DEPARTMENTAL FUNCTIONS & MISSIONS

DEPARTMENT	FUNCTION	MISSION	REQUIREMENT
D.O.E. (Cont'd)		Collection, archiving, and dissemination of climatic and oceanographic data.	3. Wave climate data; surface and sub surface current data; sea-surface temperature distributions; ice climate data.
	Protection of the Marine Environment	Promulgation and enforcement of regulations under the Ocean Dumping Act and various Fisheries Acts	4. Data suitable for detecting catastrophic or subtle long-term environmental effects of ocean dumping, exploration drilling and other human activities in the oceans or the arctic.
	Fisheries Management	Stock Assessment	5. Meteorological and oceanographic data suitable for the prediction of the quantity, distribution and growth rates of fish stocks in waters under Canadian jurisdiction (up to 200 n.m. offshore).
		Surveillance of fishing operations	6. Detection, identification, location and distribution of fishing activity in waters under Canadian jurisdiction (up to 200 n.m. offshore).
	International Ocean Management	Monitoring of scientific activity within waters under Canadain jurisdiction	7. Detection and identification of vessels and activities related to gathering of data and other scientific activities in waters under Canadian jurisdiction.

APPENDIX 3

CENSUS OF SURVEILLANCE REQUIREMENTS

BY

TARGETS AND/OR DATA REQUIRED

1980 - 2000

(Supporting data for Table 4.1)

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

1. APPLICATION(S): Marine Transportation, Fisheries Surveillance

DEPARTMENT(S): DOT, DOE, DND

INFORMATION REQUIRED:

Locations and deployment of fishing fleets.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Clusters of ships, ranging in size from 10 m up to 30-50 m, concentrated on known fishing grounds.

CHARACTERISTICS OF TARGET(S):

Many vessels carry radar reflectors; larger vessels (20m) are usually steel, smaller vessels often wood or fibreglass. Vessels often found in clusters of 30 or more over relatively small (1-1000 km^2) areas.

ACCURACY(IES) REQUIRED:

Location of centroid of fleet to 2-4 km.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Primary areas are known fishing grounds off both coasts.

FREQUENCY OF OBSERVATION NEEDED:

Daily or better

RESPONSE TIME REQUIRED:

4 - 6 hours

DATA FORMAT(S):

Photographic images, telex

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

COMMENTS:

Locations of fishing fleets are usually well known from DND, DOE and DOT patrol vessels and flights, as well as other surveillance methods. Areas of interest are often fog-covered, with visibility of less than 30 m, 5 days out of 7. Daily or more frequent all-weather radar imagery would provide useful strategic pictures of fishing fleet deployment.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

2. APPLICATION(S): Management of offshore non-renewable resources.

DEPARTMENT(S): DINA, EMR

INFORMATION REQUIRED:

Disposition, identification and activity of all drilling platforms, work boats, drilling ships, seismic survey vessels and other research or survey ships.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Need location, identification, course and speed of all targets, as well as estimate of activity. Drilling platforms are large (100 m + on a side) usually triangular platforms; drilling ships are 100 m long or larger; both have unique super-structures. Other craft often have unique super-structure features.

CHARACTERISTICS OF TARGET(S):

Most targets will be cooperative and would carry appropriate devices for identification if desired. Their characteristics are such that detection and classification should not present a problem for drilling platforms and ships (e.g. large angle-iron drilling towers). Speeds will usually be slow for working survey vessels or platforms under tow.

ACCURACY(IES) REQUIRED:

Locations needed to 50 meters for drilling sites; these may be with reference to known landmarks. For survey vessels performing a survey, position needed to 100 m. For vessels/platforms in transit, 2-4 km is adequate.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Sea waters inside edge of continental margin north of 60°N (DINA) and between 40° and 60° off east coast, between 49°N and 60°N off west coast, together with all of Hudson Bay (EMR).

FREQUENCY OF OBSERVATION NEEDED:

Maximum frequency of 4 observations per day, but once daily is acceptable.

RESPONSE TIME REQUIRED:

6 to 12 hours

DATA FORMAT(S):

Many acceptable formats, including telex, photographic images, computer-compatible format, maps, etc.

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Working locations of some survey vessels may be classified information, but not secret.

COMMENTS:

Frequent on-site inspections are made by government personnel. The purpose of this requirement is to provide more frequent information of a strategic nature on the deployment and activities of resource exploration/exploitation vessels, as well as to detect unauthorized activities or vessels.

In addition to these data, weather, sea state and ice information is needed for government agencies and industrial operators, on demand. (See appropriate requirements sheet)

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

3. APPLICATION(S): Management of non-renewable resources; arctic sovereignty.

DEPARTMENT(S): DINA, DND

INFORMATION REQUIRED:

Location, size, identification and description of seismic lines cut on land, exploration or survey parties on land or ice, lodgements and base camps on land or ice, drift stations on ice islands.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Seismic lines are clearings through trees or brush, up to 10 m wide by several km long. During survey work, there will be men and machinery in the cuts. Seismic crews on ice consist of about 15 vehicles spread out on a column. Other targets consist of clearings in treed or brush-covered areas or on snow or ice, new roads or trails in unpopulated areas, clusters of small buildings or tents, trails, vehicles and equipment, aircraft and aircraft runways.

CHARACTERISTICS OF TARGET(S):

Machinery and vehicles used by seismic crews are bulldozers, metal trailers with large rectangular bodies, trucks with cylindrical tanks 3 m dia. x 5 m long. Vehicle sizes range from 3x4 m to 5x15 m, usually strung out in columnar formation. Targets for other requirements are as stated, with sizes from one metre up to some tens of metres for large aircraft. A wide range of metallic and non-metallic materials is employed.

ACCURACY(IES) REQUIRED:

Locations required to 100 metres for survey crews; for military requirements 2-4 km is adequate.

Temperatures to $2^{o}C$ for detection; $0.25^{o}C$ for identification.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Canadian landmass and island North of $60^{o}N$ plus territorial ice-covered waters.

FREQUENCY OF OBSERVATION NEEDED:

Daily

RESPONSE TIME REQUIRED:

12 hours

DATA FORMAT(S):

Video tape, photographic imagery, maps, telex

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Targets of particular military interest may require security classification.

COMMENTS:

The targets of prime interest are small groups of men working at or near small, often rudimentary camps. They will have a variety of shelters, vehicles (often including aircraft, both rotary and fixed wing) communication facilities and other equipment.

Legitimate resource exploration parties are expected to be co-operative and, if requested, would carry electronic or other identification devices. Drift stations on ice islands, set up for scientific purposes, tend to be of a more substantial nature and operate for months at a time.

It is desirable also to check for pollution, ecological damage and/or excessive erosion caused by these activities.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

4. APPLICATION(S):

Pollution Control

DEPARTMENT(S):

DOT, DOE, DND, DINA, EMR

INFORMATION REQUIRED:

Type, location, drift and source of ocean pollution.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Oil slicks, turbidity variations or water discoloration of approximately 200 m diameter or larger. Data required are type, location, rate and direction of drift, identification of source of pollutant.

CHARACTERISTICS OF TARGET(S):

Discoloration of water, variations in turbidity and smoothing effect of oil on water.

ACCURACY(IES) REQUIRED:

Location of centroid of pollution to about 1 km.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All waters under Canadian jurisdiction. (DINA - waters N of 60^{O}N; EMR - waters S of 60^{O}N; other departments - all areas).

FREQUENCY OF OBSERVATION NEEDED:

For detection - Daily
For tracking - Continuous

RESPONSE TIME REQUIRED:

6 hours maximum

DATA FORMAT(S):

Telex, telephone, photographic imagery, etc.

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

COMMENTS:

Most major spills are reported quickly to the responsible authorities. For minor spills (pumping of bilges, etc.) the difficulty lies in obtaining adequate evidence to detect and successfully prosecute the offender. Tracking is not a problem in inshore southern areas.

The main surveillance problem for which a satellite might be suitable is detecting and tracking oil spills in the Arctic and remote ocean areas.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

5. APPLICATION(S): Marine transportation/pollution control

DEPARTMENT(S): DOT, DINA, DOE

INFORMATION REQUIRED:

Location and nature of flotsam which poses a navigational hazard or constitutes pollution.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Targets are man-made objects such as oil drums, large tanks, containers and other debris, plus icebergs, bergy bits and growlers; the sizes of interest are from 1-2 metres up to 10 metres or larger. Data required are location, rate of drift and classification and/or identification.

CHARACTERISTICS OF TARGET(S):

Some of these targets (e.g. oil drums or tanks, containers) are metallic and of such a shape as to possibly provide good radar targets. Others, such as hatch covers, large logs ("dead heads"), small boats, will be difficult to detect.

ACCURACY(IES) REQUIRED:

Location accuracy to 500 m.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All navigable waters under Canadian jurisdiction.

FREQUENCY OF OBSERVATION NEEDED:

Daily

RESPONSE TIME REQUIRED:

4 - 6 hours

DATA FORMAT(S):

Teletype, telephone or other normal format

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Nil

COMMENTS:

See requirement sheet for ice information(No.13) There is an international ice patrol which performs surveillance for icebergs, bergy bits and growlers in North Atlantic shipping lanes.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

6. APPLICATION(S):

Vessel Traffic Management;
DND support to civilian agencies,
fisheries surveillance,monitoring
activities of research vessels.

DEPARTMENT(S): DOT, DND, DOE

INFORMATION REQUIRED:

Identification, location, course, speed of all shipping.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Ships of all types, ranging from small trawlers about 20 m long to Very Large Crude Carriers, over 200 m long. Size and shape of vessel and configuration of superstructure and on-deck equipment or cargo can be used for classification. Small features (0.1m) usually needed for identification.

CHARACTERISTICS OF TARGET(S):

Most vessels are of steel or have steel structures on deck. There are many flat surfaces, joined at various angles - these make good radar reflectors. Parts of ships will have temperatures 2°C or more above water surface temperature. Wakes are an indication of course. Co-operative vessels would carry electronic identification devices.

ACCURACY(IES) REQUIRED:

Location: 2-4 km
Temperature: 2°C

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Sector to north pole bounded by 200 mile limit or edge of Continental Shelf, whichever is furthest to sea.

FREQUENCY OF OBSERVATION NEEDED:

DOE: Daily
DOT: 4 hours; DND: 12 hours

NOTE: A ship travelling at 20 kt. will pass through the 200 mile zone in 10 hours by the shortest route. Vessels in high density inshore areas and those of special military interest require continuous surveillance.

RESPONSE TIME REQUIRED:

DOT: Immediate to 4 hours
DND: 1 to 12 hours
DOE: 12 hours

DATA FORMAT(S):

Video tape, photographic film, teletype

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Classification and/or identification of some ships may require security classification.

COMMENTS:

Present and proposed Vessel Traffic Management System is based on voluntary reporting by radio at 24 hours out, mandatory reporting at 12 mile limit. A high (98%) compliance rate is expected.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

7. APPLICATION(S): Marine transportation

DEPARTMENT(S): DOT

INFORMATION REQUIRED:

1. Geographical position of floating navigation aids.

2. Whether lights and/or sound systems are functioning.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Targets are steel cylinders of 4 m diameter surmounted by a 4 m angle iron framework which carries a lamp and in many cases a standard aluminum 0.5 m radar reflector. In high traffic density areas such as the St. Lawrence River, there are very many buoys and verification of their position to very high accuracy (1 m) is required. Offshore buoys, with some special exemptions, need only be located to an accuracy of about 50 m.

CHARACTERISTICS OF TARGET(S):

At present there are over one hundred offshore buoys, located from 7 to 20 n.m. offshore. They could be equipped with appropriate radar reflectors. About 15 a year go adrift. If this condition is detected within 48 to 72 hours, they can easily be recovered by ship. (At present, they are checked quarterly). These buoys are worth about 10 to 15 thousand dollars each.

ACCURACY(IES) REQUIRED:

Location: Inshore buoys 1 m
Offshore buoys 50 m in most cases

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All navigable waters under Canadian jurisdiction, to about 20 n.m. offshore.

FREQUENCY OF OBSERVATION NEEDED:

48 to 72 hours for offshore buoys; at least every 3 hours for inshore buoys (including St. Lawrence River and similar areas).

RESPONSE TIME REQUIRED:

3 Hours

DATA FORMAT(S):

Teletype message to appropriate VTM centre or Operations Centre.

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Nil

COMMENTS:

At present, the positioning of many inshore buoys is monitored by radar. DOT is investigating, with DOC, a positive "off position/malfunction" detection system using a UHF communications satellite.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

8. APPLICATION(S): Marine transportation and facilities

DEPARTMENT(S): DOT

INFORMATION REQUIRED:

The extent, nature and cause of siltation which may endanger or restrict the flow of marine traffic or be a factor in decisions on port or waterway development.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

The horizontal and vertical extent and the horizontal and vertical growth rates of siltation are required. This is a strategic requirement for historical data for planning port and waterway developments, especially in remote areas, as well as a tactical requirement for maintenance of existing ports and waterways.

CHARACTERISTICS OF TARGET(S):

The plumes from siltation sources are often readily visible in satellite imagery. In shallow water, the growth of siltation may itself be detectable.

ACCURACY(IES) REQUIRED:

For strategic purposes, knowing the shape of silt beds or plumes to some tens of metres should suffice. For tactical purposes, accuracies of 2 m (horizontal) and 0.3 m (vertical) are required.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All navigable or potentially navigable Canadian waters.

FREQUENCY OF OBSERVATION NEEDED:

Daily (tactical)
Monthly (strategic)

RESPONSE TIME REQUIRED:

N/A

DATA FORMAT(S):

Standard Photographic Images

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Nil

COMMENTS:

The present practice is to obtain periodic aerial photographs (including IR) of critical areas. The main objective of this requirement is to obtain adequate geographic coverage for planning new ports and waterways and general "time series" data for existing ports and waterways. Periodic large area coverage, as obtained by satellite, is very useful. An example of such an application is tracing plumes from dredging work.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

9. APPLICATION(S): All marine operations, including airborne services.

DEPARTMENTS: DOT, DND, DINA, DOE, EMR

INFORMATION REQUIRED:

Weather and sea state, both actual and forecast.

The standard format is unsuitable for recording these requirements, as will be seen below.

All departments indicated the need for weather and sea state information for all ocean activities. These data are normally provided by DOE (Atmospheric Environment Service). There is a large variety of measurable parameters, many of which are correlated, so that many possible substitutions exist between input data.

Generally speaking, users of weather and sea state data need to know some or all of the following parameters, both current and forecast:

Air temperature
Air pressure
Air humidity
Wind direction and speed; fluctuations
Visibility
Cloud type and extent
Precipitation type, intensity and duration
Wave heights
Wave lengths
Sea current direction and speed

Other data required by specific users include sea temperatures (both surface and sub-surface) upper atmosphere pressures and wind speeds, etc.

AES requirements differ from operational end-users in as much as there are a wide variety of data which can be used and there are, as mentioned above, very few unique sets. The large numerical forecasting models being used or developed require as input quantitative measures of temperature, pressure and water content of the atmosphere, wind velocity profiles and other data on a global or hemispheric basis, using three-dimensional grids with spacings from 100 to 500 km. From these data, general forecasts for periods ranging from 12 to 96 hours are produced.

These large-area forecasts are then used by regional centers and combined with local knowledge, more recent observations and qualitative data to produce shorter-term more detailed regional forecasts.

At the national level, there are currently more data available (from both national and international sources) than can be effectively used within budgetary and manpower constraints. Some additional data, such as measures of surface wind velocities, especially in areas of current sparse coverage, such as the North Pacific, would, however, be useful.

At the regional level, additional data on sea state and wind and temperature distribution at sea would be very useful.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

10 . APPLICATION(S): Marine transportation, resource development and exploitation

DEPARTMENT(S): DOT, DOE, DND, DINA, EMR

INFORMATION REQUIRED:

Ice reports and forecasts

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

- Extent of ice coverage
- Type, age and thickness of ice
- Distribution and height of ridges
- Snow cover (Eastern seaboard, Gulf of St. Lawrence, Great Lakes and St. Lawrence Seaway only)
- Location, extent and size of leads
- Location and drift of icebergs, bergy bits and growlers
- Location and size of polynias

CHARACTERISTICS OF TARGET(S):

"Icebergs", "Bergy Bits: and "Growlers" refer to sizes of free-floating masses of ice. Icebergs and bergy bits are large enough to have considerable size above water; growlers are usually awash or nearly so.
For navigation purposes, need to distinguish between "first-year" and "multi-year" ice. Knowledge of snow cover, especially wet snow, important for navigation.

ACCURACY(IES) REQUIRED:

Planning: 10 - 20 km.
Strategic: 500 m
Tactical: 500 m

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Canadian Arctic;
Labrador Sea North of 55°N; Gulf of St. Lawrence and Eastern Seaboard (including Newfoundland waters); Great Lakes and St. Lawrence Seaway; Grand Banks and eastern approaches.

FREQUENCY OF OBSERVATION NEEDED:

(see comments)
Planning - twice weekly
Planning and strategic - Daily
Tactical - continuous surveillance in area within immediate range of ship.

RESPONSE TIME REQUIRED:

Strategic: 6 to 24 hours
Tactical: Immediate

DATA FORMAT(S):

- Photographic imagery or charts for ice coverage
- Telex, imagery, other means for icebergs, bergy bits and growlers.

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

It is frequently desirable to send ice information via pictorial methods direct to vessels and other users.

COMMENTS:

There are three distinct requirements for ice information:

1. Planning information. This is required for pre-season planning of ship utilization, marine insurance, hull design, regulatory policy design, etc. Data are of a statistical and time series nature, derived from the strategic data base.

2. Strategic: required for short-term planning for voyages and ice forecasting. Daily coverage is required in all areas. These data are not now available with adequate geographic coverage or frequency.

3. Tactical: this information is in support of a single ship of group of ships travelling together. It is only required within the immediate area of the ship (say 20 km) and is required with minimum delay on a continuous or nearly continuous basis.

Note that wind shifts can cause very rapid movements of ice floes, causing extreme hazard to ships trapped between floes or between ice and shore. Weather forecasts and tactical surveillance are very important in such cases.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

11. APPLICATION(S): Flood control

DEPARTMENT(S):

DOT

INFORMATION REQUIRED:

Ice coverage and form on rivers, especially the St. Lawrence River.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Extent of ice coverage, ice movement and ice jams on rivers where flood control is desirable, especially the St. Lawrence River.

CHARACTERISTICS OF TARGET(S):

N/A

ACCURACY(IES) REQUIRED:

Location of actual or potential ice jams to 10 meters

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All major rivers

FREQUENCY OF OBSERVATION NEEDED:

Continuous in major industrial/urban areas, but see comment.

RESPONSE TIME REQUIRED:

4 hours maximum

DATA FORMAT(S):

Unspecified

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Nil

COMMENTS:

In major industrial or urban areas or along major waterways such as the St. Lawrence Seaway, almost continuous coverage is required at certain times, such as the spring break-up.

At present surveillance of such areas is done from aircraft or from land-based observers.

In the 1985-2000 time frame, there may be a similar requirement for remote areas (Hudson Bay, Baffin Island) where satellite surveillance may be the most cost-effective way of obtaining the data.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

12. APPLICATION(S): Search and Rescue

DEPARTMENT(S): DOT, DND

INFORMATION REQUIRED:

1. Position and status of any vehicle and/or crew in distress, including lifeboats and rafts.
2. Identification of shipping or other activity in the area which may render assistance.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

1. Vessels of 20-30 metres or larger, dead in water, listing severely or on fire.
2. Clusters of, or isolated single lifeboats or life rafts in relatively isolated locations. These are small (3 m or larger) targets.
3. Downed aircraft.

CHARACTERISTICS OF TARGET(S):

1. Lifeboats and life rafts are often made of materials which radar does not "see", such as fibreglass, wood, rubber, etc.
2. Vehicles in distress, lifeboats, life rafts may be equipped with electronic devices (such as emergency locator transmitters) which emit distress signals.
3. Radar reflectors could be carried.

ACCURACY(IES) REQUIRED:

Location: 20 km for detection; 3 km for identification
Spatial resolution: 2 m (physical size, but note possible use of radar reflectors)
Temperature: 2^{o} (detection); $0.25^{o}C$ (Identification)

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Sector to North Pole from $30^{o}W$ to $141^{o}W$ at $40^{o}N$ off east coast and $49^{o}N$ off west coast.

FREQUENCY OF OBSERVATION NEEDED:

12 to 24 hours acceptable. Once a vessel or crew in distress has been identified, hourly to continuous coverage is desirable until rescue vehicle arrives on the scene.

RESPONSE TIME REQUIRED:

As soon as possible but not more than 6 hours.

DATA FORMAT(S):

- Direct communication (telex, telephone) of alarm signal to appropriate Rescue Co-ordination Centre.
- Video tape and/or standard photo images.

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Speed in detecting distress condition and locating the incident is important.

COMMENTS:

Preliminary feasibility studies for SARSAT[(1)] indicate that an ELT transponder satellite would be very useful for search and rescue. The SARSAT function could be combined with the other functions of a surveillance satellite, as the orbital parameters and timing are compatible. DOT is conducting feasibility studies on fitting ships with ELT's. The cost of these devices is such that lifeboats and life rafts could also be fitted with them.

Note that weather, ice and sea state data in the area of the incident is also needed for rescue operations. These are listed on separate sheets.

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(1) Search And Rescue SATellite. The European Space Agency uses the same acronym for Synthetic Aperture Radar SATellite; in this report, the letters SAR along means Synthetic Aperture Radar, described in Section 4.3.1, page 33.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

13. APPLICATION(S):

Cartography

DEPARTMENT(S):

DND, EMR

INFORMATION REQUIRED:

Current, accurate maps of Canadian Arctic and remote coastal regions.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Cartographic quality imagery required (but see comment).

CHARACTERISTICS OF TARGET(S):

Generally, the requirement involves large scale mapping of areas to be used for resource exploration and exploitation, transportation routes or facilities and military installations.

ACCURACY(IES) REQUIRED:

For normal cartography resolution of coarse detail is required to 6 m vertical, 4 m horizontal; fine detail to 2 m vertical, 1 m horizontal. However, see comments.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

Canadian Arctic and remote coastal areas.

FREQUENCY OF OBSERVATION NEEDED:

N/A

RESPONSE TIME REQUIRED:

One week to one month

DATA FORMAT(S):

Rectilinearized imagery with latitude and longitude annotation. Capacity to extract heights from imagery, or from special sensor (e.g. radar altimeter).

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

As advised

COMMENTS:

1. For normal cartography uses, location of plot that has been imaged to about 4 km is adequate. If plot is used, ground party would survey in locator points.

2. It is recognized that the resolutions required for routine cartography exceed the probable capabilities of a surveillance satellite. However, for urgent strategic and tactical needs in areas for which there are no large-scale maps or where existing maps contain gross errors, radar and MSS imagery would be very useful for construction of working maps and charts, with the exception that height data may not be sufficiently precise.

3. Hydrographic charting has not been specified since depth information is not expected from satellites.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

CENSUS OF SURVEILLANCE REQUIREMENTS

14. APPLICATION(S): Forest resources management

DEPARTMENT(S): DINA

INFORMATION REQUIRED:

1. Composition of forest stands by areas, species and volumes.
2. Location and size of fires, fuel situation, losses by area, species and volumes.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Areas of forest stands by species; volume of timber in stand. Classify immature, mature and over mature stands, standing dead timber, cut over, debris, old burn and tree survival within burned areas. Recognize smoke, active fires, determine size, intensity, perimeter, measure unburned fuels.

CHARACTERISTICS OF TARGET(S):

Classification as to species, age and condition may be possible from spectral signatures.

ACCURACY(IES) REQUIRED:

High accuracy required for location and area and volume estimates.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All forest areas in the Yukon and North West Territories.

FREQUENCY OF OBSERVATION NEEDED:

Resource management: Bi-monthly
Forest fire detection and assessment: Daily

RESPONSE TIME REQUIRED:

Resource management: 10 days to 1 month
Forest fires: 1 to 2 hours

DATA FORMAT(S):

Standard photographic imagery

SPECIAL DATA HANDLING/PROCESSING REQUIREMENTS:

Immediate notification may be essential for management of forest fires.

COMMENTS:

Determination of volume may not be possible from satellite imagery. Research being done on spectral signatures may prove fruitful for classification. Infrared and/or multispectral sensors should be able to detect forest fires, but not through cloud.

INTERDEPARTMENTAL TASK FORCE ON SURVEILLANCE SATELLITES

STATUS OF SURVEILLANCE REQUIREMENTS

14. APPLICATION(S): Forest resources management

INFORMATION REQUIRED:

1. Compilation of forest stands by areas, species and volumes.
2. Location and size of fires, fuel situation, [illegible] by area, species and volumes.

DESCRIPTION OF TARGET(S) OR DATA REQUIRED:

Forest stands by species; volume of trees in stand. Classify immature, mature and over mature stands; standing dead timber, cut over, debris, old burns and tree survival within burned areas. Recognize smoke, active fires, determine perimeter, measure [illegible]

[illegible]

[illegible] to species, age and [illegible] may be possible from spectral signatures.

ACCURACY (IES) REQUIRED:

High accuracy required for location and area and volume estimates.

AREA(S) OF INTEREST/SPATIAL GRID SIZE(S):

All forest areas in the Yukon and North West Territories.

APPENDIX 4

A CANADIAN SURVEILLANCE SATELLITE SYSTEM

A CANADIAN SURVEILLANCE SATELLITE SYSTEM

It would be extremely difficult, costly, and inefficient to meet all the user requirements with a satellite system. Instead, minimum and maximum versions of a satellite system are discussed which meet the majority of the strategic measurement requirements. The tactical requirements are better met by ships or aircraft as often a physical presence also is needed. In most cases the frequency of observation requested by the users would need 3 or more satellites simultaneously in equi-spaced orbits. Also it is assumed that for an operational system the service to the users should be provided over at least a 10-year life.

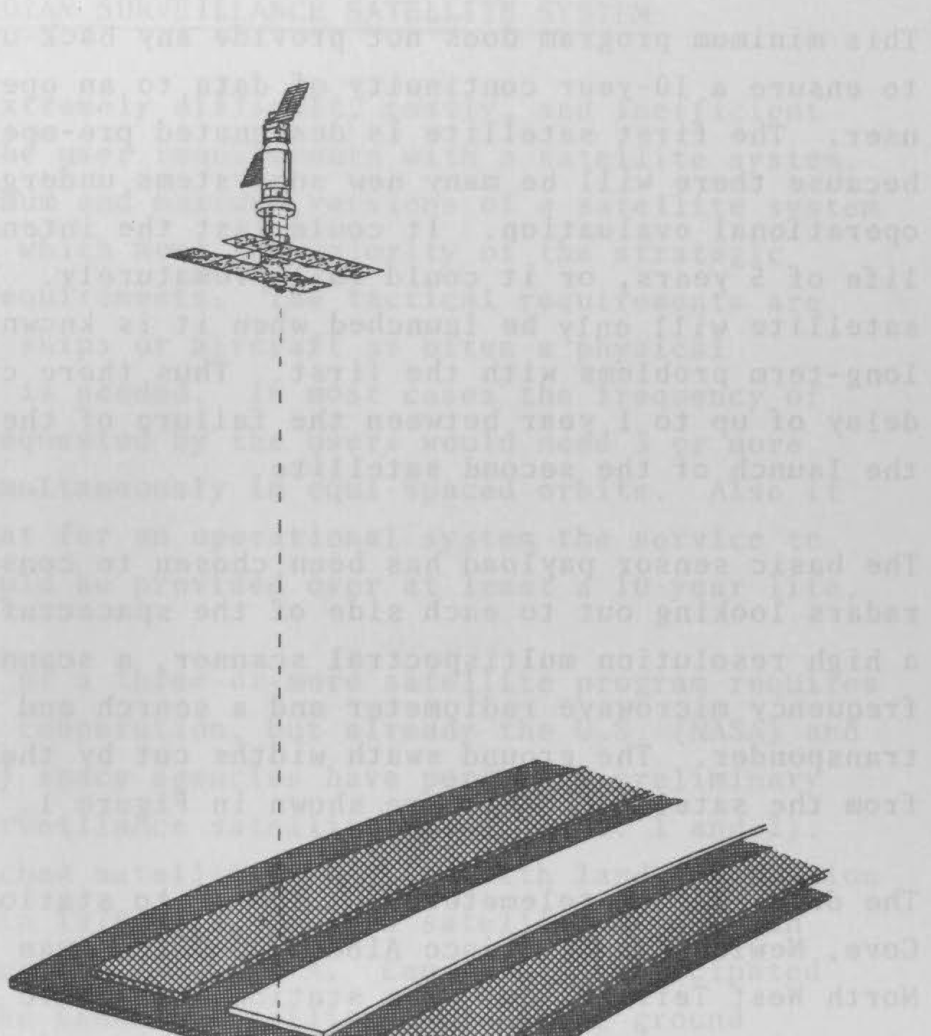
The magnitude of a three-or-more satellite program requires international cooperation, but already the U.S. (NASA) and European (ESA) space agencies have performed preliminary studies in surveillance satellite areas (Refs. 1 and 2). NASA has launched satellites equipped with land observation sensors and, in 1978, will orbit a satellite with ocean observation sensors - Seasat A. Canada has participated actively in the Landsat satellites, producing ground stations that have been sold internationally. Also a preliminary Canadian study (Ref. 3) has been conducted for an operational land and ocean observation satellite. A minimum practical Canadian program would involve building two (one pre-operational, one spare) long-life satellites, and the development of three ground stations for controlling, the spacecraft and receiving and processing the satellite data. One satellite could provide Canadian surveillance data every 2-3 days, three satellites would provide daily surveillance data.

This minimum program does not provide any back-up satellite to ensure a 10-year continuity of data to an operational user. The first satellite is designated pre-operational because there will be many new subsystems undergoing operational evaluation. It could last the intended design life of 5 years, or it could fail prematurely. The second satellite will only be launched when it is known there are no long-term problems with the first. Thus there could be a delay of up to 1 year between the failure of the first and the launch of the second satellite.

The basic sensor payload has been chosen to consist of two radars looking out to each side of the spacecraft nadir, a high resolution multispectral scanner, a scanning multi-frequency microwave radiometer and a search and rescue beacon transponder. The ground swath widths cut by these sensors from the satellite orbit are shown in Figure 1.

The data will be telemetered at X-band to stations at Shoe Cove, Newfoundland, Prince Albert, Saskatchewan and Resolute, North West Territories. The stations will have digital processing equipment to produce image data and will be linked by ANIK and the planned multi-purpose UHF satellites to users and user agencies.

A detailed system design of the satellite program will be needed to determine the best choices for the performance of the spacecraft bus, sensors, and ground stations in order to provide timely image data products to the users. The following descriptions are conservative estimates of the capabilities for each part of the satellite system.



□ Multi-Spectral Scanner (200 Km)

▩ Synthetic Aperture Radar (200/400/200 Km)

■ Scanning Multi-frequency Microwave Radiometer (920 Km)

FIGURE 1 SATELLITE GROUND SWATHS

1. Mission Analysis

By employing redundant sets for the most failure-prone assemblies on the spacecraft, it is possible to build economically a satellite which has a 70% chance of lasting for 5 years. A second satellite would be kept as a spare to be used after the failure of the first.

A single satellite in a sun-synchronous circular orbit at an altitude of 693 km provides almost complete Canadian coverage by the radar swaths every 5 days. If data is gathered both day and night (subject to availability of electric power), each point north of 45 degrees N. latitude will be covered twice in five days. Also, north of 57 degrees N. latitude to within 350 km of the north pole, 95% coverage would be obtained by either north or south passes in two days.

Further improvements in frequency of coverage are possible if more satellites are deployed.

The orbit inclination is 98^{o} which is within the direction window of the U.S. Western Test Range but outside the direction window of the Eastern Test Range. It is assumed that the satellite will be launched in the early 1980s by a Delta 3910 rocket launch vehicle with a 700-km sun-synchronous payload capability of 1670 Kg. To ensure continuity of launches cost effectively, it is recommended that the spacecraft design be compatible with both the expendable Delta and the reusable shuttle launch vehicles.

The U.S. shuttle orbiter is presently scheduled to become operational at the Western Test Range in 1983. However, the shuttle program is still in its developmental stage and the date of 1983 should be treated with caution. From the Western Test Range, a shuttle launch using two orbital manoeuvre system (OMS) kits has the capability of placing approximately 4500 Kg. of cargo into a 700-km sun-synchronous orbit. This raises the interesting possibility of launching up to three surveillance satellites simultaneously, or alternatively sharing the cargo capability with other satellites having similar orbit destinations.

It will be possible, between 1980 and 1983, to utilize satellite-attached upper stages for changing the orbit inclination to 98^{o} from an Eastern Test Range launch of the shuttle. Development plans for an interim upper stage by USAF and a lower-cost spinning upper stage by NASA are currently under way. Both of them are expected to be operational by 1980. This approach probably would be more expensive and risky than that using a proven expendable vehicle launch from the Western Test Range.

2. Synthetic Aperture Radar (SAR)

The prime surveillance sensor is the radar, because it can penetrate clouds and most precipitation, and can produce high resolution imagery emphasizing metallic objects. A resolution of 20 metres was chosen as a baseline design parameter mainly because of the limitation imposed by the digital tape recorder and the large swaths required for frequent coverage. Theoretically it is possible to achieve higher resolution but the technological difficulties increase.

2. <u>cont'd</u>

As the resolution is improved the following radar parameters are also effected:

(a) Improved range resolution increases the radar system bandwidth, average and peak transmitter power. A 2.5 m range resolution requires a bandwidth of 200 MHz.

(b) Improved azimuth resolution reduces the swath width and puts greater demands on the stability and knowledge of spacecraft dynamics. At typical orbit altitudes, theoretically an azimuth resolution of 2.5 metres can be achieved with a swath width of 150 Km. In practice a swath width of 20-40 Km would be more typical.

(c) Both range and azimuth resolution improvements increase the data rate for recording, and increase the complexity and size of the signal processing and image handling equipment. Signal recorders present a major impediment to increased resolution satellite radars. Using current optical recorders it is possible to achieve a 5 metre resolution across a swath of 50 Kms. Digital recorders are under development that could record 2.5 m resolution over a swath of about 12 Kms.

To achieve an along-track resolution of 20 metres on the ground requires an antenna of several kilometres in extent in space. Such an antenna size cannot be attained physically but it can be synthesized by summing pulse returns coherently. An across-track resolution of 20 metres can be achieved readily using modern pulse compression techniques.

For the desired frequency of coverage, two 200-km swath widths will be imaged, one on each side of the nadir as shown in Figure 1. At such steep depression angles, the range resolution will vary from 28.7 metres to 16.1 metres from near to far range.

Space-borne synthetic aperture radars acquire large volumes of data at high rates. The practicality of real-time, in-flight data processing to generate imagery is considered to be questionable in the 1980-1990 time frame. Furthermore, the on-board digital recording of raw data for subsequent dumps when the satellite is within view of a participating earth station will not likely be achievable by then. The

2. <u>cont'd</u>

implication is that the radar data for Canadian coverage will be linked continuously to earth stations where it will be recorded and subsequently processed to from images.

Based on the current experience with digital recorders, a 240 megabits per second write rate capability may be expected within five years. This will allow SAR data (single polarized) from two, 200-km swaths and with a resolution of 20 metres to be digitized and recorded. Dual polarization is not recommended because of the lower level of the cross-polarized return, the depolarization that could occur in the ionosphere, and the insensitivity of man-made surveillance targets to polarization.

The ionosphere has a more serious impact on the radar and the choice of frequency because it can disturb the coherence of the transmitted pulse and hence degrade both the range and azimith resolution. A further concern is the degradation of the SAR signal coherence in a ground link utilizing the lower frequencies. A preliminary examination of these points suggests that studies must be conducted to examine such ionospheric effects in detail, particularly for Canadian latitudes, prior to the selection of radar and data-link operating frequencies.

There are many imaging advantages that would accrue if the radar was operated at X-band rather than the lower L-band frequencies: improved textural information on natural scenes such as sea-ice, greater depth of focus, lower sensitivity to target motions, and greater immunity to ionospheric disturbances. The major disadvantages are technical difficulties in the spacecraft: tighter tolerances on the radar antenna rigidity, an order of magnitude increase in radar power, and the present unavailability of reliable high-power, solid-state transmitters. A possible solution is to employ a high-gain, electronically-scanned beam in the across-track direction, but this leads to greater complexity and unreliability of the spacecraft. With

2. cont'd

current technology, an L-band radar system is well within the spacecraft capabilities; but due to the desirable aspects of X-band radar, further work should be performed in radar scattering properties of various surfaces, high-power solid-state transmitters, and antenna design.

3. Optical Sensors

A wide variety of television camera systems and multi-spectral scanner systems have been orbited (Table 1) by NASA. The television cameras produce a 'snapshot' image which then is telemetered to the ground line-by-line. They have been used for producing low to moderate resolution (4000 to 80 metres) black and white images. It is extremely difficult to register scenes taken simultaneously by different camera filter combinations to produce a colour image.

The multi-spectral scanners produce images on a line-by-line basis using the same optical system, which is finally filtered into the desired spectral bands. Individual detectors convert this spectral energy into digital signals which are telemetered to the ground station. The detectors have better radiometric performance than a television camera, and the spectral data is inherently registered for colour images.

In the basic sensor payload, one high-resolution, multi-spectral scanner is recommended. It would have a swath of 200 km directly below the satellite and produce registered digital data with resolution 40 m x 40 m for 4 optical spectral bands and a resolution of 120 m x 120 m for a thermal infra-red band. This level of performance can be achieved using the same telescope combination as the Landsat scanner, and increasing the number of detectors per band from 6 to 100. A development program to produce such a scanner is currently underway in the U.S. A possible alternative is a push-broom scanner using photo-sensitive diodes that are read out electronically. An airborne prototype is currently under development in Canada.

OPTICAL SENSORS

SENSOR	SATELLITE	RESOLUTION (METRES)	SPECTRAL BANDS
VISSR	SMS, GOES	900 (9000)*	2
SR	NOAA, 2,3,4	4000 (4000)*	2
VHRR	NOAA 3,4	900 (900) *	2
AVHRR	NOAA 5, TIROS-N	1000 (4000)*	4
MSS	LANDSAT 1,2	80	4
RBV	LANDSAT 1,2	80	3

* RESOLUTION OF THERMAL BAND

TABLE 1 - OPTICAL SENSORS

In the maximum payload configuration, two scanners are recommended covering the full 400-km gap between the two radar swaths. In cloud-free conditions, this gives a very wide surveillance swath width of 800 km. at 20-40 metre resolution that is repeated every 2-3 days. In addition to ocean surveillance, the scanner will also be able to serve a variety of land observation requirements in forestry, agriculture, etc.

4. <u>Scanning Microwave Multifrequency Radiometer</u>

A scanning multifrequency microwave radiometer (SMMR) will be used aboard Seasat-A to record absolute sea-surface temperatures to within 2 degrees and relative temperatures with 1 degree under all weather conditions. The sensor will have a footprint of 100 kilometres and will utilize other frequency channels to produce compensation data for clouds and other weather effects. The limitation on the spatial resolution is set by the size of the antenna, which could be doubled in order to achieve a resolution of 50 kilometres on future flights. It is not feasible to alter the frequencies used as they are the most sensitive to sea surface temperature and atmospheric pertubations. The swath width covered by the Seasat-A sensor is 920 kilometres and it is unlikely that it will be increased significantly in the future. With such a swath width it is possible to obtain global coverage every 40 hours.

The SMMR can also be used for measuring surface winds with a spatial resolution of 50 kilometres, and an accuracy of ±2 metres per second or 10% over a range 7 to 50 metres per second. A third use of the SMMR is in the measurement of sea ice extent and its highest frequency achieves a resolution of between 10 to 15 kilometres. The instrument also can be used to measure water vapour in the atmosphere to an accuracy of 20% with a resolution of 50 kilometers. Because of its wide range of applications and all-weather performance, this sensor is recommended for the basic sensor payload.

5. Scatterometer

A scatterometer is an active microwave sensor that employs doppler filtering of the returns to measure radar back-scatter as a function of look angle. Over the sea it can be used to measure the direction and strength of surface winds. On Seasat-A it covers two swaths, each 500 km wide, displaced 230 km from nadir on each side of the spacecraft track. The wind measurement is the average over an area 50 km square and gives direction to $\pm 20^{o}$ and strength to ± 2 metres/sec. in the 3-25 metres/sec. range. One satellite provides global ocean coverage every 40 hours. Since the scatterometer provides only a wind direction as an extra measurement over the SMMR, it is not included in the basic payload, and Seasat-A experience should be acquired before including it in the maximum payload.

6. Search and Rescue

Due to its low weight and power requirements, a search and rescue transponder has been included in the basic payload. Assuming that the emergency locator transmitters in mountainous terrain would need an angle greater than 35^{o} to 'view' the satellite, then it covers a swath of 1670 km per pass. One satellite would provide almost complete coverage of southern Canadian latitudes every 24 hours, and complete coverage north of 60^{o} latitude every 12 hours. The frequency of coverage would be correspondingly higher with three satellites.

7. Spacecraft Design

The spacecraft configuration will be greatly affected by the launch vehicle: the Delta 3910 rocket or the shuttle. If the first satellite is to be launched in 1982, the Delta would be chosen; if the first flight is later than 1984, then the shuttle becomes the more attractive alternative. Since the Delta has greater constraints on payload volume and weight, a configuration that is feasible on it will certainly be accommodated by the shuttle.

The essential requirements of the spacecraft configurations are: to carry during launch and to deploy in orbit a sensor module complement of two radars with large antennas, a multispectral scanner, a microwave scanning radiometer and an ELT transponder; to provide adequate power by means of a deployable sun-tracking array and battery system; to maintain an acceptable dimensional stability of the structure with a predictable orientation; to maintain the desired attitude and orbit characteristics; to provide an adequate communications system for receiving and transmitting payload and housekeeping data; and to provide an acceptable thermal environment for the components on board the spacecraft.

a) Structure

A possible structure and in-orbit payload configuration is shown in Figure 2. The upper section is the 3-axis stabilized spacecraft bus including the houskeeping complement and solar arrays. The lower section carries the sensor complement. It

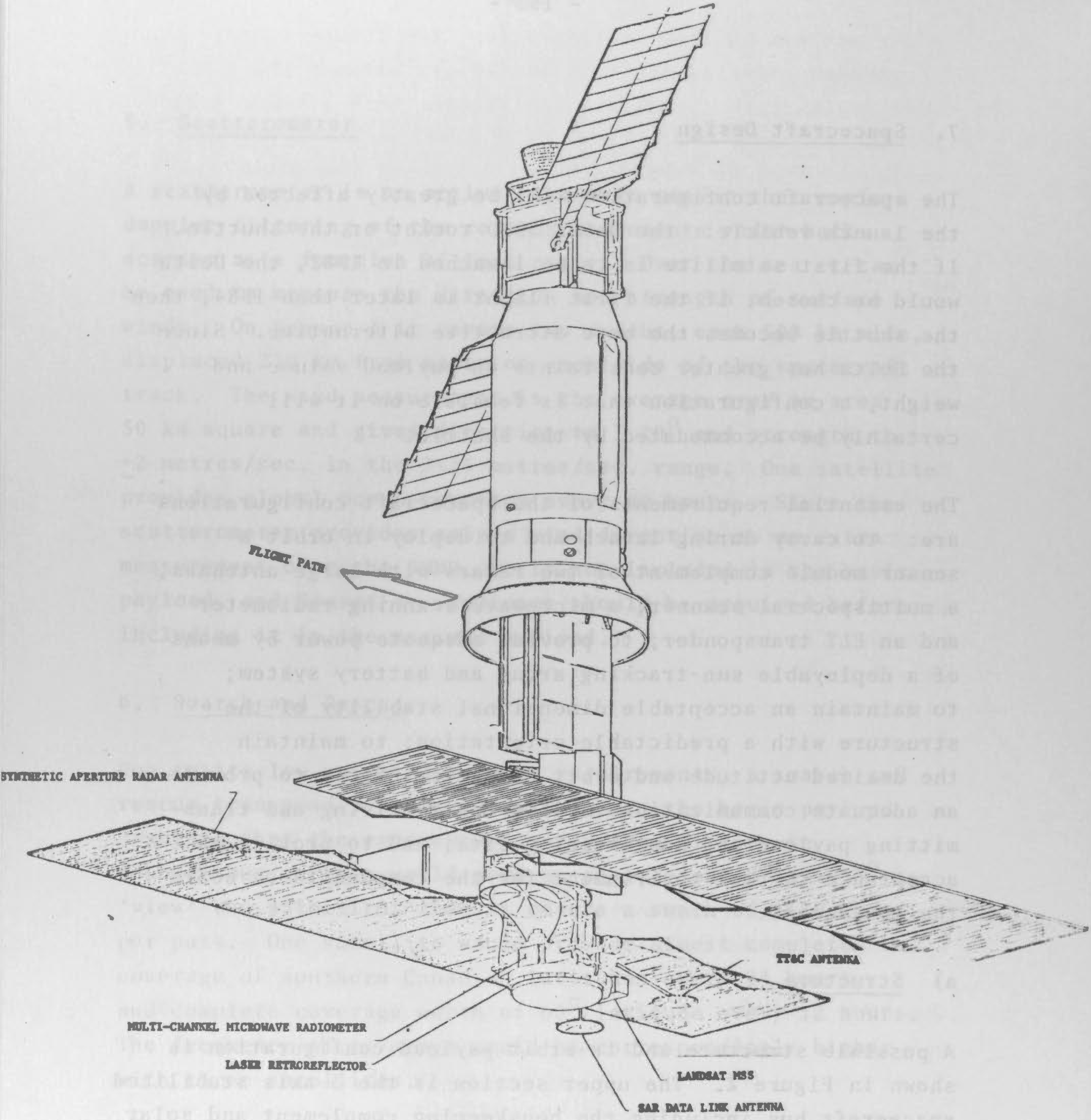


FIGURE 2 SPACECRAFT CONFIGURATION

is recommended that graphite-fibre epoxy material be used for the radar antenna support structure as it offers high strength and stiffness per unit weight with very low thermal distortion.

Each radar antenna when deployed is 10 m long and 1.6 m wide. It could be packaged as three panels, 3.3 m x 1.6 m, to fit inside the Delta fairing. (A Shuttle might accept the full size antenna).

The use of a pantograph to carry out a controlled solar array deployment has been flight proven on the U.S. Skylab mission. A similar controlled deployment lightweight array is now being developed in Canada for communications spacecraft and can be considered a candidate mechanism for the radar antennas and the solar arrays. Low thermal distortion can be obtained with the use of high performance graphite fibre composite materials. Development models of large space structures using this material have been built by both General Dynamics and Boeing in the U.S. for the Large Space Telescope Project. On a smaller scale, Bristol Aerospace in Winnipeg has built wave guides of the same material to replace those made with invar leading to substantial weight saving. They are now flying on CTS and the two U.S. RCA Satcoms. The development of the radar antennae and solar arrays will need to be carried out concurrently with the spacecraft design to ensure that the correct interfaces are taken into account.

b) Power Subsystem

For L-band radars, a power subsystem using current Canadian technology is adequate for continuous operation of all sensors during daylight; but in eclipse the radar can be operated for 10 minutes only. Twice the needed battery capacity will be carried to improve reliability. A large deployable solar array using a rigid frame is presently under development in Canada. The drive and track mechanism to maintain the correct angle of solar illumination (single axis because of sun-synchronism) can be an improved derivative of the CTS design.

c) Attitude Control Subsystem (ACS)

Present attitude control subsystems will satisfy the accuracy required by the sensor complement. The present ACS earth horizon sensors are capable of $\pm 0.05^{\circ}$ in pitch and roll, $\pm 0.005^{\circ}$/sec in pitch and roll rates. Yaw sensing accuracy with inertially stablized systems is of the order of 0.4°, and 0.05°/sec in rate. Improved yaw sensing can be achieved by using a star tracker sensor which would increase the cost and complexity of the subsystem. Smooth attitude error correction can be accomplished by momentum systems using electric motor-driven wheels. For reliability, the reaction wheel system will be fully redundant. An on-board microprocessor controls the error correction and the desaturation of the momentum wheels. Although the technology is available for designing a satisfactory ACS careful consideration will need to be given to the flexibility effects of the satellite structure.

d) Reaction Control Subsystem

A well proven method for providing torques and forces on the spacecraft for periodic attitude and orbit correction is the use of thrusters using hydrazine as the fuel. Care should be taken to locate the fuel tanks close to the centre of mass of the spacecraft. The fuel storage assembly and the plumbing all must be maintained within the specified temperature limits. Adequate redundancy should be provided in the thrusters and valves.

Design of a hydrazine system for launch on the space shuttle will require additional precautions because of its corrosive properties and potential for explosion, which could endanger the astronauts.

e) Thermal Subsystem

For a sun-synchronous orbit, the two satellite side faces receive little direct sunlight and can be used for mounting the high dissipation components with the remaining four faces receiving the low dissipation components. The design philosophy recommended is similar to CTS, which is a passive-designed spacecraft for the hot faces, with the use of electric heaters in the cold faces. The heaters should be thermostatically operated with a ground override capability.

f) Telemetry and Command

The major requirements for telemetry are posed by the two radars (each 30 MHz video bandwidth) and the scanner (35Mbits/sec digital). The band 8025-8400 MHz is designated for satellite telemetry links, and a large portion of this 375 MHz bandwidth must be requested for the mission. Depending on the modulation scheme for the sensor telemetry, the bandwidth requirements range from 100 to 275 MHz. The other sensors and the housekeeping data can be accommodated in less than 30 KHz. If there is participation by NASA in the program, it is recommended that the housekeeping data also be transmitted at 2 GHz to obtain additional tracking by the NASA network.

Also there should be an adequate number of housekeeping channels to ensure the proper maintenance of the spacecraft performance.

The command procedure uses redundant digital encoding to protect against noise, and the command is verified at the ground station before it is enabled.

8. Ground Stations

For an orbit of approximately 700 kilometers, 3 ground stations give complete coverage of Canada's oceans, landmass and the Arctic areas. Figure 3 shows the coverage circles at 5^{o} antenna elevation angles for stations located at Prince Albert, Saskatchewan, Shoe Cove, Newfoundland, and Frobisher Bay. Each station would contain a conventional auto-tracking 10-metre antenna with solid state RF receivers. The choice of modulation of the down link probably will change from analog to digital in the next 5-10 years and quadriphase modulation or polyphase techniques might be used to conserve bandwidths. Experience with the radar on Seasat-A will decide the number of bits required for adequate dynamic range and signal-to-noise ratio.

An alternate reception technology, the Tracking Data and Relay Satellite System to be launched by NASA in 1979,

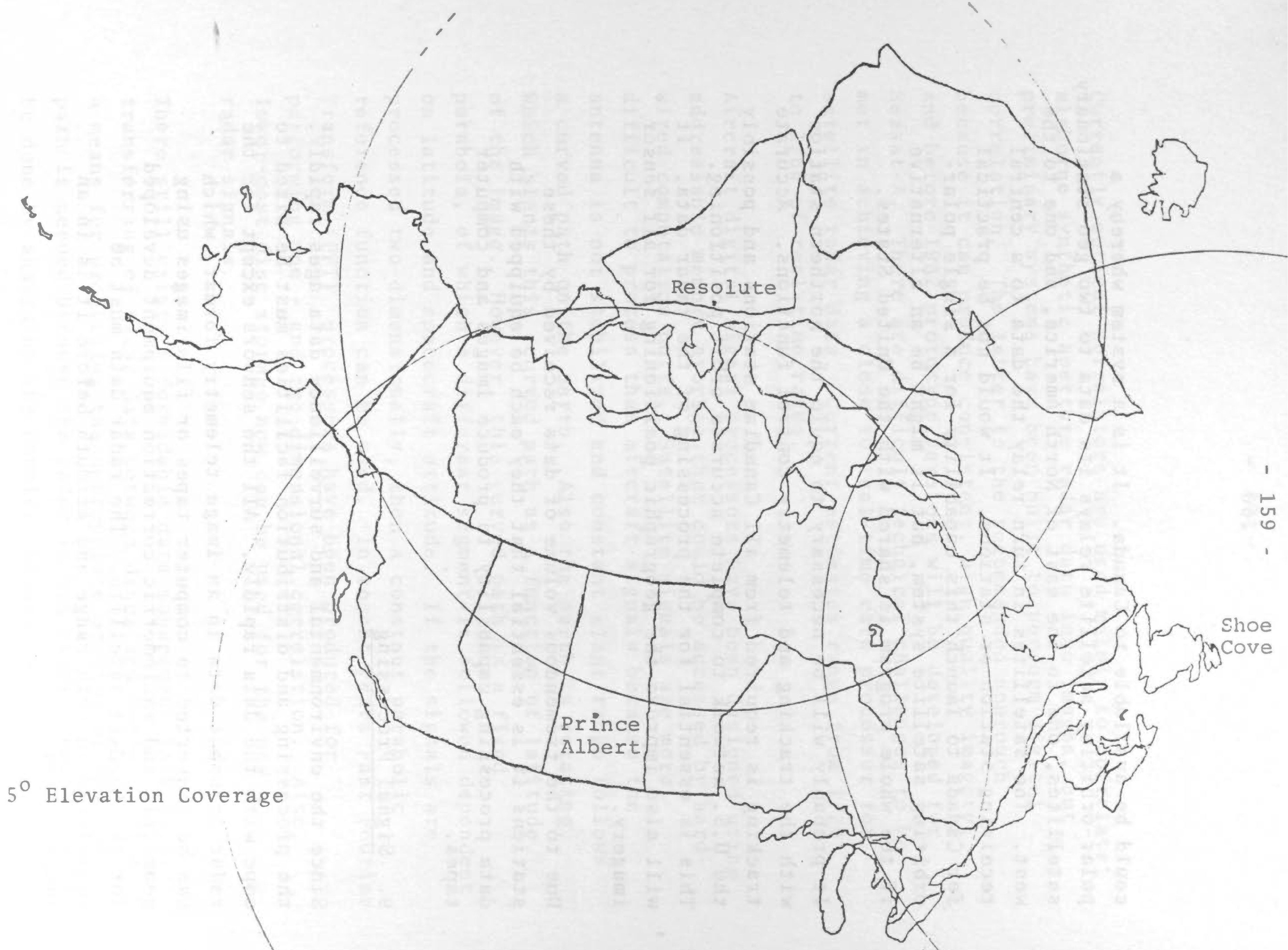


FIGURE 3 GROUND STATION COVERAGE

could be available to Canada. It is a system whereby a polar-orbiting satellite relays its data to two geo-stationary satellites, one to the east of North America, and one to the west. The satellites in turn relay the data to a central receiving station or stations. It would not be practical for Canada to launch this capability for a single polar-orbiting satellite system, but it might be an alternative if the whole program is shared with the United States.

It probably will be necessary to equip the northern station with the tracking and telemetry control functions. Accurate tracking is required from all Canadian stations and possibly the U.S. network to complete accurate orbit positioning. This is essential for the processing of the radar data. It will also improve the geographic positioning for all sensor imagery.

Due to the tremendous volume of data received by these stations it is essential that they each be equipped with data processing capability to produce images and computer tapes.

9. Signal Processing

Since the environmental and surveillance data ages rapidly, the processing and distribution facilities must be sized to cope with the data rapidly. All the sensors except for the radar transmit data in an image telemetry format, which can be converted to computer tapes or film images using geometric and radiometric correction equipment developed for the Landsat satellite. The radar data must be correlated in both range and azimuth before it is in an image format.

Currently optical correlators are used mainly to correlate airborne synthetic aperture radar data into images, but preliminary systems have been built to perform digital correlation. The latter is the recommended approach because it can produce consistent, high quality imagery, and before 1982 prototype versions will be developed for Seasat-A. There are difficult technical challenges to be met in achieving a close to real-time rate processor for satellite radar data. Current estimates range from 1/20 to 1/60 of real-time rates.

Aircraft digital signal processors have been designed using addressable memory storage that could be accessed by hard-wired computation units. Satellite signals are more difficult to process than aircraft signals because the antenna is not stabilized and constant slant range follows a curved path on the earth. Also the earth is rotating, which slants this curved path as a function of latitude of the image. However, this curved path is a fixed parabola, of which a different segment is followed dependent on latitude and spacecraft attitude. If the signals are processed two-dimensionally, then a constant parabolic reference function can be used. In recent years Fast Fourier Transform (FFT) processors have been produced for performing one - and two-dimensional correlation. Also, lower-cost disc storage now can be used for the new radar signals.

There still exists a formidable data management task (i.e. transferring of radar data between discs and FFT's). Also a means for predicting the appropriate portion of the curved path is needed because the radar is not stabilized, but this can be done by analysing the Doppler changes in the raw radar returns.

10. Data Handling and Distribution

The problem of handling vast quantities of data to extract surveillance and environmental information is common to all methods of data acquisition: satellites, aircraft, ships or buoys. Satellites produce the largest volume of data over a wide area, although aircraft can provide concentrated monitoring for a specific area. Since the user requirements were stated without regard to platform, an appropriate mixture of platforms is needed to provide surveillance without prohibitive cost. The single satellite described did not meet many of the users' needs for frequency of coverage; but even so, it provides a tremendous data handling volume.

The potential numbers of images of the Canadian landmass and adjacent oceans are as follows:

Image Sensor	Area	Resolution	No./24 hrs.	Pixels/Image
Radar	200x200 km^2	20 m	160	100 Million
Optical Scanner (MSS)	200x200 km^2	40 m	80	103 Million
Microwave Scanner (SMMR)	920x920 km^2	15 km	50	20 Thousand

Approximately a third of these images cover the designated surveillance areas. Facilities to screen the images for human activity should be established on the east and west coasts and in the Arctic. Ideally they should be co-located with the ground reception station. Alternatively they could be linked by wide-band communications satellite (ANIK) for the radar, optical and microwave scanner images. The multipurpose UHF satellite (MUSAT) is suitable for relaying interpreted images (wind, wave, temperature plots) directly to shipping, or through low-cost receive-only ground stations to remote northern posts.

a) Radar Data

The radar data is transmitted as an analog signal to the ground stations where it is converted to digital data and recorded on high-density tape recorders. The two southern stations each receive about 40 Canadian images every 24 hours, and 15 of these fall in the surveillance areas. The Arctic station receives twice as much data as the southern stations due to the convergence of the orbit tracks near the pole. Actually each station could acquire more data if it received data from the overlap region with its neighbouring station. Since the satellite produces two radar images every 30 seconds, the southern stations record 10 minutes and the arctic station records 20 minutes of independent data every day.

The radar tapes will then be replayed at low speed (1/4 or 1/8 of the record time) into a processor which correlates the radar signals and records the radar images on another high-density tape recorder. (NASA has evolved a flexible but comprehensive format for recording line scan images on a serial high-density tape recorder).

The above procedure anticipates a major improvement in radar digital processing technology. The current estimate for the processing rate of Seasat-A radar data is 1/64 of real-time recording rates for a 100 km swath. A 400 km swath at 1/8 of the real-time recording rate represents a processor throughput 32 times faster than present design goals. At the 1/8 rate, it takes 160 minutes for the Arctic station to correlate its radar signal tapes.

The high-density radar image tapes must be converted into images to extract target or environmental information.

Targets are characterized by the intensity of their returns relative to the background, and for larger targets by their shapes. The traditional approach to surveillance has been visual interpretation of images by trained observers. Except for certain periodic phenomena, computers have not been able to outperform observers at pattern recognition. They can, however, easily differentiate intensity levels better than observers viewing black and white film or CRT displays.

The lowest cost approach to target extraction is to convert the radar image tapes to high resolution black and white images using a laser beam film recorder. Then, trained observers can screen the images. A more accurate but costlier approach is to build a computer system that automatically detects targets in the radar images, then displays only the target and adjacent area on a colour CRT display. Detection would be based on a significant amplitude increase of the target returns over the locally-computed background amplitudes. The display would show the amplitudes of the radar returns as uniquely different colours. The observer could then confirm the spatial and intensity characteristics on the one display. With this system it might be possible to differentiate between icebergs and ships, which are difficult to separate on radar film images.

The automatic detection algorithm could be quite sophisticated, but will be constrained by the load of 15-30 surveillance images, each containing 100 million pixels. Assuming that a box-car filter can provide a reasonable estimate of the local noise, which can then be used to threshold each pixel, the detection function can be performed in a few microseconds per pixel.

It would take about 5 minutes/image for automatic detection. Displaying and confirming each target detected would take 2-3 minutes. Multiple display stations could be employed if the target loading was too high. A file of targets and their locations could be built-up for referencing with new detections, and for relaying to appropriate agencies.

As the data is screened, this system also could perform extracting of wave information as a background task for the sea images. Computing the two-dimensional fourier transform of the data produces the wave-directional spectrum, which gives directly the wavelength and direction of the sea-waves, and by inference the wave-height, wind direction and speed. This information would be relayed promptly by the appropriate agency via satellite or conventional links to shipping.

b) High Resolution Multi-Spectral Scanner Data (MSS)

The MSS data is similar to Landsat data, except that it has twice the resolution. It can be handled in a similar fashion. Since it covers the 200 km directly below the satellite in clear weather, it provides complementary coverage to the radar.

The image data is transmitted in digital format at 70 Mbits/sec. from the satellite to the ground station for recording. One spectral band of the data can be recorded by the laser beam recorder in real-time for applications such as sea-ice, weather or surveillance visual screening. Digital facsimile transmissions can be used for the agencies needing fast response time. Other applications requiring slower response can be handled by slow-speed replay, with the formation of images from computer tapes.

There is a computer image tape format recognized by NASA, Canada and Italy that is rapidly becoming a standard for digital image data. There is more variation in film image formats, but 241 mm aerial film is a standard, yielding radar and MSS images at a scale of 1:1,000,000 with date, time, and location as a standard annotation. The location for repetitive orbits of satellites can be given by track and frame numbers, now a Landsat standard. There is no standard at this time for image facsimile; it depends on the equipment being used.

Further analysis and processing of the MSS data can be performed by the facilities developed for geometric and radiometric correction and classification of the Landsat data.

c) Scanning Multi-Frequency Microwave Radiometer (SMMR)

The data handling volume from this sensor is much lower than the other two. Low resolution ice-images can be produced readily from the 39 GHz channel at a scale of 1:4,000,000. An independent computer system, or spare capacity on the radar target system, could produce a temperature map for the sea images. The low-frequency channel provides the basic temperature measurement, while the other four channels are used to measure and compensate for atmospheric path effects. The foam on the sea-surface effectively increases the surface temperature and can be used to infer the wind speed. The exact processing algorithm for this sensor will be developed for the Seasat-A and Nimbus-G satellites.

d) ELT Data

This signal is an analogue relay of the emergency locator transponder transmission from a distressed vehicle. The doppler shift of incoming signal is used to note the minimum distance between satellite and vehicle. From a knowledge of satellite orbital position, it is possible to compute an approximate location of the vehicle. Successive orbital passes can refine this position and resolve any ambiguity. Handling this data requires some special doppler tracking equipment to look into the transponder signals, and provide an output of frequency-versus-time to the computer. A computer program then can relate the frequency changes to satellite orbital position, to provide an estimate of the distressed vehicle position with little additional loading of the computer.

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APPENDIX 5

RESEARCH AND DEVELOPMENT IMPLICATIONS OF A

CANADIAN SURVEILLANCE SATELLITE

RESEARCH AND DEVELOPMENT IMPLICATIONS OF A CANADIAN SURVEILLANCE SATELLITE

The Research and Development Group of the Surveillance Satellite Task Force, listed in Appendix 1, addressed the question of the amount and type of research and development (R and D) needed to support the various options open to Canada as described in Section 6. This appendix summarizes the findings and describes the basic systems studies and technology development programs required for the launching of a Canadian surveillance satellite in 1983.

Appendix 4 described a satellite system which would mobilize the sensor and spacecraft technology available by the mid-1980's to meet Canadian surveillance requirements. A great deal of the basic technology required, particularly for the spacecraft, has been developed already in Canada through the Canadian Space Program. However, technology development will be necessary in certain critical areas. Thus, the design and construction in Canada of the system described in Appendix 4 will require the early establishment of an R and D program to ensure the necessary technology is available in Canadian industry when needed.

The areas requiring R and D are related primarily to the radar, and the requirements it imposes upon the spacecraft and data sub-systems. It is to be noted that, except for the radar, the proposed sensors are fairly straightforward extensions of sensors already flown successfully in various NASA space programs. However, while radars have been used extensively in aircraft, such systems have not been used to image the surface of the earth from a satellite. This will be done for the first time in the forthcoming Seasat-A program which is the NASA technology experiment to prepare for an operational series of earth observation satellites using imaging radars.

Considerable knowledge of the technology relating to imaging radars exists at the Communications Research Centre (CRC) of the DOC where for several years there has been an R and D program in support of DND airborne radar requirements. The knowledge was recently used when CRC personnel participated in an assessment of various technical alternatives associated with possible Canadian participation in the Seasat-A experiment. It was demonstrated that the expertise of a government R and D group in this area could be transferred to a participating industrial group. Also demonstrated was the very great advantage to be gained by working cooperatively with another country in the technology development phase of such a program. While working with the U.S. design team, the Canadian engineers quickly became cognizant of the design constraints of satellite-borne imaging radar systems to an extent that would have taken up to two years working alone. Thus there is a core of knowledge now in Canada concerning the technology and R and D required to develop a satellite-borne imaging radar system to meet Canadian surveillance requirements.

1. Radar Research and Development

The major questions concerning the imaging radar sensor, and which require R and D to provide answers, fall into two classes. In the first class are two fundamental systems questions, each of which relate to the unique geometry involved in imaging with a synthetic aperture radar, and to the very long synthetic aperture when using a satellite system as compared with an aircraft system.

<u>Class I</u> - questions requiring fundamental Systems Research:

a) to what extent can specific targets be imaged and to what extent does surrounding backscatter (clutter) degrade this imaging capability? To what extent can existing radar models for target and clutter reflectivity be used to predict imaging radar performance with the satellite geometry involved? Answers to these questions will set limitations on such crucial radar design parameters as wavelength and bandwidth.

b) to what extent will the imaging radar be impaired by the ionosphere, and particularly the disturbed ionosphere at Canadian latitudes? The ability to focus radar images depends upon the ability of the radar system to achieve coherent reflections from the earth across the full synthetic aperture. Refraction during passage of the radar signals through the ionosphere will degrade this coherence to a greater or lesser extent, depending upon the total electron content of the ionospheric layer, and its homogeneity across the synthetic aperture length. While these effects can be modelled and calculated for a normal undisturbed ionosphere, not enough is known in detail of ionospheric inhomogeneity at Canadian latitudes to predict confidently imaging radar performance. Answers to this question will critically determine the wavelength and other radar parameters required for a Canadian surveillance system. For example, it is considered that the Seasat-A radar wavelength may not be optimum for Canadian latitudes; a shorter wavelength may be necessary for a Canadian system.

c) how can the imagery be disseminated most effectively to users?

The second class of questions on the imaging radar are concerned with the technology involved in constructing and operating such a satellite system.

Class II - areas requiring Technology Development:

a) the practicality of near real-time image processing
b) the ability to record radar image data at a rate of 240 megabits per second,
c) the reliable generation of sufficient microwave power for the radar transmitter at the desired frequency,
d) development of the necessary high-power solar array,
e) development of a suitable deployable radar antenna and the required attitude control system.

The relative difficulty in implementing an imaging radar system, especially with respect to the latter three of these areas, will be a function of the wavelength required for the radar - a parameter that will be determined by the answers to the first class of questions.

2. Seasat-A Participation

Class II areas can be dealt with through the application of sufficient engineering resources. However, the first set of questions are fundamental to the system and govern the basic capability to image targets and the earth's surface with the desired resolution of 20 metres. It is in the answers it can provide to these basic questions that the Seasat-A experiment is most important. Thus, there is a good case for Canadian participation in Seasat-A. At the same time, the participating Canadian engineers and scientists would become familiar with United States technology developments which could assist the Canadian program in areas related to the second set of technology areas.

An early decision must be made regarding Canadian participation in the Seasat-A program. The options for a Canadian contributions are as follows:

a) no participation

b) contribution by reading out data from a Canadian ground station, to be processed in the U.S.

c) contribution by reading out data from a Canadian ground station, and with a Canadian processing facility.

Experience with Seasat-A SAR imagery will provide a timely opportunity to assess the accuracy of theoretical predictions of:

a) the impact of the ionosphere at Canadian latitudes on space-borne SAR performance,

b) the ability of space-borne SAR to image targets of concern to Canadian users.

Simple access to already-processed Seasat imagery will not provide an opportunity to assess these factors. Only by direct involvement in the generation of Seasat-A data, and with a background of engineering knowledge of the signal processing involved in the Seasat-A SAR system, will it be possible to use the resulting imagery to make such assessments.

Development of the processor would be done in close cooperation with the NASA agencies involved so that detailed knowledge of the Seasat radar design would be obtained. Other benefits will flow to the Canadian program from this form of participation in Seasat-A, such as an opportunity to follow directly the technology developments involved, primarily in the data reduction, handling and dissemination area; and secondarily, in the satellite hardware area.

Furthermore, it is suggested that a final decision regarding development of a Canadian surveillance satellite be postponed until after experience has been gained with Seasat-A conclusions drawn regarding the feasibility of such a system at Canadian latitudes and for Canadian requirements.

3. Spacecraft Research and Development

The key technical area requiring R and D is the extendible 10-metre radar antenna and the attitude control system required to stabilize the satellite and antenna structure in low polar orbit. A secondary or contingent concern is the mechanical, electrical and thermal design of the required spacecraft bus.

4. Cooperation with Europe and Japan

In addition to the proposed cooperation with the U.S., preliminary discussions have been held with the European Space Agency and with Japan regarding cooperation in the technology development required for remote sensing satellite systems. It is recommended that they be followed up, and cooperative studies be established in the critical areas of technology development. Not only will such studies expose Canadian engineers to the ideas and developments in these other countries, but they provide a means of keeping the door open to future cooperation in the operational phase of a satellite surveillance system.

5. Systems Studies, Project Definition and Development Activities

A summary of the topics requiring basic systems studies and technology development is provided in Tables A and B, which include the time frame over which each activity is expected to span, based on a launch date of 1983 for the first satellite. The basic systems studies listed in Table A have been estimated to cost $9.2 million, 75% of which would be spent in Canadian industry.

The basic systems studies span a time interval covering almost the entire period of the program from the present to 1982. They consist of essential scientific and technological background support activities, some of which would proceed whether or not a surveillance satellite program were initiated. For example, radar research has been conducted at the Communications Research Centre in support of both military and civilian programs since its inception; and CCRS has been studying radar remote sensing systems for many years. Studies 1, 3, and 5 in Table A are very general in nature and are important to Canada for radar surveillance from aircraft as well as satellites. It should be noted that aircraft experimentation with side-looking radar could be of significant value in assessing the expected performance of a spaceborne SAR. The remainder are more directly related to Seasat-A or other specific platforms.

Table B lists the major portions of the Project Definition Phase, including Seasat-A involvement. Seasat-A cost estimates including in-house costs are as follows:

1.	Modifications to Shoe Cove ground station	$1.25 million
2.	SAR processor development (digital version using novel Canadian approach)	1.8 million
3.	Verification experiments to prove radar performance*	0.75 million
	Total	$3.8 million

Approximately 80% of the total would be spent in Canadian industry. The remaining portion of the Project Definition Phase is estimated as $4.2 million.

The costs of the development phase are estimated as $78.0 million, but they may be reduced significantly through international participation. For example, approximately $42 million is required for sensor development (radar, MSS, SMMR and ELT Transponder) which could be shared with other nations, or Canada could share in existing programs such as now are underway in the U.S.

* Such experiments are those deemed to be necessary only to verify performance of the spacecraft SAR for sovereignty control and do not include scientific or other applications where SAR could be of value.

TABLE A: BASIC SYSTEMS STUDIES FOR FIRST SYSTEMS LAUNCH IN 1983

	STUDIES REQUIRED	TIME FRAME
1.	Modelling of effects of disturbed ionosphere on SAR.	1976 - 1978
2.	Use Seasat-A data to verify and further develop ionosphere studies.	1978 - 1979
3.	Radar target signature modelling, using experimental radar data	1976 - 1978
4.	Use Seasat-A data to verify and extend modelling studies	1978 - 1979
5.	Develop hardware and conduct radar experiments to support 3 and 4	1976 - 1980
6.	Aircraft and space-borne experiments (e.g., SPACELAB) for studies of proposed sensor systems*	1978 - 1982
7.	Development of experimental sensor systems for 6.*	1976 - 1982

* Before 1980 - impacts on the satellite design

After 1980 - impacts on application of data obtained by the satellite sensors.

TABLE B: TECHNOLOGY DEVELOPMENT FOR FIRST SYSTEMS LAUNCH IN 1983

STUDIES REQUIRED	TIME FRAME
Project Definition Phase	
Seasat-A - Shoe Cove Station Modifications	1977 - 1978
SAR processor	1977 - 1978
Radar Verification Experiments	1977 - 1978
Spacecraft configuration studies	1977 - 1979
Digital studies for possible on-board processing	1977 - 1979
Sensor simulations and configuration studies	1977 - 1979
Development Phase	
Spacecraft systems	1979 - 1981
- Antenna and Deployment system (X-band)	
- Attitude control system (no star tracker)	
- Solar array and power system	
- Spacecraft structure	
- Telemetry, tracking and command	
- Thermal subsystem	
- Reaction control system	
- System design and test	
Sensor systems	1979 - 1981
- Radar	
- MSS*	
- SMMR*	
- ELT Transponder*	
Digital Data Recording* & Processing Systems	1976 - 1981
Data Correction and Extraction Systems	1976 - 1981
Data Communication System	1979 - 1981

* Costs could be reduced by sharing in developments underway in USA