CANADA

OVERHEAD REMOTE SENSING FOR UNITED NATIONS PEACEKEEPING

APRIL 1990

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PREFACE

In his speech on 27 September 1989 to the forty-fourth session of the United Nations General Assembly, Canada's Secretary of State for External Affairs, the Right Honourable Joe Clark, announced that Canada would make available to the United Nations the results of Canadian investigations into the utility of overhead sensing technologies (both airborne and satellite-based) for peacekeeping. The primary objective of the original Canadian research, which was undertaken by the Verification Research Unit of External Affairs and International Trade Canada, was to examine the applicability of such technology for verification of arms control agreements relating to the control of conventional armaments in Europe. In the course of this work, it became increasingly evident that the relevant sensing technologies could also be beneficially employed in United Nations peacekeeping to provide cost effective supplementary information and support to ground-based United Nations forces. This report and the oral briefing which accompanies it represent the fulfilment of the Secretary of State's undertaking.

ACKNOWLEDGEMENTS

External Affairs and International Trade Canada wishes to acknowledge the work in preparing this report performed under contract by Intera Technologies Ltd. of Ottawa. It is also appropriate to mention that this work benefited from support by individuals within industry and the Government of Canada. Without the help of senior officials of the Department of National Defence, this report would have been impossible. In addition, valuable assistance was offered by two companies: Banner and Associates, and Dorschner Intelligence and Operations Specialists.

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I. INTRODUCTION

In the past, United Nations peacekeeping efforts have depended on traditional methods of monitoring for the surveillance and supervision of combatant forces. Patrolling and surveillance of borders, demilitarized zones and coastlines have been conducted primarily by use of ground-based personnel in vehicles, on boats or on foot. Aerial patrols, if used at all, have been normally focussed on the daytime visual reconnaissance of key areas. United Nations peacekeeping operations, however, often involve extremely large territories which would seem to invite the use of more efficient and effective techniques of large scale monitoring.

The use of airborne imagery in support of peacekeeping missions is not unprecedented. During the Sinai Disengagement Process (1972 - 1979), American aerial photo reconnaissance was used extensively for information gathering purposes. In the Yemen in 1963 - 1964, UNYOM was one of the few examples where overhead reconnaissance was used directly in United Nations peacekeeping. In this case, the United Nations had the support of eight reconnaissance aircraft because of the mountainous terrain and difficult accessibility for ground troops. In Central America, ONUCA is currently planning to use eight light helicopters for reconnaissance purposes.

In future operations, the incorporation of airborne imagery sensors into an aerial patrolling program could enable United Nations peacekeeping forces to operate over larger and more remote areas during both daytime and nighttime. Information from these operations could give ground-based United Nations personnel data not normally available to them because of distance or darkness.

Sophisticated forms of overhead imagery are available that could widen the window of observation opportunity. Synthetic aperture radars for an all-weather, day or night capability and thermal infrared sensing to detect heat sources at night are two alternative methods of airborne sensing that could, in addition to photo-optical sensors, provide valuable supplementary information to United Nations peacekeepers in the field.

Although the emphasis of this report is on airborne overhead reconnaissance, the use of commercially available satellite imagery for peacekeeping support is discussed. High resolution commercial satellite imagery, such as that available from SPOT-Image or Soyuzcarta, could provide additional preparatory information to ground-based peacekeeping forces for updating existing maps in terms of roads, large structures or camps.

The primary purpose of this report is to identify specific airborne sensor types and aircraft platforms that may have an application in United Nations peacekeeping, and to outline the cost of this equipment. It will also attempt to demonstrate how the use of this equipment could increase the United Nations observers efficiency and, ultimately, their effectiveness during peacekeeping deployments.

II. PEACEKEEPING AND REMOTE SENSING - IMPORTANT CONSIDERATIONS

Several key factors must be considered before airborne remote sensing activity could be used successfully as a United Nations peacekeeping support tool. Areas of concern include: the United Nations peacekeeping mandate, the level of political support, the control and command of peacekeeping forces, the type of terrain in which the peacekeeping forces will be operating and the impartiality that the United Nations's role should exemplify.

Peacekeeping Mandate

"Peacekeeping" includes a variety of definitions all of which incorporate an impartial third party to keep a number of hostile states or communities separated. In the context of United Nations operations the International Peace Academy defines peacekeeping as:

> "the prevention, containment, moderation and termination of hostilities between or within states, through the mediation of a peaceful third party intervention organized and directed internationally using multinational forces of soldiers, police and civilians to restore and maintain peace".[1]

In terms of United Nations peacekeeping missions, the definition would include the following functions within their mandate: observing, reporting, maintaining communication, patrolling and mediating low level disputes and complaints. The sole authority under which a peacekeeping force can operate is the mandate of any operation as devised by the Security Council. A clear and concise objective of the peacekeeping force must be established for it to be effective.

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[1] International Peace Academy, Peacekeeper's Handbook, New York: Pergamon Press, 1984, p.22.

The Peacekeeper's Handbook states that mandates set out by the Security Council are commonly broadly phrased in order to meet all requirements and desires of the parties involved. Mandates of a peacekeeping force are also typically short-term. Even so, aerial reconnaissance in support of peacekeeping should be incorporated into any mandates as prescribed by the Security Council in order to ensure the acceptance of this method as applied to the desired goals of a particular peacekeeping mission. The role of aerial reconnaissance should be defined in the mandate so that this technology is clearly established as a tool to complement information acquired by ground-based observer groups.

Acceptability and Political Support

Clearly, political support from the nations where a peacekeeping force will operate must be obtained. The inclusion of aerial reconnaissance activity as an observational tool available to the peacekeeping forces must be accepted explicitly and have the support of the various parties to a dispute. An airborne remote sensing system, incorporated as support to United Nations peacekeeping initiatives, must be perceived not as a covert means of intelligence gathering, but as a source of informational support to help observers do their job more efficiently. Each party must perceive that the benefits from aerial overflights will apply to every party. By allowing overhead reconnaissance in peacekeeping operations, all parties can contribute to and benefit from increased openness. In this way, aerial overflights can assist in the confidence building process that is indispensable to the re-establishment of a durable peace.

Command and Control

Command and control as it relates to peacekeeping operations involves two separate groups: the United Nations peacekeeping forces itself and the combatant forces involved in the dispute. Command and control of the sort of overhead monitoring program envisaged in this report would be the responsibility of the peacekeeping force.

In peacekeeping operations, information gained from a variety of sources including overhead monitoring must be properly interpreted, analyzed and disseminated to enhance the actions of ground-based peacekeepers. Timely and accurate information can provide the basis for better mediation efforts, conflict resolution and dispute avoidance. The proper command and control of this information is vital in decision making processes. Aerial overflights that gather data from preselected areas within individual sectors or throughout numerous sectors must be capable of providing the information necessary to make effective decisions on the ground. Control of the information gained as a result of the use of these airborne imaging sensors must remain in the hands of the United Nations peacekeeping forces in order for the use of these sensors to be viewed as a fair and impartial tool for decision making. Dissemination of necessary information and data sharing with other parties should be the peacekeepers' responsibility.

The proper reporting of airborne remote sensing information entails a high degree of organization and structure. Incorporation of such a potentially powerful information source must be carefully controlled and planned so as to maximize its full potential as a useful and effective means of data gathering and to avoid any misuse.

Terrain and Climate

The nature and extent of the terrain in which the peacekeeping force must operate directly affects the efficiency of any operation. Peacekeeping forces in Namibia, for example, contended with huge tracts of land in their border monitoring activities and coastal surveillance duties. Frontier areas in Namibia consisted of vast open desert, semi-desert areas, bushland and woodland. The reduction in the initially planned size of the UNTAG forces combined with this large land mass inevitably required prioritizing zones where United Nations forces could be active. The inherent dry climate and open land characteristics of the area made the jobs of the peacekeepers easier. Given these same conditions, however, overhead remote sensing would probably have contributed to the more efficient use of UNTAG resources.

As another example, in a climate and topography like Central America, a much different operating procedure in terms of peacekeeping is required. Major obstacles will be encountered as a result of the extremely mountainous terrain, dense vegetation and tropical climate. The mobility of peacekeeping missions will be restricted by the dense jungle and mountains within the area. Vegetation will hinder verification and observation procedures. In Central America, as in many other locales, peacekeeping forces must often contend with poorly developed road networks which greatly obstruct needed transportation.

There are thus many natural obstacles facing peacekeepers which could impede their activities. Aerial patrols using carefully selected imaging sensors can be part of the answer to the challenges that the United Nations peacekeepers will face in a variety of geographic terrains and climates. Aircraft and their associated sensors can monitor large areas in a short period of time. While their effectiveness depends in part on characteristics of terrain and climate, such airborne sensors are far more mobile than ground observers and can be put to good use in a wide variety of geographical situations. Lengthy borders can be patrolled and large coastal areas can be mapped in a fraction of the time it would take ground-based or ship-based personnel.

Impartiality

Peacekeeping forces within an area of conflict must be perceived as impartial. This is indispensable in gaining the confidence of the parties involved. Information gained by United Nations peacekeeping missions has been traditionally handled in such a way as to settle disputes as amicably as possible. In the past, the information used in this mediatory function has been generally gained by observations and reports from various ground-based observers. The introduction of airborne sensors should be considered as merely an additional source of relevant information available to United Nations peacekeepers. It is important to emphasize that the way this information is handled and disseminated should not be significantly different from the way data is handled by ground-based observer networks. It should be characterized by the same impartiality with which other information is treated. The method in which airborne sensor data is collected must be viewed as a non-covert activity and as merely providing support for the United Nations peacekeeping forces in performing their objectives as stated in the mandate for the peacekeeping operation in question. All parties within a region of conflict must be made aware that the incorporation of airborne patrolling into a peacekeeping operation, like the peacekeeping operation itself, is of benefit to all.

III. SENSOR SYSTEMS

Many airborne platforms can be outfitted with off-the-shelf, commercially available sensors capable of producing high quality images which can play an important role when their data are utilized for peacekeeping purposes. Imagery from several satellite systems offer some utility for peacekeeping and is currently available for purchase. The basic principles of these sensor systems and their data products must be understood for a full appreciation of the strengths and weaknesses of each.

For the purposes of this report, sensor systems that are proposed for incorporation into United Nations peacekeeping efforts are restricted to imaging sensors only. Signal intelligence gathering sensors have no direct role in promoting neutral and impartial decision making in peacekeeping since the use of these systems can arouse fears of spying.

Airborne Sensors

Airborne remote sensors can provide useful information for peacekeeping observation missions in a number of applications. The ability to respond quickly in order to gather information on a particular area of concern as well as regular monitoring sorties over widespread areas enable airborne imaging systems to be very effective. Real-time on-board processing of images gives the peacekeeper an ability to react very quickly to developing situations.

There are four airborne mounted sensor systems which can be of use for United Nations peacekeeping operations. They are:

1) Airborne synthetic aperture radars (SARs)
2) Airborne infrared linescanners (IRs)
3) Airborne forward looking infrared systems (FLIRs)
4) Airborne photographic or electro-optical cameras

Table 1 describes how each of these systems could be utilized as tools in support to peacekeeping forces.

Synthetic Aperture Radar (SAR)

Imaging radar systems are unique in their capability to provide useful information under conditions when other sensors are rendered useless because of adverse weather or absence of light. Microwave radar systems are considered active sensors, in that they illuminate the terrain by a series of carefully timed microwave pulses of pre-set length. The reflection of these microwave pulses from the terrain is recorded on the aircraft. It is the reflection capabilities of specific targets on the ground that determine radar imagery characteristics.

There are two types of Side Looking Radar Systems (SLAR) commonly used for remote sensing purposes, Real Aperture Radars (RAR) and Synthetic Aperture Radars (SAR). Each system has basic differences which directly influence data quality. As the name suggests, SLAR systems operate by illuminating the terrain to the side of the aircraft, at significant stand-off ranges of 25-100 km away from the target. The earliest airborne radar surveillance systems used unfocused Side Looking Airborne Radar techniques known as Real Aperture Radars (RAR). Resolution of RAR systems are determined by the length of the antenna which transmits and receives the microwave pulses.

In RAR's the antenna length, is limited by the ability of an aircraft to support and carry it. Hence, most RAR antennas are not less than 6 m in length, limiting the overall ability of the system to resolve objects not less than 20 m in size.

Synthetic Aperture Radars (SARs) were developed to overcome the serious resolution limitations of RARs as a result of restrictive antenna lengths. By performing computations on the [redacted] **TABLE 1** **Advantages and Applications of Airborne Remote Sensing Systems**

SENSOR	ADVANTAGES	APPLICATIONS
Synthetic Aperture Radar System	Day/night, all weather capability; stand-off imaging sensor; wide swath coverage	Wide area coverage of borders, coastal areas; monitoring of large scale construction projects, transportation.
Infrared Linescanner	Day/night capability; high thermal and spatial resolution; realtime imagery	Monitoring of heat sources from vehicular activity, buildings, human activity.
Forward Looking Infrared System	Day/night capability; very high spatial resolution; low level data acquisition	Detection and monitoring of heat sources from vehicles, humans, buildings; tracking of moving objects.
Photography and Electro-optical System	Day capability; very high spatial resolution	Monitoring of buildings, vehicles large scale troop movement.

received radar signal which incorporate the aircraft's own forward movement, SAR's create the effect of focusing the radar image through creation of a "synthetic" antenna up to a kilometre or more in length. SAR resolution is virtually independent of altitude and stand-off range, unlike the earlier RARs. SAR has an improved resolution over RAR by a factor of one hundred or more. Early SARs were limited because of the cumbersome optical processors required for the synthetic focusing operation. The newer commercially available state-of-the-art SARs are now capable of processing real time synthetic aperture information on-board relatively small twin engine turbo-prop aircraft. SAR systems can also incorporate a Moving Target Indicator (MTI) that automatically cues the operator to moving targets within the radar scene. The wide swath coverage enables very large areas to be searched quickly and comprehensively.

SAR systems can acquire data in two modes; high resolution mode (23 km swath width) or wide swath mode (46 km swath width) from an operating altitude of 11,000 m above ground level. The base system parameters for commercially available SARs are as follows:

Frequency:	X-band (3 cm wavelength)
Polarization:	HH, parallel
Pixel Size:	Azimuth: 6 m
(Resolution)	Range: 6 m (23 km swath width) or 12 m (46 km swath width)
No. of Looks:	7
Weight:	450 kg, including antenna and recording systems

The SAR systems use real-time, on-board digital processing. The data products and replay capabilities include an interface for on-board, real-time display and digital recording, as well as the capability to downlink a digital data stream to a ground-based receiving station. In other words, the operator on the aircraft can see immediately an image of what the SAR sees. The data can also be transmitted to a ground station or recorded

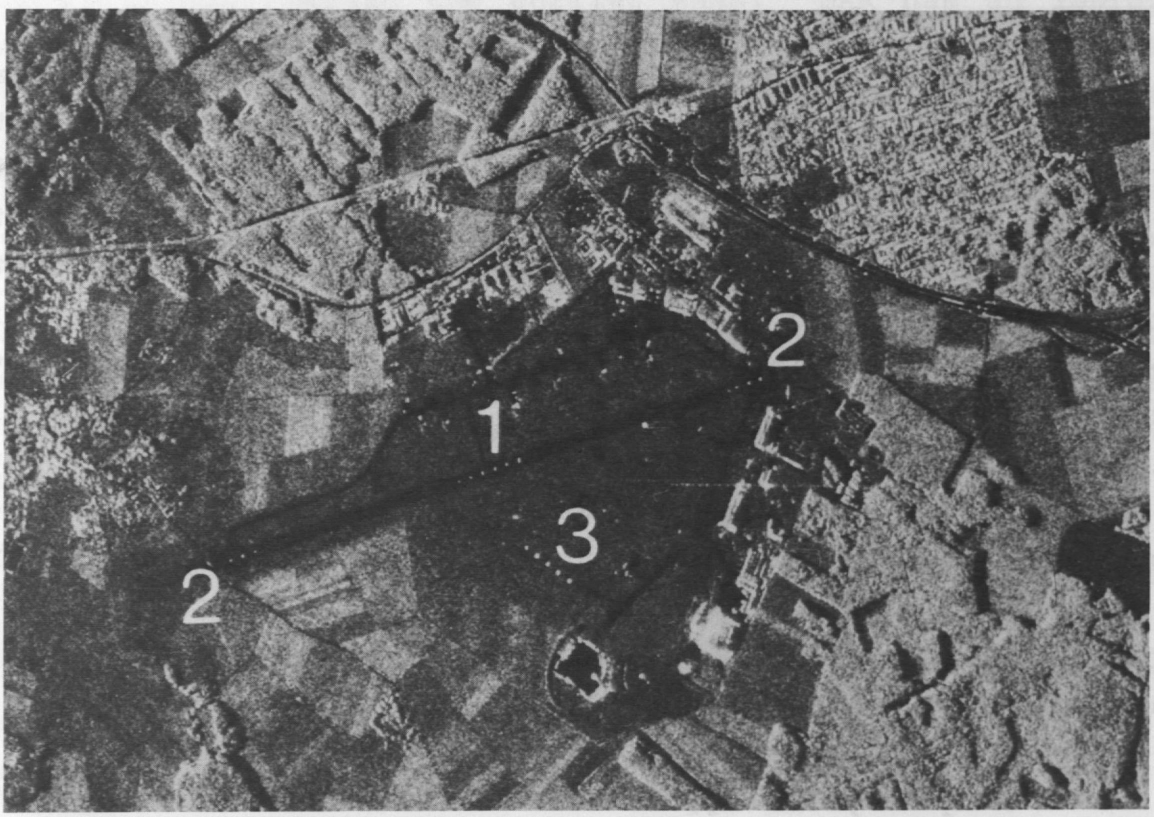
The data can also be transmitted to a ground station or recorded on tape for further processing.

Interpretation of SAR Images

Synthetic aperture radar systems illuminate the terrain with a series of microwave pulses. These pulses reflect from the surface objects on the ground and are returned back to the aircraft. The brightness of the objects on the SAR images directly correspond to the amount of microwave energy reflected back to the aircraft sensor. Smooth objects such as water or pavement will appear very dark to black on the radar imagery because most of the microwave radiation is reflected away from the aircraft, much like shining a flashlight beam from an angle onto a mirror. Rough objects, such as cobbled roads, corn fields, or trees, will reflect much of the transmitted radiation back to the SAR sensor receiver on-board the aircraft and, therefore, will appear as brighter targets. It is this surface roughness characteristic of an object that determines how it will appear on SAR imagery.

Many objects appear on SAR data that are below the theoretical resolving capabilities of the system, which is usually three to six meters. This is possible when their edges react as "corner reflectors", thus acting as high reflectors. Often power lines and hydro poles will be observable because of this phenomenon. Figure 1 is a six meter resolution SAR image of a controlled series of four sets of targets placed on a runway and surrounding taxiways. In Area 1, six corner reflectors are visible, having a size of 55 cm, 40 cm, 40 cm, 40 cm, 28 cm and 28 cm. Area 2 has three reflectors, 55 cm, 40 cm and 28 cm in size. Area 3 has five corner reflectors, 55 cm, 70 cm, 90 cm and 90 cm in size. All targets are separated by a distance of 50 m.

FIGURE 1 Synthetic Aperture Radar Resolution



Synthetic aperture radar imagery has a very good spatial resolution. This SAR image shows a series of four sets of radar reflecting targets used for resolution calibration. In Area 1, six corner reflectors are visible, having a size of 55 cm, 40 cm, 40 cm, 40 cm, 28 cm and 28 cm. Area 2 has three reflectors, 55 cm, 40 cm and 28 cm in size. Area 3 has five corner reflectors, 55 cm, 70 cm, 90 cm and 90 cm in size. All targets are separated by a distance of 50 m. The flying height of the aircraft was 10,000 m above the ground. (Image courtesy Intera Technologies Ltd).

As a result of illuminating the terrain from an angle, shadows adjacent to taller objects are produced. This is evident in Figure 1 and is pronounced in mountainous terrain. Shadows can be large enough to disrupt interpretation of the data in hilly or mountainous terrain. Therefore, to overcome this effect, the orientation of the imaging radar must be carefully planned during mission planning procedures. For on-board interpretation purposes, SAR imagery can be printed onto film negatives or onto a dry silver paper product. This would enable United Nations on-board observer to view the target area and commence preliminary interpretation and analysis.

The SAR data is recorded onto video or magnetic tape for archiving and later digital processing if required. The SAR data can be downlinked via a digital data stream to a ground receiving station for immediate analysis if the situation requires real time tactical decisions.

SAR for Peacekeeping

Airborne SAR imaging systems have considerable potential for patrols by peacekeeping groups particularly when large areas are to be covered. Since the swath width covered by SAR systems is typically 25 km in the high resolution mode, this airborne sensor can be utilized to monitor those areas where normal ground-based observing may be impractical due to manpower or time constraints.

Environmental conditions, nature of the terrain and vegetative cover will determine the effectiveness of SAR overflights for patrolling large areas. In locales where climatic effects result in persistent cloud cover, SAR overflights may well be the only practical means of surveilling large areas. This would appear to be the case for an area such as Central America where cloud cover is common. The application and interpretation of SAR imagery is somewhat more difficult, however, in mountainous terrain or over areas of dense vegetative cover. SAR imagery cannot penetrate foliage cover, and its use would prove limited if specific target areas were hidden under a canopy of vegetation.

SAR imagery could be particularly useful in support of United Nations peacekeeping groups for border surveillance activities in certain contexts. The ability of this sensor to image a wide swath of 25 km at a time from a considerable stand-off distance, would provide the peacekeepers with an alternative means of border monitoring. The surveillance of large land masses, frontier areas and long border zones can typically drain available manpower resources from a peacekeeping force. Regular SAR overflights of these large land masses would not only lessen the strain on available resources, but would facilitate the establishment of a United Nations presence in isolated and remote areas; something which may be very important for the objective of the peacekeeping mission.

The information provided by SAR imagery is readily transferable to established verification centres either by down-linking of the data to a receiving station or by landing with the imagery that was produced on the aircraft. This is particularly important when time sensitive information is acquired within a frontier zone or isolated area. Dissemination of the results of the SAR overflight to ground-based observer teams would be a vital component of the operation.

SAR can be very effective for locating the position of large military equipment such as aircraft, tanks or ships except when they are under cover. Because these objects have highly reflective microwave characteristics, they appear quite readily on

SAR imagery. Figures 2 and 3 show examples of relevant targets as bright signatures on the SAR images. The SAR data would be useful United Nations peacekeeping missions for airfield reconnaissance, coastal surveillance and the monitoring of important installations. The lengths of runways can be calculated, port utilization can be mapped and new construction determined. SAR does have limitations with respect to the detection of ships in rough water, however, due to the highly reflective nature of wave activity and the constant motion of the target.

Thermal Infrared Sensors

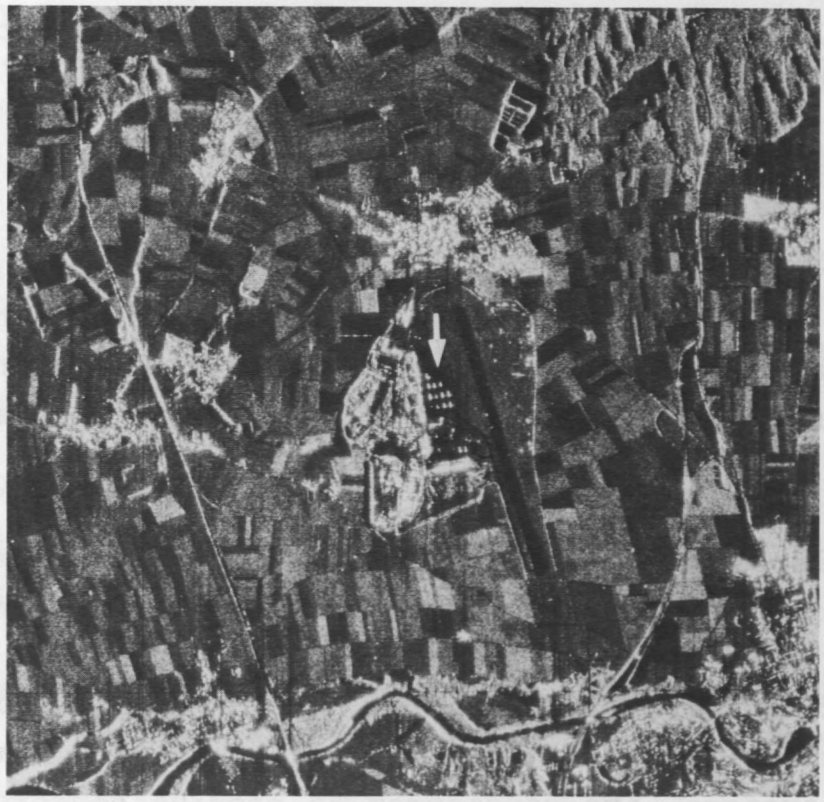
Everything radiates energy at thermal infrared wavelengths both day and night. The ability to detect and record this thermal radiation in image form at night has obvious reconnaissance applications that are relevant to peacekeeping.

The ability and efficiency of an object to radiate thermal infrared radiation is termed as that object's "emissivity". Emissivity is defined as the ratio of radiant flux from a body to that from a black body at the same kinetic temperature. Materials with a high emissivity absorb and radiate large proportions of incident and kinetic energy. Thermal infrared remote sensing systems, therefore, are considered as passive sensors since they merely record this energy emitted by all objects without generating any energy pulses like radars.

There are two types of infrared sensors that are commercially available and could be useful in terms of support for United Nations peacekeeping operations. They are classified as infrared linescanners and forward looking infrared (FLIR) systems.

Imaging thermal infrared linescanners have been developed and utilized for a variety of military, commercial and scientific

FIGURE 2 Synthetic Aperture Radar Image of An Airfield



This SAR image was acquired over an airfield from an altitude of 10,000 m above the ground. Note the aircraft on the apron and their relative position near the runway. The length of runways and airstrips can be readily measured using this type of airborne imagery. (Image courtesy Intera Technologies Ltd.)

[redacted] **FIGURE 3 Synthetic Aperture Radar Image of Ships**

The bright targets on the right side of this SAR image are "mothballed" ships docked in a bay. Note the very high reflective signature exhibited by the ships. An airport is also visible on the image. (Image courtesy of Intera Technologies Ltd.)

applications. Airborne linescanner systems consist of three basic components: an optical-mechanical scanning subsystem, a thermal infrared detector and an image recording and printing subsystem.

Most infrared linescanners collect infrared data by flying directly over the target. A rotating scan mirror reflects the emitted radiation from the ground surface onto a super-cooled infrared sensitive detector. The infrared detector utilized is dependent on the ground target of interest. Generally, for "earth" temperatures between $-50^{\circ}C$ and $+50^{\circ}C$, an 8.5-13.5 micrometer infrared detector is used for imaging purposes. The area covered by the swath of the rotating scan mirror is from 1.6 to 2.5 times greater than the altitude of the aircraft. From an airborne operating altitude of 600 m above ground level, a swath of between 1,000 m and 1,500 m can be obtained.

The spatial resolution of infrared linescanning systems is dependent on the size of the infrared detector utilized within the linescanner. Optimum size infrared detectors for reconnaissance purposes for peacekeeping operations would be 1.0 milliradians or less. Using a 1.0 milliradian detector from an operating altitude of 300 m above ground level would result in a spatial resolution of 0.3 m. The resolution is inversely proportional to the aircraft operating altitude, that is, the lower the sensor platform, the higher the spatial resolution.

Airborne thermal infrared linescanning systems have the advantage of operating at night at low level (300 - 1,000 m above ground level) to provide high resolution images of the infrared emission of objects from the terrain below. Real-time, on-board high resolution imagery can be produced in this way to help peacekeeping observers in tactical reconnaissance situations.

Closely related to the airborne thermal infrared linescanning systems is the forward looking infrared system (FLIR). This imaging infrared video system is typically mounted in a low level reconnaissance aircraft or helicopter. Detector types and spatial resolution for FLIR systems is similar to that of the infrared linescanners. FLIR's have the advantage of identifying small targets such as people or vehicles for confirmation of ground activity. The infrared images from the FLIR are recorded directly onto videotape with latitude and longitude positional information. The FLIR has the capability to rotate 360° around the aircraft as well as 180° in the forward and aft directions. Thus, FLIR systems have an advantage over linescan systems in that they are capable of tracking a target by movement of the sensor. This movement is controlled by the operator within the aircraft through the use of a real-time monitor image and sensor controller.

There are a number of commercially available FLIR systems. All operate very much alike with respect to data acquisition parameters. The main scan head is mounted on a gimbal and turret configuration and its direction is internally controlled by the system's operator. Most FLIR systems have several field-of-views (FOVs): wide FOV, medium FOV and narrow FOV.

The FOV is selected by the on-board systems operator. An important characteristic is the FLIR's ability to retain a high spatial resolution in the narrowest FOV. This is very useful when the monitoring of the movements of objects on the ground is required. Superior FLIR systems retain their very good resolving capabilities in their narrow FOV. The better FLIR systems are built to military specifications and are considerably more expensive than inferior commercial grade models.

Interpretation of Thermal Images

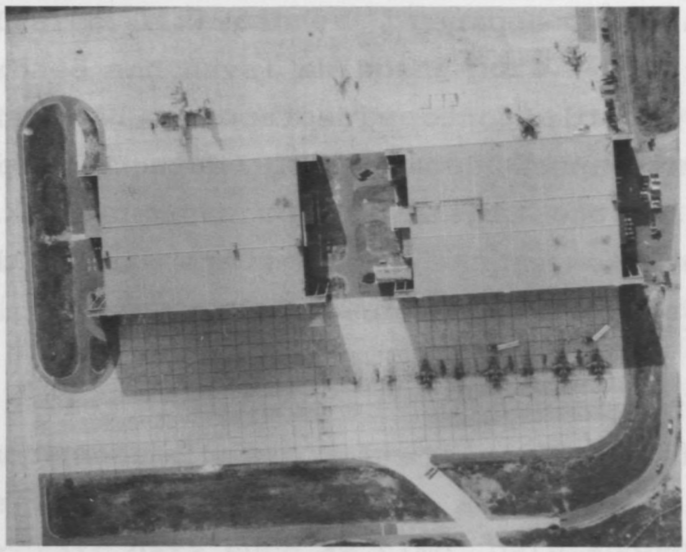
Thermal infrared imagery records the heat emitted by objects as black and white tones. The intensity of the tones is directly proportional to the amount of thermal radiation being emitted by the object. Warm objects or areas will appear dark on thermal infrared imagery negatives and cooler areas will be represented by lighter tones.

Temperature variations as little as 0.2°C can be differentiated using airborne thermal infrared sensors. This is termed as the thermal resolution of the system. The spatial resolution of thermal sensors refers to the ability of the system to differentiate between two objects of a specified size. This characteristic of thermal sensors is determined by the size of the infrared detector element used. Most infrared linescanning systems and FLIRs have spatial resolutions of 0.5 m to 0.25 m from an operating altitude of 300 m above the ground.

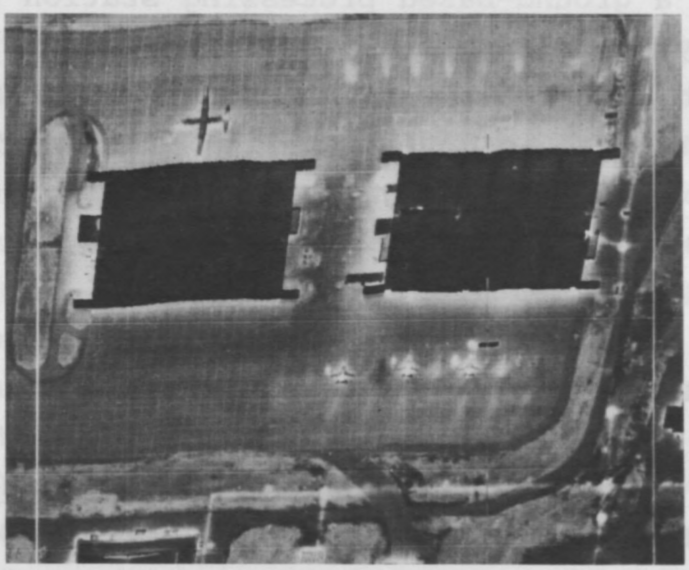
The use of thermal infrared imagery is optimized when collected at night, after sundown and before sunrise. During the day, solar radiation causes a thermal "blanket" to be cast on the terrain. As a result, everything on the ground appears relatively warm and it is difficult to measure the natural infrared radiation emitted by objects during daytime operation. Thermal imagery is also affected by water vapour and aerosols in the atmosphere between the sensor and the target. These result in attenuation of the infrared radiation emitted by the object, which could play a role in hindering the identification of a target in extremely humid or dusty situations.

Figure 4 is a comparison between a nighttime thermal infrared linescanner image and a daytime aerial photograph. Note in the thermal infrared image, the warmer aircraft, their thermal

FIGURE 4 Comparison Between Aerial Photography and Infrared Linescanning



Aerial Photography, Daytime



Thermal Infrared Image, Nighttime

A comparison between daytime black and white 70 mm photography and nighttime infrared linescanning can be seen here. Note the warm thermal shadows near the hangars on the thermal image and the warm underground buried heating lines. The spatial resolution of the airphoto is better than the resolution of the infrared image. The scale of the image is 2.5 cm = 101.5 m. (Images Courtesy of Canadian Department of National Defence) shadows and buried heating lines providing indirect clues of human presence. Aircraft are visible on the aerial photograph which has a higher spatial resolution than the corresponding thermal picture. However, no evidence of aircraft heat is visible on the airphoto and the buried steamlines are not apparent.

FLIR imagery is recorded onto videotape as black and white tones similar to linescanner data. FLIR data generally provides an oblique view of the objects below thereby making identification and interpretation of the ground scene easier than vertically acquired images such as linescanner data.

Infrared linescanner imagery can be printed in real-time onto film, dry silver paper, or videotape for immediate on-board interpretation and analysis. The data is stored onto tape for further analysis if necessary.

Both the infrared linescanner and FLIR data can be downlinked in real-time to a ground-based processing station for further digital image analysis on computer processing equipment. This is an expensive option and probably not necessary since the on-board observer will be trained in interpretation skills. The aircrew will be in radio contact with ground-based patrols at all times, therefore, having the capability of transmitting important tactical information readily, if required.

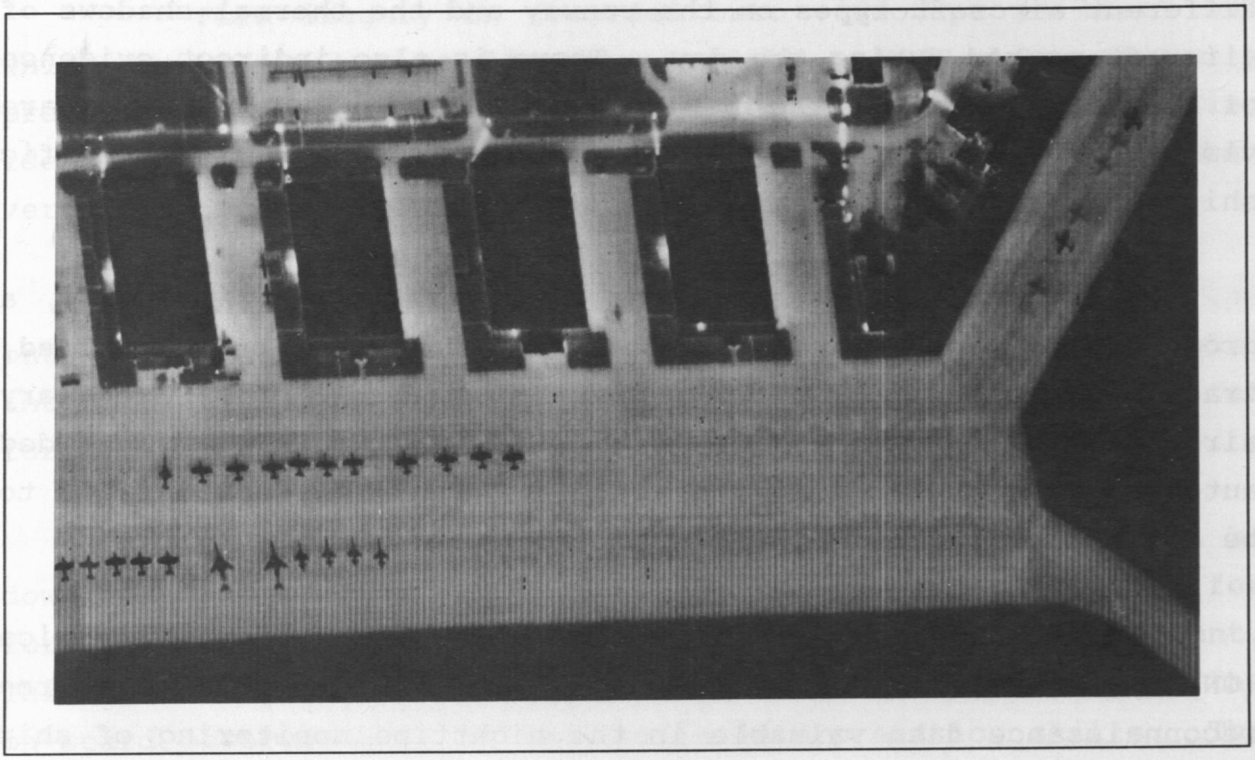
Thermal Infrared for Peacekeeping

Airborne thermal infrared sensing equipment, because of its ability to operate usefully at nighttime, would be extremely valuable to improve the efficiency and effectiveness of United Nations peacekeeping forces. Thermal infrared imagery can be used to map normally unseen objects such as camps, aircraft engine heat or heat produced from boats. Since all objects emit varying amounts of infrared radiation, nighttime activities of personnel, ground-based vehicles or aircraft can be determined. Thermal infrared sensors could be considered as a second pair of "eyes" for use at night by peacekeeping forces. Figures 5 and 6 are thermal infrared linescanner images acquired at night over a military airbase and naval shipping port. Note in Figure 5 the presence of different aircraft types on the runway and the thermal shadows of aircraft parked during the day. There is also indirect evidence of human presence as the buried heating distribution lines are visible indicating the heating of buildings. In Figure 6 specific ship types and class of ships can be determined.

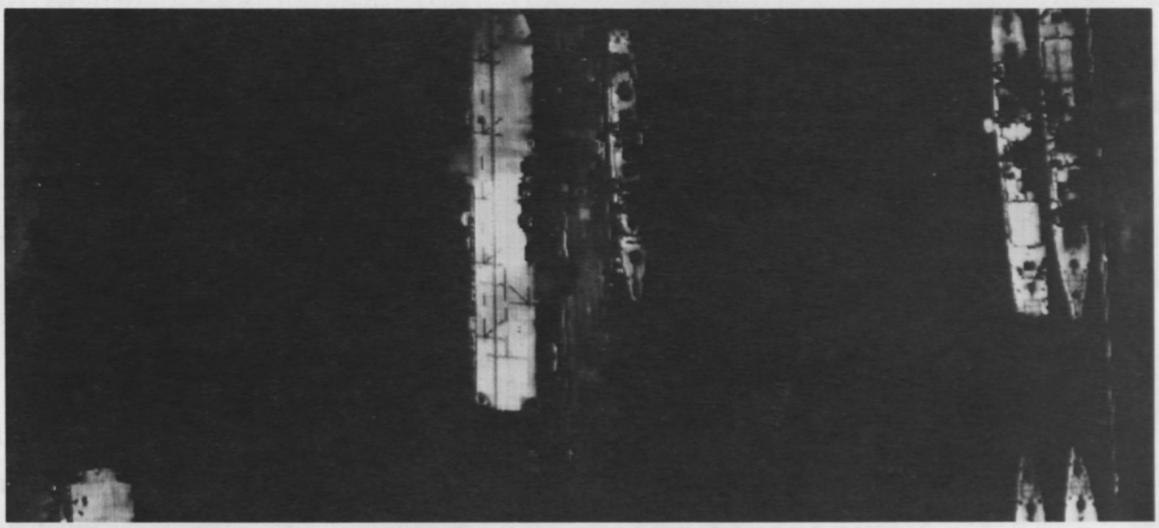
Using FLIR sensors from an aircraft, a moving ship, a ground-based vehicle or a group of individuals can be identified, tracked and followed for an extended period of time. Ancillary aircraft data such as time, date and present position are recorded automatically on the infrared video images. This could prove to be an important feature if reports of violations are disputed.

The United Nations observer force in Central America (ONUCA), for example, could find the use of FLIR airborne reconnaissance data valuable in the nighttime monitoring of ship and boat activity in the Gulf of Fonseca. Support could be provided through such airborne surveillance to United Nations patrol boats in terms of identifying the type and position of suspicious shipping activity. Once located, the airborne FLIR could provide a means of monitoring the inspection by United Nations ground forces by loitering over the target. Figure 7 is a hard copy FLIR image of a ship produced from video tape data. Note the warm smokestack and detail within the ships infrastructure. From an operating altitude of 610 m above ground level, the FLIR's resolution is sufficient to resolve individual people and their activity.

FIGURE 5 Thermal Infrared Linescanner Image of Aircraft

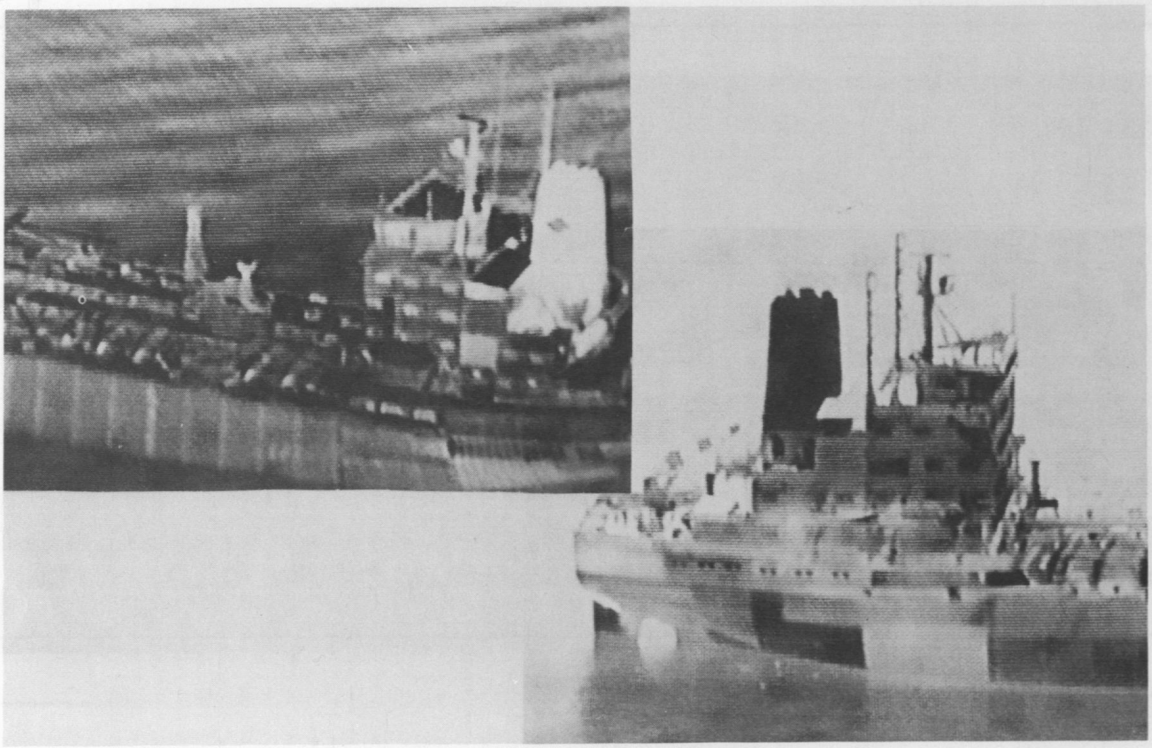


This thermal infrared linescanner image was acquired at night over a military air base. Note the different aircraft types and the thermal shadows of the aircraft parking areas during the previous day. Indirect evidence of human presence can be interpreted since the buried heating distribution lines are activated. (Images courtesy of the Canadian Department of National Defence) [redacted] **FIGURE 6 Thermal Infrared Linescanner Image of Ships**



Thermal infrared linescanning can be used to monitor shipping activity. This infrared image clearly shows the types and classes of ships moored at port. The scale of this image is 2.5 cm = 91.5 m. (Image courtesy of Intera Kenting Ltd.)

[redacted] **FIGURE 7 Forward Looking Infrared (FLIR) Image of Ships**



This Forward Looking Infrared (FLIR) image of a ship illustrates the resolution obtainable from the system. FLIR imagery is typically recorded onto videotape. Such hard copy prints from videotaped data do not do justice to the true spatial resolution of a FLIR sensor. (Image courtesy of Dorschner Intelligence Specialists)

Airborne Optical Sensors

Normal daytime aerial photography using films or electro-optical sensors must be considered as a prime method of reconnaissance information for incorporation into the United Nations peacekeeping operations. Photographic systems including aerial photography and especially today's sophisticated electro-optical systems have extremely high resolution capabilities. Black and white photographic negatives can provide useful images of high resolution. Electro-optical images are digitally produced and can be enhanced and processed on specialized computer equipment.

Traditional photography using a standard aerial camera is a relatively economical and reliable aerial reconnaissance method. Film is inexpensive and has the advantage of being capable of enlargements for interpretation purposes. A darkroom capability is required, however, which could prove to be a difficult provision in remote or isolated areas. Aerial photography is restricted to fairly high light levels and must be acquired during daylight hours, usually between 10:00 a.m. and 2:00 p.m. Cloud cover can also pose a serious problem for aerial photography.

Recently, a relatively new concept in solid state signal processing and imaging has given rise to electro-optical systems known as charged-coupled devices or CCDs. Unlike aerial photography, CCD systems record imagery onto a magnetic tape and is viewed on a television monitor. CCD imaging systems are available as small, light weight portable units which can be readily installed for aircraft operations. Compared to aerial camera systems, CCDs are relatively expensive, but very effective and reliable sensors.

The acquired imagery from CCD systems is normally in the visible portions of the spectrum, but can be filtered for specific applications. The imagery produced is recorded onto videotape for immediate use as a very high resolution source of surveillance information. Ancillary information such as positional information and time/date can be overlaid on the CCD image for cataloguing purposes.

CCD imaging systems have similar restrictions to those for normal photographic cameras. Their use is restricted to the daylight hours in relatively good weather conditions. There are CCD systems which can operate in low light level conditions but their resolution characteristics are reduced as a result. CCD data is recorded digitally, however, and has the capability of being manipulated for interpretation purposes by computers.

The evolution of CCD camera systems has led to the development of long range optical photography (LOROP) systems. These cameras can produce very high resolution imagery from a considerable stand-off distance from the target. The average cost of three to five million dollars per system, however, may be a prohibitive factor.

Multispectral camera systems, one form of electro-optical sensor, consist of electromechanical linescanning devices or pushbroom scanners. Several channels of multispectral data can be recorded or viewed simultaneously. These scanning systems can image and record very narrow spectral wavelengths, a feature that is particularly useful when imaging camouflaged targets. The data reduction and image processing required to produce imagery from these sensors can be a complex operation requiring radiometric and geometric corrections.

Resolution from airborne optical sensors is determined mainly by the altitude of the aircraft platform during data acquisition. A spatial resolution of 0.15 cm is obtainable from flying heights of 305 to 915 m above ground level.

Optical Sensors for Peacekeeping

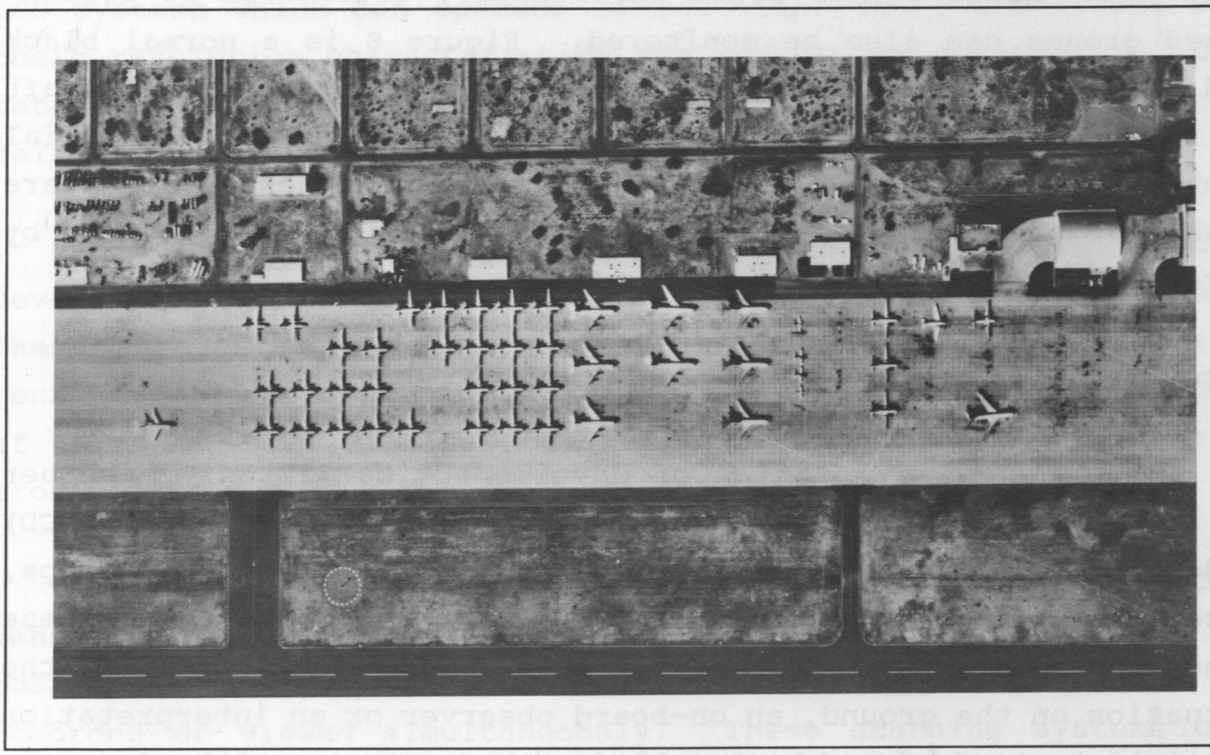
Aerial cameras, charged coupled devices and multispectral scanners have great potential for United Nations peacekeeping operations. Airfield activity, selected installations, tank storage areas and ship docking areas can be readily monitored. Base camps along border zones and military activities of ground-based groups can also be monitored. Figure 8 is a normal black and white aerial photograph over an airfield. Note the aircraft on the runway and the resolution obtainable from standard aerial photography. Because of their high resolution these systems are highly recommended, despite the limitations on their use posed by adverse weather conditions and darkness.

Interpretation of Daytime Optical Imagery

The interpretation of daytime optical imagery, whether it is normal aerial photography or charged coupled device (CCD) video data, is based on seven basic principles. These are: shape, size, tone, shadows, pattern, location and texture. Using these concepts as an interpretation guide as well as understanding the situation on the ground, an on-board observer or an interpretation specialist should be able to obtain information readily from the imagery provided.

Interpretation of aerial optical imagery will be conducted from either photographic negatives or prints, or from videotaped CCD data, depending on the system used during data collection. The electro-optical imagery has the capability of being downlinked in real-time from the aircraft to a ground processing station if required. An additional advantage of an electro-optical sensor over photographic systems is that the on-board observer can conduct immediate analysis of the imagery on the aircraft; normal photography requires processing of the negatives and prints on the ground. CCD sensors can also be used in low light level conditions while aerial photographic systems require

FIGURE 8 Airphoto of Aircraft



Aerial photography can provide some of the highest resolution available at the most economical cost of all the airborne imaging systems. This black and white photograph over an airfield shows a number of mothballed aircraft. (Image courtesy of Dorschner Intelligence Specialists) a high sun angle to produce useable imagery. The cost of electro-optical systems may be a prohibitive factor, however, with typical prices of approximately (US) $250,000.

Satellite Imagery

Current overhead commercially available satellite imagery might be used to provide some kinds of information to support United Nations peacekeeping operations. There are, at present, two sources of commercially available satellite imagery which have sufficient resolution to be of use for United Nations peacekeeping support: the French SPOT satellite program and the Soviet Soyuzcarta satellite program. Imagery from the American LANDSAT satellite program is also available, but with resolutions of not less than 30 m this imagery would not be useful in mapping smaller features on the ground.

SPOT

The French SPOT-1 and recently launched SPOT-2 (Systeme Pour l'Observation de la Terre) satellites supply digital satellite imagery with a high spatial resolution. The two High Resolution Visible (HRV) sensors provide three-channel multispectral images with a resolution of about 20 x 20 m or single-channel panchromatic images with 10 x 10 m approximate resolution on the ground.

Table 2 outlines the general spectral, spatial and radiometric characteristics of the SPOT HRV sensors. The panchromatic mode is intended for users requiring fine geometric detail as would be required for peacekeeping support. The bands provided in the multispectral mode were optimized for analysis of vegetation which will typically have a response peak in the green band, strong absorption in the red band and a pronounced response in the near-infrared band.

[redacted] **TABLE 2 Characteristics of SPOT Satellite Data**

	PANCHROMATIC	MULTISPECTRAL
Swath Width	60 to 81 km	60 to 81 km
Spatial Resolution	10 to 13.5 m	20 to 27 m
Spectral Bands	0.51 to 0.73 um	0.50 - 0.59 um (green) 0.61 - 0.68 um (red) 0.79 - 0.89 um (near IR)
Radiometric Resolution	64 gray levels	256 gray levels

[redacted] **TABLE 3 Characteristics of Soyuzcarta Satellite Data**

	MK-4	KFA-1000
Number of Channels	4	1
Focal Length	300 mm	1000 mm
Frame Format	180 x 180 mm	300 x 300 mm
Scale (depending on altitude of survey)	1:650,000 1:1,500,000	1:220 - 280,000
Longitudinal Overlap	60%	60%
Width of the Survey Band	120 - 270 km	120 km
Possible spectral bands of channels (nm)	635 - 690 nm 810 - 900 515 - 565 460 - 505 580 - 800 400 - 700	560 - 670 nm 760 - 810
Resolution	6 m	5 m

The HRV instrument operates as a pushbroom scanner. Entire lines of imagery are collected at once using 6,000 charge-coupled device (CCD) detectors arranged in linear arrays. The motion of the satellite provides the second dimension for the image. Use of a pushbroom scanner eliminates geometric distortions caused by acceleration and deceleration of the oscillating mirror used in mechanical scanners.

The HRV sensors have the capability to operate over a range of look angles out to 27° from vertical. A strip selection mirror for each sensor can be instructed from the ground to observe areas of interest which are not directly beneath the satellite, providing a 950 km wide observable corridor centred on the satellite's ground track. The width of the imaged area on the ground will vary from 60 km if the area was directly beneath the satellite to 81 km if the image was acquired obliquely. Lengths of the imaged scenes remain constant at about 60 km.

If the satellite were only capable of vertical viewing, it would be possible to image a particular location only once during the 26-day orbital cycle of the satellite. Oblique viewing provides the means to collect images more frequently for a particular site.

Soyuzcarta

Recently, the Soviet Soyuzcarta satellite program has made data available for public use. Data is available for all areas of the world with the exception of the USSR, Eastern Europe, China, Vietnam, North Korea, Afghanistan, Mongolia and Cuba. However, special acquisition in these areas will be considered, if requested. Two types of photographic imagery are available, the KFA-1000 imagery and the MK-4 photographic data, both having approximately five meters resolution capability. Table 3 outlines the characteristics of the MK-4 and KFA-1000 camera systems.

The KFA-1000 photography is available in both panchromatic and colour formats at a purported 5 m resolution. The KFA-1000 images are taken by the satellites two photographic camera systems and is jettisoned back to Earth and retrieved and processed for subsequent distribution. Each image covers an area approximately 80 km by 80 km in size, on a negative of 30 cm x 30 cm. There is 60 percent north-south overlap for stereoscopic coverage. The colour film is spectrozonal in nature, with two individual emulsion layers. The colour of the final photographic product depends on the number of filters used during film processing.

The KFA-1000 is a photographic product, but work is now underway to digitize the negatives to provide a digital format compatible with SPOT data. All digital data is produced from the original film positives or negatives.

The MK-4 system is the most sophisticated of the Soviet Union's large format topographic cameras. This system is a multispectral camera recording four separate black and white images which may be combined to produce a colour image. The resolution of the MK-4 imagery is approximately 6 m.

Photographic products are available in either film negative or positive format or prints. The area covered on the ground by the MK-4 data is 160 km by 160 km. Digital products are available for the MK-4 data and are produced from the digitization of the first generation film positives or negatives.

Satellite Imagery for Peacekeeping

Commercially available satellite imagery can be usefully incorporated into the United Nations peacekeeping operations for some ancillary applications.

Before the peacekeeping forces first arrive on site, they should become familiar with the area in which they will be operating. For example, it would be desirable to have a complete and accurate record of the existing road network to facilitate their own operations, such as organizing patrols to monitor for potential infiltration of military forces into a buffer zone. Existing maps may be inaccurate and will almost certainly not include some specific types of information which would be of interest to the peacekeeping forces.

Useful information could be interpreted from panchromatic SPOT imagery in the form of 1:200,000 scale transparencies. Using this small scale, features such as roads and encampments could be interpreted but any fears regarding potential use of the imagery for intelligence gathering purposes could be largely avoided. Results of the interpretation could be transferred to the existing basemaps for use in the field. Optionally, photographic prints of the imagery could also be made for use in the field.

Satellite imagery can be acquired for a specific location of interest for which precise latitude and longitude coordinates are known. A photographic print of such an image could be used by patrols as a guide to the locations of buildings and other features which would be large enough to be evident on commercially available imagery but are not usually marked on maps.

Satellite data could be used to detect change over a specified target area over a period of time. If large scale changes were scheduled to occur at a specific site, such as the construction or destruction of buildings, satellite imagery could be used to confirm or refute that such changes were occurring. Limitations on the spatial resolution and timeliness of commercially available imagery precludes its use for change detection applications which might be considered intelligence gathering, such as the detection and tracking of convoys of military vehicles. In this way, the use of commercially available satellite imagery might be acceptable within a peacekeeping context.

There are several factors that must be considered if satellite information is to be used for map updating purposes for United Nations peacekeeping. Time to order and process the satellite images for a specific site can be a limiting factor if speed is required. Satellite images can take as long as one month to arrive once ordered, although special requests are sometimes considered. The frequency of the satellite overpasses of an area of interest is dependent on the repeat cycle of the particular spacecraft. For example, the SPOT satellite overflies the same point on the ground approximately every 26 days. Therefore, a careful catalogue search must be done before any data is chosen and ordered. The spatial resolution of satellite imagery restricts the use of such data to large scale mapping such as major construction projects of large buildings or transportation systems.

In contrast to commercial satellite systems, airborne imagery is much more versatile and flexible. It can be acquired over any particular area at almost any time required assuming an aircraft and sensors are available. Delays in obtaining the information are minimal and the resolution of the images is generally superior to that provided by satellite data.

IV. AIRBORNE REMOTE SENSING PLATFORMS

The characteristics of an airborne remote sensing platform for peacekeeping forces is of considerable importance. The aircraft must be capable of carrying a sensor payload which could be effectively used in a specific terrain environment and it must be able to safely transport the crew in order to conduct its mission. Long range endurance must be provided with sufficient fuel capacity to ferry the crew and sensors to the target, conduct a particular mission, and return the crew to a predetermined base. It is most probable, for peacekeeping support, that the aircraft would be operating from remote airstrips and would therefore, require a short take-off and landing (STOL) capability. It should have sufficient power to quickly climb to a safe altitude away from any mountains below.

The type of sensor systems and data acquisition parameters have a direct influence on the type of aircraft suited for a particular peacekeeping surveillance role. High level synthetic aperture radar missions above 9,000 meters require aircraft pressurization. Lower level FLIR and IR missions require slower operating speeds (100 knots) and low flying altitudes of 300 m in order to obtain high resolution thermal images.

On patrolling missions where the detection of an aircraft may seem threatening to some parties below, it is desirable to have a relatively quiet aircraft. This is not to imply that the operation is a covert activity, but only to ensure a measure of safety for the flight crew if operating in an area of possible hazardous confrontation.

Other airborne platforms that are available for monitoring purposes include helicopters, balloons, dirigibles and remotely piloted vehicles (RPV). Helicopter mounted sensors systems could be considered as an optional platform for obtaining overhead imagery for peacekeeping applications in some contexts. The relative operating costs to fixed wing aircraft, however, should be recognized: helicopters are approximately twice as expensive to operate and maintain than fixed wing aircraft of comparable size. Helicopters are also generally restricted to visual flight rule (VFR) conditions and are restricted in their ability to fly in adverse weather or instrument flight rule (IFR) conditions.

Balloons or Small Aerostatic Surveillance Systems (SASS) are now operating in reconnaissance modes for aircraft surveillance purposes in the United States. These SASS platforms use a high resolution air to air radar system for the tracking of suspicious aircraft. They are tethered by a cable which doubles as a data link route to a ground receiving station. The main disadvantage of these systems is their limited ability to move to a different area. As a result, a series of SASS balloons is required to provide overlapping coverage. The cost for such a program is so high that it would be hard to justify its use for United Nations peacekeeping operations.

Manned dirigibles might be of use to a United Nations peacekeeping force for reconnaissance purposes. These platforms can carry large payloads, have a long flight duration capability, and would be cost effective in terms of maintenance and operation. Dirigibles, however, are very susceptible to weather conditions due to their size, require large ground support resources and are relatively slow in moving a crew and sensors from one location to another. Storage of these platforms requires a large facility, one which may not be available in some of the remote locations where the United Nations peacekeepers operate.

Remotely piloted vehicles (RPVs) have been used for tactical surveillance in situations where the threat to human life is high enough to warrant no direct human interaction. RPVs are restricted to line-of-sight to facilitate their effective launch and continuous control. Therefore, in hilly or mountainous terrains RPVs would be virtually useless. RPVs cannot carry large payloads and have a limited range and endurance due to fuel restrictions. Maintenance and staffing for an RPV is similar to that required for an aircraft.

Airborne platforms discussed below for United Nations peacekeeping operations will be restricted to fixed wing aircraft. This is not to say that some of the unmanned platforms and balloons mentioned previously are without potential in peacekeeping activities. But these systems do not have the flexibility required in terms of mobility and costs that fixed wing aircraft can provide to United Nations peacekeeping.

Reconnaissance operations for United Nations peacekeeping activities would require two classes of aircraft; light to medium twin engine fixed wing aircraft (up to 6,800 kilograms) and specialized high powered single engine aircraft.

Twin Engine Aircraft

Aircraft capable of carrying a SAR sensor as its prime payload must be twin engined. SAR systems weigh typically on the order of 400-500 kilograms. This weight, combined with the additional weight of a systems operator, a pilot and perhaps on-board United Nations observer and their associated supplies, justifies the requirement for a twin engine turbine powered platform. The airframe must be spacious enough within the cabin to allow for the installation of SAR system equipment. The aircraft must also be capable of carrying an externally mounted antenna system with sufficient clearance beneath the fuselage for adequate aircraft performance.

Proven examples of aircraft types which could adequately carry a SAR system are the Cessna Conquest 441 and the Beechcraft King Air 300. These platforms are turbine powered aircraft which have sufficient power and space for a complete SAR installation package. There are a variety of other suitable twin engine platforms produced internationally which could be used for a SAR platform. It should be noted, however, that there is a substantial amount of structural engineering work required for installation of a SAR into an aircraft platform.

The average maximum operating altitude of these twin engine aircraft is 9,300 meters with an average cruise speed of approximately 250 nautical miles per hour. Typical endurance is five to six hours at cruise speed, with long range capability of seven to nine hours possible with the addition of extra fuel tanks.

There is a broad array of used twin engine aircraft available within the aviation industry. A used, fully functional twin engine platform with avionics could be acquired for approximately (US) $750,000. A new aircraft would cost between (US) $ 1 - 1.3 million dollars.

Single Engine Aircraft

The second category of appropriate aircraft includes a very specialized, high powered single engine platform. There are very few of these type of aircraft available but one example of is the Turbo Thrush. This aircraft was originally designed for agricultural crop dusting and seeding purposes. Special models of have been produced with reconnaissance and surveillance applications in mind. The Turbo Thrush is an ideal platform for such imaging systems as an infrared linescanner, a FLIR or an electro-optical camera system.

In peacekeeping operations in remote locations, the Turbo Thrush provides a short takeoff and landing capability, under 230 m at normal surveillance mission weights. The Turbo Thrush can fly at very slow airspeeds (70 knots), a requirement for maximizing the usefulness of FLIR imagery. The endurance of this aircraft is seven hours, an essential characteristic when patrolling requirements are addressed.

The Turbo Thrush has a very high powered engine with 1376 horsepower. It has been designed to climb rapidly to ensure the safety of its crew if operating in a mountainous environment or in places of possibly hazardous confrontations. The maximum speed of the aircraft is 200 knots.

The cost of the Turbo Thrush, compared to the price of a twin engine aircraft is relatively expensive at (US) $750,000. This is mainly due to the modifications required to configure it for surveillance applications. Maintenance costs, on the other hand, are minimized for the Turbo Thrush. Approximately ten minutes of maintenance per flight hour is required.

The Turbo Thrush seats two people, a pilot and a systems operator. During a reconnaissance mission, the operator typically provides instructions to the pilot based on the imagery provided by the FLIR, linescanner or optical camera system.

V. COSTS

Remote sensing technology has provided many countries with support in environmental and engineering monitoring studies. Canada, for example, has developed a very strong base in the development of sophisticated remote sensing hardware, their operation and in the processing of data. There are a number of private commercial airborne remote sensing firms with a strong base in data acquisition, image processing and interpretation, and analysis of a variety of remotely sensed data products. While the description of many of the sensor systems and the airborne applications described in this report is based on what is available from Canadian commercial remote sensing companies, similar capabilities exist in other countries. These airborne remote sensing services are a result of decades of sensor and program development for specific applications.

The United Nations has three general options in terms of acquiring airborne remote sensing for peacekeeping operations:

1) purchasing off-the-shelf remote sensors and installing them into aircraft and operating the systems itself;
2) leasing complete sensor outfitted aircraft including the service to operate and maintain these systems; or
3) having the system contributed by member states to particular peacekeeping missions.

The following discussion will focus on the first two options. There is a considerable difference between the cost of purchasing versus the cost of leasing commercially available remote sensing systems.

Purchasing

Buying remote sensing systems and aircraft platforms is the more expensive option open to the United Nations because of the capital costs involved. If the sensors are to be installed into a new aircraft, there is a considerable cost to modify the aircraft before sensor integration can occur. (Of course, this capital cost could be reduced if a suitable aircraft platform or sensors was contributed by a member state.) Another expense that the United Nations would incur with buying sensors and aircraft would be the cost of training pilots, sensor operators, engineers and image interpretation specialists. Proper and adequate training of personnel is a time consuming venture with an expected duration of three to four months required for a staff of fifteen to twenty people. The skills required would also require very specialized training.

Other costs to consider if a remote sensing system were purchased and operated by the United Nations would be annual carrying costs of the capital equipment, miscellaneous sensor and aircraft parts and spares costs, aircraft operating costs and staffing costs. Table 4 summarizes the estimated costs for the provision of two aircraft outfitted with a SAR, a FLIR, an infrared linescanner and an optical camera system. The cost includes the aircraft, the sensors (including sensor integration), and parts and spares.

A principal disadvantage with the purchasing option is the problem of keeping the aircraft and related systems busy when not directly involved in a United Nations peacekeeping program. One possibility could be to utilize the systems and the imagery provided for environmental monitoring or mapping applications.

[redacted] **TABLE 4** **Typical Airborne Remote Sensing System Costs**

	ANNUAL LEASE ESTIMATES*	PURCHASE ESTIMATES**
Sensors		
Synthetic Aperture Radar (SAR)	4,500,000 U.S.	7,100,000 U.S.
Forward Looking Infrared (FLIR)	500,000	800,000
Infrared Linescanner	400,000	600,000
Photographic/E/O System	200,000	300,000
Aircraft		
Two aircraft platforms, one twin engine, one single engine including parts and spares	2,000,000	3,900,000
Training	19,000	200,000
Staffing	2,500,000	2,500,000/year
Carrying Costs	- -	1,700,000
TOTAL	10,119,000	17,100,000

* These costs include all associated costs to provide a complete turn key service for a one year airborne reconnaissance program including 300 missions for a total of 2000 flying hours.

** These costs do not include costs for maintenance, depreciation and operations.

Leasing

Leasing complete remote sensing reconnaissance services on an annual or pre-selected time basis has several advantages for the United Nations. Leasing of aircraft and sensors together with imagery interpretation services would free the United Nations from carrying a financial burden for an extended period of time. Leasing would also enable the United Nations to use an airborne system only when required. Contracting a commercial firm which specializes in airborne remote sensing services would provide the United Nations with the least overall cost with maximum flexibility in terms of required operating timeframes. Provision and training of staff would not be necessary if a leased system were used. The contractor would be responsible for a complete "turn-key" service, providing the United Nations with a package that could be designed to meet the needs of the peacekeeping forces, including the analysis of overhead imagery. A United Nations on-board observer or sensor operator should be trained, however, to act as the liaison between the contractor and the United Nations force.

Table 4 shows the estimated annual lease costs for a remote sensing system and the costs associated with the purchase of a facility. The costs are not directly comparable, but they provide a relative perspective of the expected expenses.

A third alternative for the acquisition of an overhead sensing system would be the borrowing of the necessary equipment and related resources from a contributing United Nations member. Expenses associated with this option for the United Nations would likely include the manpower, operating and maintenance costs of the remote sensing program for the duration of the peacekeeping mission.

VI. ORGANIZATIONAL STRUCTURE

The framework, structure, and organization of an overhead reconnaissance program for United Nations peacekeeping operations are important considerations. Guidelines and methods by which an effective and efficient operation is to be implemented must be outlined so standard procedures are ensured.

Standard Operating Procedures

Standard operating procedures are generally designed for every peacekeeping operation to suit the particular requirements and circumstances of the situation. In the case of the initiation of a regular airborne patrolling network as well as ad hoc aerial reconnaissance missions, standard operating procedures would include several key aspects. Command and control of the operation by the Force Commander must be understood: the airborne observation team must know to whom they report and from whom they take orders. United Nations control of all aspects related to the operation is essential and can be accomplished with regular briefings given to operations headquarters and newly arrived contingents or units within an area.

The standard operating procedures for an airborne reconnaissance program should also include a complete section on information reporting. Aerial surveillance and patrolling techniques can gather a tremendous amount of information covering a wide area of interest in a relatively short period of time. To use effectively the information gathered by this method, standardized reporting procedures must be implemented. Speed, accuracy and proper analysis of this data is essential. Operational information may have to be transmitted laterally, as well as vertically, to all United Nations officers who could be affected and concerned.

Basic instructions for night flights, limitations on flying and any special directions given for specific types of missions must be outlined in the standard operating procedures. Night patrols have traditionally been frowned upon and discouraged in United Nations operations, mainly because of identification problems and the understanding that information gained during night observation missions is minimal. However, airborne patrolling using imaging infrared sensors can provide a safe means of acquiring very useful information at night.

Flight restrictions over areas of possible danger must be outlined and understood to ensure the safety of the United Nations airborne patrolling mission. In the case of ONUCA, for example, where aircraft and helicopters might be flying through the airspace of five separate nations, arrangements with host countries' authorities might include:

a) establishment of visual corridors to cross borders;
b) identification of flight plan routes;
c) proper use of colour, marks and call signs;
d) adequate communications; and
e) the location of refuelling services.

VII. AIRBORNE OPERATIONS

An airborne reconnaissance system operating as support for a United Nations peacekeeping mission would be part of the Air Operations component of the force. Air Operations would be under the command of the Force Commander located at the Force headquarters.

For an airborne reconnaissance program to be effectively used, an United Nations Air Liaison Officer (ALO) should be assigned. All requests for overflights would be addressed to the ALO. The ALO would be the direct link between the aircrew and the United Nations peacekeeping force. The ALO would be responsible for briefing the pilot and on-board observer to ensure the aim and purpose of the mission is fully understood and all flight parameters are outlined clearly. It is the pilot who ultimately makes the final decision on conducting the mission, based on his analysis of the situation, to ensure safety for the crew.

Information received as a result of the overflights would be relayed by the ALO or, possibly, by the on-board observer to individual sector commanders. The utility of the information gained will determine who would receive the information. This decision should be made immediately by the ALO or the on-board observer to ensure the timely use of the information collected. "Operations Immediate" information must be effectively transmitted to all who will be affected. If appropriate, this information should be reported vertically to the higher ranking peacekeepers, especially if deemed as operations immediate. The reporting of relevant information should include copies to the Military Information Officer and his staff. The Military Information Officer would be responsible for updating maps with the latest information. Imaging airborne sensor and satellite data could prove to be a useful in this regard. Routine information of a general nature gathered during overflights would be archived in an appropriate database under procedures established by the United Nations for a specific area or topic.

Possible Airborne Patrol Procedures

Before any airborne patrol can fulfil its mission as effectively as possible, a particular and well defined set of procedures must be established. According to the Peacekeepers Handbook there are three phases to a patrol operation:

1) Mission planning, preparation and briefing;
2) Mission execution; and
3) Debriefing and reporting;

Mission Planning, Preparation and Briefing

The objective of the aerial patrol should be understood by all individuals involved, most likely including the Air Liaison Officer, the pilot and the on-board United Nations observer. These objectives and aims will be determined by the nature of the original request for overflight reconnaissance support. The sensor selection and the time of day for the flight will be a direct function of the target of interest and the type of information required over that site. For example, a nighttime mission using the FLIR or infrared linescanner would be appropriate, if most of the type of activity previously reported had occurred after sundown.

During mission planning, the transit routes to be followed, flight lines and altitudes over particular targets of interest would be determined. Existing information on the patrol area and imposed restrictions over these areas or enroute to the target would be checked. Each member of the aerial patrol would be briefed prior to departure.

Mission Execution

During the execution of the mission it is important for the crew to follow the patrol flight plan as closely as possible. Continuous radio contact with an established ground-based patrol base or verification centre would be maintained. Observations of ground-based activity would be made and recorded as a written record.

Sensor information would be acquired over the previously designated target areas and recorded onto the appropriate medium for further processing and analysis. Observations made from any real time imagery available on-board the aircraft would be made, recorded, and if necessary, transmitted via radio link to ground personnel.

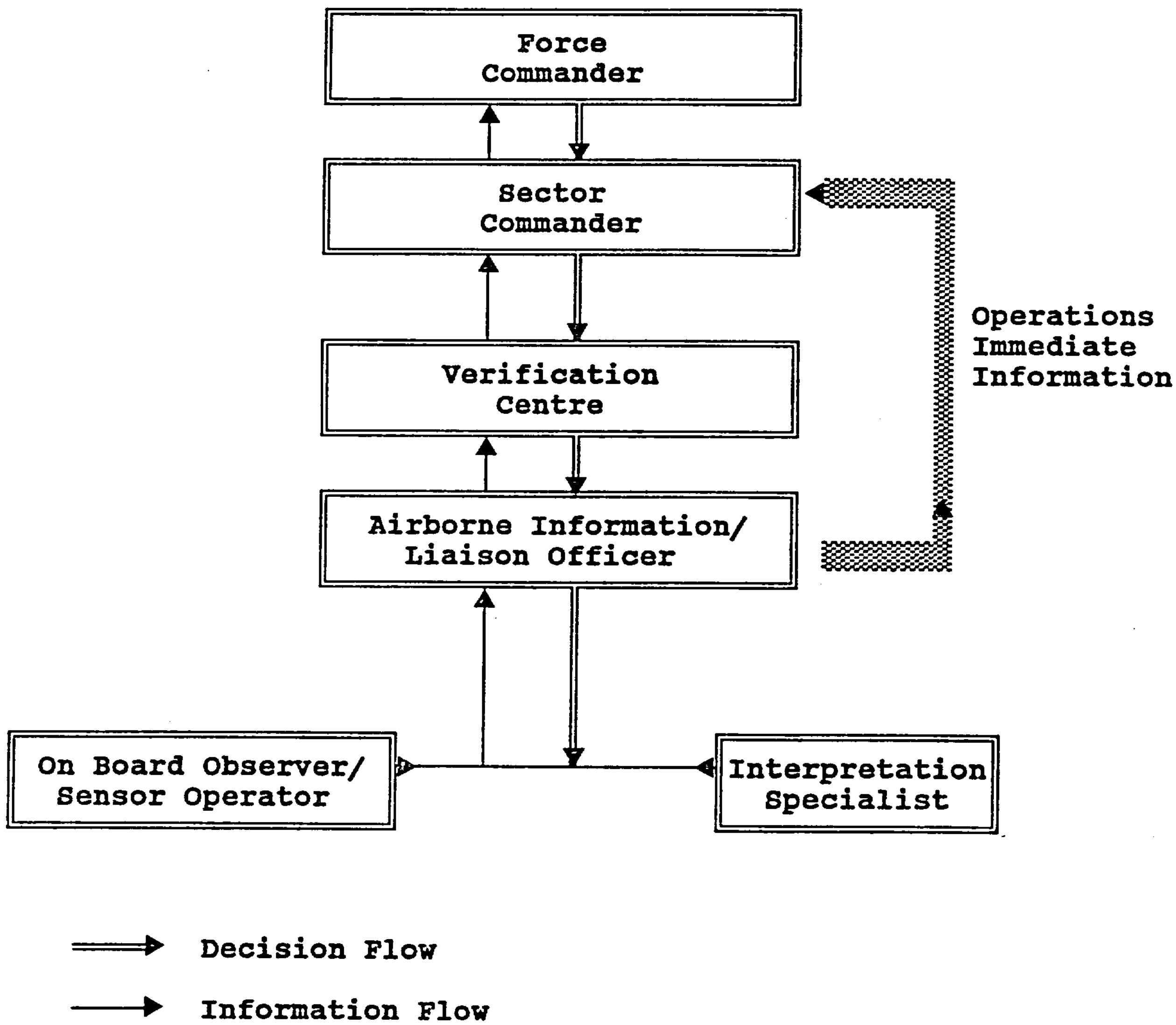
Debriefing and Reporting

After return of the patrol aircraft, the crew would report immediately for a debriefing session. Detailed written reports would be provided on observations made and the flight parameters followed. Log sheets for aircraft and sensor usage would be completed.

Sensor data such as FLIR or electro-optical video tape or aerial photographic negatives would be processed, reviewed and interpreted as soon as possible at the operations base. A summary report detailing basic information gained from the sensor data would be compiled by the on-board observer and forwarded to the Air Liaison Officer for distribution to appropriate personnel.

Figure 9 is a block diagram of how the airborne patrol might operate and report.

[redacted] FIGURE 9 Flow Chart for Reporting Procedures and Control of Aerial Patrol Information



Flight Limits

The time that the aircrew could effectively operate could be determined by the rules and regulations as adopted by the air survey industry. In general, aircrew members are restricted to 120 hours of air time per 30 day period, 300 hours of air time per 90 day period or 1,200 hours total air time per year. Crew members normally operate on a 15 hour duty day with a 24 hour rest day provided if a duty day is exceeded. The United Nations on-board observers/sensor operators would fall into this category and be considered as air crew.

Mission Scenario

In order to illustrate how airborne remote sensing could be incorporated into United Nations peacekeeping operations a hypothetical mission scenario is outlined below. The most recent United Nations peacekeeping observer force ONUCA in Central America will be used for illustrative purposes as the location for this sample mission scenario. The scenario outlined assumes that the missions in question are responding to specific information requests. It is also probable that missions would be flown on a routine basis to provide regular updates to the United Nations peacekeeping command's database.

Information Request Scenario

Tegucigalpa, Honduras. HQ ONUCA 14:30 hrs local time. There have been reports by observers from one of the ONUCA verification centres that a number of unidentified boats were entering the Gulf of Fonseca. Their final destination and purpose are questionable. More information on this irregular activity was requested.

There have also been requests by United Nations headquarters in one of the Central American countries to obtain as much information as possible on the number of unspecified base camps located along the one of borders in the region. This census of camps is required to update existing maps.

After reviewing the requests for the required information, the Air Liaison Officer, the United Nations on-board observers/sensor operators and the pilots discuss possible mission profiles.

The recent poor weather and low cloud conditions, especially in the mountains, would make visual monitoring of the points of interest by light helicopter risky. It has been decided that the SAR high flying aircraft should be used to map the border zone for the camp census request. The SAR has proven to be an all weather sensor, and its 25 km stand-off imaging capability will ensure that the crew are out of immediate danger from small arms fire below. A flight altitude of 10,000 meters has been determined as well as the optimum transit route to the area and specific flight lines to be flown parallel to the border in question. The flight crew has been selected; one pilot, one United Nations observer and one sensor operator.

The request for informational support on the nighttime movement of suspicious boat activity in the Gulf of Fonseca has been reviewed. Since the majority of previous illicit movement has been reported at night, it has been decided to use the low flying single engine aircraft equipped with FLIR sensors. The FLIR aircraft will fly at 1,800 m above the water and will monitor any boating activity. Information on specific targets viewed by the FLIR will be forwarded by radio link to United Nations patrol boats. Once the United Nations naval patrols have intercepted the target boat, the FLIR aircraft will loiter overhead at an altitude of 600 m to monitor activity and obtain a videotape of occurrences for United Nations records at HQ ONUCA. On completion of the FLIR patrol mission, the aircraft will land and provide the United Nations verification centre with a summary report and any copies of relevant videotape material.

Flight maps showing the routing of the two aircraft during transits and while acquiring imagery will be compiled and forwarded directly to the nearest Air Traffic Control which will in turn forward by radio all relevant information on the flight plan to other appropriate Air Traffic Control centres.

Flight clearance requests have been facilitated as a result of previous United Nations freedom of movement agreements. The detailed flight plan will be approved or rejected as soon as possible by the Air Traffic Control centres according to standard international rules.

<u>17:30 hr local</u>. Flight clearances have been approved for both aircraft as outlined in the submitted flight plans. Flight crews are alerted and briefed on the mission requirements and parameters.

<u>21:00 hrs local - HQ ONUCA</u>. The SAR aircraft departs enroute to the border area.

<u>21:30 hrs local - HQ ONUCA</u>. The FLIR aircraft departs enroute to the Gulf of Fonseca after initial radio communication to alert United Nations naval patrols.

<u>21:40 hrs local</u>. The SAR aircraft commences the first of six flight lines along border zones. High resolution (6 m resolution) imagery is acquired over the 60 km area of known intense base camp activity. The flight lines are oriented in

different directions to ensure that there is no obstruction of the terrain caused by shadows produced by the SAR sensor. Real-time imagery is recorded onto film to highlight highly reflective targets such as small buildings or large vehicles. The data is also recorded on magnetic tape so that additional copies of the imagery can be produced on the ground following the mission. The on-board observer identifies and marks all areas resembling base camp activity on the imagery. These will be compared later to known areas indicated on existing maps by the interpretation specialist and new possible zones of activity will be identified. The interpreted information will be forwarded to the requesting United Nations headquarters. The imagery and magnetic tape will be stored in the secure storage area at HQ ONUCA.

23:15 hrs local. The SAR mission ends and the aircraft returns to base.

21:43 hrs local. The FLIR aircraft commences flight lines at an altitude of 1830 m above the Gulf. The on-board United Nations observer/sensor operator utilizes the FLIR system to scan the water below looking for the thermal signatures of boats and the wake action produced from the movement of boats.

Individual boat targets entering the Gulf are identified with their latitude and longitude coordinates and their heading. This information is immediately relayed to United Nations patrol vessel to cue them for inspections of individual boats. Videotapes of all relevant targets are produced.

23:00 hrs local. The FLIR mission ends. Aircraft lands with copy of videotape.

00:20 hrs local. The FLIR aircraft returns to base.

Mission Summary

After returning to HQ ONUCA the flight crews are debriefed by the on duty Air Liaison Officer and all data products are forwarded for further evaluation to the image interpretation specialists. The requesting agencies are given final results by the Air Liaison Officer as per their initial requests in the form of a summary report compiled by the on-board observer and the interpretation specialist. All image data and tapes will be stored at HQ ONUCA in a secure area. If the information is of utmost importance and is considered a high priority, the results will be given directly to the Sector Commander, otherwise it will be forwarded to individual Verification Centres.

As this illustration demonstrates relevant overhead imagery can be available very rapidly to United Nations peacekeeping forces and complete records of this data maintained for further analysis or use.

VIII. CONCLUSION

United Nations peacekeeping operations can benefit substantially from the use of overhead imagery particularly that from airborne reconnaissance aircraft. Commercial satellite imagery can be used to update pre-existing maps of an area in advance of deployment of a peacekeepers force. Aerial reconnaissance could increase the ground coverage by observer groups and could confirm information already received from other ground sources. The incorporation of special night and all-weather imaging sensors could radically increase the time in which peacekeeping forces can operate effectively within a given territory. Finally, and perhaps most important in the long run, the increased network of observation provided by an airborne reconnaissance program could also help build confidence between the parties by demonstrating the commitment of the parties involved to reducing tensions.

Real cost savings in terms of manpower could also be realized, especially when compared to traditional methods of peacekeeping observation methods. The costs of aircraft operations are relatively modest when weighed against some proposals for traditional style United Nations peacekeeping operations. An airborne program for the United Nations peacekeeping forces could be purchased and operated by the United Nations itself, donated by a host country, or be leased from a commercial firm.