CANADA

AIRBORNE REMOTE SENSING FOR VERIFICATION OF THE BIOLOGICAL AND TOXIN WEAPONS CONVENTION

MAY 1993

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PREFACE

In September 1991, the Third Review Conference of the Parties to the Convention on the Prohibition of the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction decided to establish an Ad Hoc Group of Governmental Experts open to all States Parties to identify and examine potential verification measures from a scientific and technical standpoint.

The mandate stated:

" The Group shall seek to identify measures which could determine:

- Whether a State Party is developing, producing, stockpiling, acquiring or retaining microbial or other biological agents or toxins, of types and in quantities that have no justification for prophylactic, protective or peaceful purposes;

- Whether a State Party is developing, producing, stockpiling, acquiring or retaining weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict.

"Such measures could be addressed singly or in combination. Specifically, the Group shall seek to evaluate potential verification measures, taking into account the broad range of types and quantities of microbial and other biological agents and toxins, whether naturally occurring or altered, which are capable of being used as means of warfare.

"To these ends the Group could examine potential verification measures in terms of the following main criteria:

- Their strengths and weaknesses based on, but not limited to, the amount and quality of information they provide, and fail to provide;
- Their ability to differentiate between prohibited and permitted activities;
- Their ability to resolve ambiguities about compliance;
- Their technology, material, manpower, and equipment requirements;
- Their financial, legal, safety and organizational implications;
- Their impact on scientific research, scientific cooperation, industrial development and other permitted activities, and their implications for the confidentiality of commercial proprietary information.

In March/April 1992, the Group held its first meeting and compiled lists of potential verification measures in the three broad areas of <u>development</u>, <u>acquisition or production</u>, and <u>stockpiling or retaining</u>. The lists, containing twenty-one potential verification measures, were considered indicative and requiring further discussion.

In November/December 1992, the Group held its second meeting and concluded the general "examination" phase of the twenty-one measures. This established a consensus baseline representing a factual description of the examination from which to move forward to the more detailed "evaluation" phase. Although certain initial efforts were made with regard to evaluation of certain measures, it was recognized that a good deal more detailed work would need to be done in preparation for the next Group meeting, May/June 1993.

Moderators and Rapporteurs were requested to continue to assist the Group in its work. Rapporteurs were requested to prepare introductory papers on their respective measures to facilitate their evaluation.

This introductory paper entitled "Airborne Remote Sensing For Verification Of The Biological And Toxin Weapons Convention" constitutes fulfilment of the Rapporteur's task with regard to that potential verification measure.

INTRODUCTION

There is at present no specific verification regime integral to the Biological and Toxin Weapons Convention (BTWC). However, Article V specifies the States Parties "...undertake to consult one another and to cooperate in solving any problems which may arise in relation to the objective of, or in the application of the provisions of the Convention." Article VI (1) also specifies a complaint procedure with regard to a "... breach of obligations deriving from the provisions of the Convention...", which would see a State Party lodging its complaint with the Security Council of the United Nations. "Such a complaint should include all possible evidence confirming its validity...."

It is worth recalling two of the Sixteen Verification Principles agreed by consensus in a Working Group of the United Nations Disarmament Commission and subsequently endorsed by the United Nations General Assembly in Resolution A/RES/43/81(B) dated 1 December 1988. These two particular principles say:

- "Adequate and effective verification is an essential element of all arms limitation and disarmament agreements."

- "Adequate and effective verification requires employment of different techniques, such as national technical means, international technical means and international procedures, including on-site inspections."

It is reasonable, then, to contemplate verification of the BTWC in terms of mutually supporting and well defined measures contributing to the consideration of "all possible evidence" that may support a judgement of compliance or non-compliance with obligations under the Convention. The UNDC report on "Verification in All its Aspects", and the corresponding UNGA Resolution, recognized that the effectiveness of verification can be enhanced through the synergistic effects of interacting verification measures.

This paper is intended to contribute to the evaluation of airborne remote sensing as one of a number of potential measures for the verification of compliance with the BTWC. It will attempt, where possible, to address specific observations to the three areas of activity of interest (development, acquisition or production, and stockpiling or retaining), recognizing that clear descriptions and delineations of these areas of activities do not exist. Finally, in relation to the criteria, it must be recognized that there are overlaps. Thus, in addressing the "strengths and weaknesses" of certain measures, these may be seen not only in terms of some inherent technical properties, but also described in terms of "their ability to differentiate between prohibited and permitted activities", and in terms of "their ability to resolve ambiguities about compliance". As a result, this paper's commentary is addressed to what is, in effect, a composite of these three criteria. Similarly, in discussing the technology requirements, it seemed appropriate to mention costs at the same time rather than have to repeat the listing of all of the technologies under the subsequent criterion relating to financial implications. It was the author's belief that this would lead to a sharper image and less repetition.

SETTING THE SCENE: THE CONTEXT

The general examination of Surveillance by Aircraft (BWC/CONF.III/VEREX/WP.75) highlighted the limitations that apply to airborne sensors in relation to the ease with which prohibited activities may be hidden or camouflaged, and in relation to the difficulty to differentiate between prohibited and permitted activities. These observations, clearly, were directed at the ability of airborne sensors in the first instance to detect prohibited activity. The thrust of the discussion was not that such detection is impossible, but rather that a treaty violator would need to make a number of very serious mistakes before airborne sensors might even have an opportunity to detect a treaty violation. Proceeding with an analysis of this kind would make any conclusions scenario-dependent, and would not be very satisfactory. It would always be possible to develop a scenario in which all sensors could be defeated. This might lead to the erroneous conclusion that airborne sensors have nothing to offer.

This paper focuses on the support role to be played by airborne sensors, in conjunction with other verification measures.

Assumptions

1. Aerial inspection would take place within a cooperative framework and its application would be agreed by all State Parties to the Convention;

2. Any aerial inspection regime related to the BTWC would be under the jurisdiction and control of an internationally recognized organization, such as a BTWC Secretariat or the United Nations, and all imagery collected would remain under the control of this organization;

3. All imagery and data collected as a result of an aerial inspection would be used by the BTWC Secretariat or the United Nations for the sole purpose of determining compliance or non-compliance;

4. Aerial inspections of the BTWC could include provisions for routine as well as challenge inspections as an instrumental part of the data collection and analysis capability of such a regime;

5. Aerial inspection, when conducted in conjunction with on-site inspection, could allow for loitering over the inspected facility;

6. Aerial inspections could be used for confidence-building purposes and as a transparency measure.

STRENGTHS AND WEAKNESSES
ABILITY TO DIFFERENTIATE
ABILITY TO RESOLVE AMBIGUITIES

General Comments

The concept of using aircraft as a tool for arms control verification is not a new one. If one just focuses on recent history, there are examples that are instructive to this study.

The Treaty on Conventional Armed Forces in Europe (CFE) allows for the use of national aircraft for the conveyance of an inspection team to a point of entry on the territory of the inspected Party. The CFE Treaty also makes provision for aerial inspections, although it still remains to be seen how this provision will be developed (see BWC/CONF.III/VEREX/WP.67).

The Open Skies Treaty, now in its nascent stage, will provide to many nations, not privy to National Technical Means (NTM) imagery, a source of information relevant to other arms control undertakings and complementary to them.

There is no doubt that overhead imagery could make an important contribution to peacekeeping operations, and considerable research has been undertaken in this regard.

In all of the examples mentioned above, airborne sensors were considered to play a role of general area surveillance and, thus, be complementary to other more intrusive measures or activities. In peacekeeping, for example, they can be particularly useful in updating maps (this can be precise or rough, depending on airborne platform operating constraints) and site diagrams to help prepare inspectors for deployment.

The effectiveness of any airborne monitoring regime is dependent on several key factors. One of the most important is the proper and accurate evaluation of the images that are acquired. Timely and accurate analysis and interpretation of any data collected by an aerial inspection regime is fundamental in assessing what is happening on the ground. The information gained must be properly coordinated with other types of data that are available. Aerial data are merely another information source that, when interpreted by an experienced analyst, can be utilized to make better estimates of actual events at a ground-based site.

Aerial Photography

Airborne surveillance using standard aerial photography has been utilized for decades. Aerial photography can range from very simple cost effective methods to relatively complex and expensive modes. The simplest aerial photography available is the use of hand-held 35 mm cameras taken from the window of an aircraft. This type of reconnaissance is relatively inexpensive in terms of cost of equipment required. The only cost is the aircraft operation itself, the 35mm camera and inexpensive film processing. The spatial resolution, that is, the smallest feature discernible on the ground, is relatively high using this method; however, the trade-off is a rather narrow field-of-view (swath width) of the ground surface. Hand-held photography using this method is traditionally accomplished using a low-level fixed wing aircraft or helicopter, and is usually oblique viewing. Photographs taken from an oblique angle do not allow for information that can be utilized readily for accurate mapping purposes. In the event that accurate base maps are required in preparation for a BTWC on-site inspection, this type of photography would not be adequate. The information from the oblique images would be useful for general reconnaissance purposes, however.

In the same realm of this type of aerial camera system, in terms of costs and simplicity, is the video camera. Video camera systems have progressed substantially over the past decade. The advent of charged couple device (CCD) technology has led to widespread production of accessible, inexpensive high resolution video cameras. This means can provide a complementary database to that of hand-held photography, both being acquired during helicopter overflights, and is especially useful as a portal and perimeter monitoring tool during an on-site inspection. The Open Skies Treaty currently allows for the inclusion of video cameras as part of the approved sensor suite. The main advantage of video camera imagery in aerial inspections is its ability to catalogue the activity of a particular area by automatic annotation inherent in many available camera systems. Although the spatial resolution is inferior to that of "still photography", and hard copy images are difficult to produce, video imagery does have a supporting role for other types of imaging devices.

The next level of sophistication of aerial photography is a fixed mounted, vertical looking "framing" camera system. These cameras range in format size from the simple 35mm hand-held variety, to more complex 70mm and 9 inch models. It is not surprising that cameras (including lens systems) and film become proportionately more expensive as they increase in sophistication. These cameras produce images with a noticeable increase in spatial resolution compared with hand-held cameras. Spatial resolutions in the order of 6-10 centimetres are available using these systems when flown at lower altitudes. Also, the swath coverage on the ground is considerably larger, thus providing more information over a wider area, at a greater cost. In the context of providing useful information for verification of the BTWC, framing cameras can acquire very detailed, high resolution photography for the preparation of updated base maps of a particular site. Figure 1 is a vertical aerial photograph taken by a metric framing survey camera. It should be noted that there are trade-offs in spatial resolution and swath coverage based on the altitude of the aircraft platform. The lower the altitude, the higher the resolution and the narrower the field-of-view. One therefore has to acquire more images of a particular area. The Open Skies Treaty allows for the use of framing cameras that are limited to a spatial resolution of 30 centimetres.

A special breed of aerial camera systems has been developed specifically with reconnaissance purposes in mind. These camera systems consist of two types; panoramic cameras and long range oblique photographic (LOROP) systems. Panoramic cameras were developed for military reconnaissance applications to provide very wide angle (horizon to horizon) coverage in order to reduce the number of passes over a particular target area. The advantage of modern panoramic cameras is their ability to collect stereoscopic images of a 180 degree swath below the aircraft. Within the context of the BTWC, panoramic cameras would be able to acquire considerable reconnaissance data over a wide swath of a particular area. However, because of the oblique viewing characteristics and the varying scales and spatial resolution of the imagery, precise mapping of the area would be precluded. The second type of reconnaissance cameras are the LOROP cameras. They are specialized, very expensive camera systems developed to acquire high resolution aerial photography of an area where long stand-off distances are required. Again, the disadvantage of the utilization of LOROP imagery is the oblique viewing angle of the data.

Development, Acquisition, Production and Stockpiling

If development of biological weapons were to occur within an enclosed facility, without any external distinctive features present, then the **direct** detection of a BTWC violation would be most unlikely using aerial photographic techniques. Regardless of how good the spatial resolution of the photography, only **indirect** clues of the presence of activity within an enclosed building or complex of buildings would be discernible. For example, if a specific facility were suspected in BW production, then the presence of activity within that facility could be confirmed by something as simple as the number of cars parked in the parking lot. Obviously, that in itself would not tell you much.

The effectiveness of inspections through the use of aerial photography would also be seriously degraded due to the inherent time-lags involved in flight notifications. Any developmental or testing characteristics of biological weapons that could be identified by aerial photography could possibly be camouflaged or moved in the time a flight plan was filed and clearance to enter the zone of interest was granted.

Aerial photography would be most useful in updating maps of an area of interest. New construction of buildings, transportation networks and security fences could be monitored on a routine basis. Multi-temporal images from two or more different time periods could provide important information on infrastructure changes within a particular area. Wide-swath aerial photography using wide angle lenses or panoramic cameras from high altitude aircraft can provide an abundance of ancillary information of the area surrounding a particular facility. Narrower-swath photography from lower flying aircraft platforms can provide highly detailed information on smaller features associated with specific functions of a suspected developmental or testing facility. Any information gained as a result of aerial photography, when analyzed and interpreted with skill, could be useful in providing on-site inspectors with an additional layer of information.

Any effective use of aerial photography within the context of the BTWC must take into account the weather and local lighting conditions in which overhead images are acquired. Aerial photography is weather-dependent. Aerial photographs can not be taken through clouds, and those images acquired from beneath the clouds will have resultant shadows. For example, if aerial photographs are acquired during the day beneath a cloud layer of thirty percent, then the expected shadow cast on the ground will be thirty percent. Shadows cast by these clouds will have an adverse effect on the interpretability of the imagery. Also, aerial photography can only be acquired during daylight hours, optimally two hours before and after solar noon. Useful photography can be collected for a brief period on either side of this "acquisition window", but problems in image analysis may result due to a loss in image quality. The use of specially adapted low-light cameras or special film processing techniques could be utilized to overcome some of these obstacles, however.

The verification of compliance of the BTWC with respect to <u>acquisition or production</u> of biological weapons using aerial photography is a difficult objective. The direct detection of such non-compliance using aerial images seems rather unlikely. Indirect evidence such as human activity within a suspected facility could be achieved, however, through the use of higher resolution aerial photography. Change detection of a particular area over time, combined with additional ground-based information, may provide the on-site inspector with clues as to production locations or acquisition procedures.

Monitoring of areas which may be related to the <u>stockpiling or retaining</u> of biological weapons could be accomplished using aerial photography. If the stockpiling of biological weapons components or systems, such as suspected delivery systems, occurs outside of a facility, then high resolution photography might conceivably point to general storage activity. Change detection using images collected over the same area from two different times could be of benefit. However, the importance of accurate interpretation of the photographs, synergized with other data such as prior knowledge of the site and other sources of information, cannot be overemphasized.

<u>Electro-optical and Multi-spectral Imagery</u>

Electo-optical and multi-spectral imagers produce imagery very similar to that of aerial photography, but by electronic means. As a result, data that is collected using these types of systems can be manipulated and exploited to a much greater extent than traditional aerial photography. The spatial resolution of the imagery that these systems provide is similar to that of aerial photography, and is altitude dependent. Electro-optical and multi-spectral sensors are grouped together here because of their similarity in operation. These vertical looking systems, like photography, are restricted to daytime and good weather operations; however, they collect image data in very different ways.

For both of these systems, reflected radiation from the sun is focused onto one or more electronic detectors that convert the light intensity of the scene to proportional electronic voltages, which are then stored onto magnetic tape, rather than film. The electronic detectors within any particular system vary in number. Multi-spectral systems, as the name suggest, use several detectors focused simultaneously on several narrow spectral bands, ranging from ultraviolet wavelengths to the visible and thermal segments of the spectrum. Each channel or discrete band can be analyzed individually or simultaneously through the use of electronic digital imaging processing equipment.. The major advantage of the use of multi-spectral sensors over aerial photography or simple electro-optical sensors, is the depth of manipulation of the received spectral channels. Since all objects reflect different proportions of the spectrum, image processing techniques can exploit specific spectral bands characteristic of certain objects on the ground. For example, if a camouflaged weapon is hidden within a vegetated area, the differentiation between the spectral signature of the vegetation and the camouflage can be readily distinguished.

The swath width of these systems is usually somewhat less than that of aerial camera systems, especially the panoramic type. Although the field-of-view is reduced, the amount of information is considerably larger, since several bands or channels of information are collected for each scene. This results in a need for substantial data storage and data processing capabilities. Data reduction, or image processing of multi-spectral and electro-optical imagery is far more complex and time consuming than the production of an aerial photograph. This is a disadvantage when timely information is required.

Development, Acquisition or Production, and Stockpiling

The limitations, and possibilities, of using electro-optical and multi-spectral sensors to monitor the development of biological weapons are similar to those as when aerial photography is utilized. If there are indicators of the development of biological weapons outside of a suspected facility, or if identification of abnormal activity is detected around a specific area, then this type of imagery may be of use to provide **indirect** clues. It is unlikely, if not impossible, to utilize these sensors to detect any type of developmental activity that occurs within an enclosed facility.

Similar comments can be made about the utility of these sensors in attempting to detect the acquisition or production of biological weapons. Only indirect clues of activity around a given facility could be gained using these methods. The inherent properties of spectral signature identification of multi-spectral systems may assist in determining suspected camouflaged buildings or production related components. Prior knowledge of the spectral signatures of a specific area could be useful for monitoring change detection over a period of time. This imagery could also be used for updating the quality of site diagrams or base maps of an area to assist in on-site inspections.

Again, the prospects of detecting the stockpiling or retaining of biological weapons that one is intent on hiding would seem rather unlikely using electro-optical or multi-spectral means.

Infrared Systems

All matter radiates energy at thermal infrared wavelengths, both day and night. The ability to detect and record this thermal radiation in image form, especially at night, has obvious reconnaissance applications that are relevant in a general way to the monitoring of activity related to biological weapons. There must be a distinction made here on the difference between photographic infrared and thermal infrared. Photographic infrared sensitive film can image **reflected** infrared energy at wavelengths from 900 nanometres to 1.1 micrometers. Thermal infrared systems detect **emitted** infrared energy at wavelengths from 3 micrometers to 15 micrometers. There is a common misconception that infrared sensitive film can be used to measure heat differences.

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 naturally. Clouds, rain, and atmospheric moisture will adversely affect the performance of infrared systems. Their optimum performance is restricted to good weather conditions, preferably at night. Imagery acquired from thermal infrared systems is best when collected during the evening, to avoid thermal interruptance by daytime solar activity.

There are two broad categories of infrared sensor that are available. They are classified as infrared linescanners (IRLS) and forward looking infrared (FLIR) systems.

Thermal infrared linescanners have been developed and utilized for a variety of military, commercial and scientific applications. Airborne linescanning 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 look vertically and collect infrared data by flying directly over the target. A rotating mirror reflects the emitted radiation from the ground surface onto a cooled infrared sensitive detector. Generally, for imaging "earth" temperatures between minus fifty degrees Celsius and plus fifty degrees Celsius, an 8.5-13.5 micrometer infrared detector is used. The swath coverage of infrared linescanners is directly proportional to the flying height of the aircraft and is usually 1.5 to 2.5 times greater than the aircraft altitude.

The resolution of infrared remote sensing systems is categorized into two types: spatial resolution and thermal resolution. 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 would be 1.0 milliradians. Using a 1.0 milliradian detector from an operating altitude of 300 metres above the ground, a spatial resolution of approximately 0.3 metres could be expected. The thermal resolution of infrared is relatively standard for most available systems, that is, they are capable of detecting thermal differences of 0.2 degrees Celsius. The Open Skies Treaty allows for infrared linescanners with 30 centimetre spatial resolution and 0.2 degree Celsius thermal resolution. Figure 2 is a thermal infrared linescanner image of an airbase. Note the indirect evidence of human activity by the presence of underground heating distribution lines, heated buildings. Also evident is vehicular activity such as the aircraft parked on the apron, and the cars in the parking lot.

Airborne thermal infrared linescanning systems have the advantage of operating at night at low levels (300-1000 metres above the ground) to provide high resolution images of the infrared emissions of objects from the terrain below. Real-time imagery can be produced on-board an aircraft and can be down-linked immediately to a ground station if timely information is required.

Forward looking infrared systems (FLIRs) are imaging infrared video systems closely related to the infrared linescanner. Typically, they are mounted in a low level reconnaissance aircraft or helicopter and used to monitor movement of personnel or vehicle activity on the ground. FLIRs have the advantage of being able to look obliquely at an object on the ground, and the capability of being "steered" by the operator within the aircraft. Most FLIRs have several field-of-views ranging from wide swath mode to narrow swath. An important characteristic of the FLIR is it's ability to retain a high spatial resolution in the narrowest field-of-view. This is very important when the monitoring of the movements of objects on the ground is required.

Development, Acquisition or Production, and Stockpiling

Thermal infrared imaging sensors, when utilized at night after solar cooling has occurred, would be effective in identifying sources of heat that would be indicative of human activity. Heated or air conditioned buildings would be discernible using thermal imaging systems, as well as buried heating distribution lines and warm vehicular activity. FLIR systems, using their controllable pointing capability, would be useful in monitoring personnel movement from building to building within a specific facility. The oblique viewing characteristics of FLIRs would enable the imaging of the sides of buildings and activity associated near or around (but not inside) an enclosed facility. FLIRs would record on videotape, or transmit directly to a ground receiving station in real-time the data being collected including positional and time information for archiving purposes.

Radar Systems

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 is determined by the length of the antenna which transmits and receives the microwave pulses.

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 received radar signal which incorporate the aircraft's own forward movement, SARs 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.

Commercial SAR systems can acquire data in various modes: for example high resolution mode (20-25 km swath width) or wide swath mode (40-50 km swath width) from an operating altitude of 9000-11,000 m above ground level.

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 on tape for further processing.

Development, Acquisition or Production, and Stockpiling

The use of synthetic radar imagery for the detection of the development, acquisition, production or stockpiling of biological weapons is constrained by the relatively poor spatial resolution of the sensor. Current SAR systems with capabilities to acquire imagery in "spotlight" mode are able to discern objects approximately one meter in size. Such features as buildings, vehicles and general storage areas could be imaged, but the operational characteristics of SARs in imaging the microwave reflective patterns of objects would make positive interpretation of objects difficult.

SAR systems could be useful in providing broad area coverage of particular sites. The detection and recognition of main transportation routes, secure perimeter fences and power lines could be accomplished using SARs. Figure 3 is a SAR image of an airbase. Note the presence of vehicles (presumably aircraft), buildings and perimeter fences in the image. In areas of concern where weather is poor, the use of SAR systems would not be preempted by clouds or darkness.

Digital SAR systems could collect imagery in real-time and downlink it electronically to a ground receiving station if immediate data were required. The oblique viewing characteristics of side looking radar (approximately 25 kilometres) would provide a stand-off position from the site of interest.

TECHNOLOGY, MANPOWER, MATERIAL, AND EQUIPMENT REQUIREMENTS

The requirement depends upon whether a service is provided by a donor country, some or all of the job is contracted out commercially, or an in-house capability must be developed. It is assumed that unclassified off-the-shelf civilian technology would likely be used.

Sensor Platforms

The sensor platform would conceivably be chosen to match the requirements of the specific mission. The type of aircraft or helicopter used for overflights must meet the requirements for range, sensor payload, passenger room, safety, reliability and negotiability. Factors determining the suitability of a platform include:

- the intended mission,
- geography and weather of the operating area,
- capital and operating costs,
- performance capabilities,
- safety, and
- the ease with which it can be outfitted to carry the required sensors and other equipment.

Airplanes are especially useful for missions that require fast airspeed, long durations, large sensor payloads, or film changing and sensor maintenance in flight. Aircraft such as the twin-engined Cessna Conquest (as shown in Figure 4) and Boeing Dash 8 (in Figure 5) would be practical and cost effective platforms.

Helicopters are generally more limited with respect to speed and range than airplanes. They are most appropriate for low-level flying, slow flying and temporary hovering and close-quarter landing. Helicopters, like airplanes, may allow sensors to be adjusted or re-loaded with film during flight. A sensor-bearing helicopter can combine the role of aerial monitor and on-site inspector. Such a helicopter, if an anomaly were detected from the air, could conceivably land to permit inspectors to investigate further and document what is found. A helicopter could be used to hover over an inspection site, watching the perimeter to ensure that materials are not removed without the knowledge of on-site inspectors on the ground.

Sensors

Photographic systems

The photographic camera is the optimal sensor if imagery with maximum spatial detail is required. Suitable civilian camera systems are readily available which could be used to obtain aerial photographs for BTWC-related missions. Cameras which might be used range in sophistication from hand-held 35-mm cameras to aerial survey cameras for precision mapping.

Hand-held 35-mm cameras are inexpensive and convenient to use, but the small film format does not make it an ideal camera system. A larger-format camera (as seen in Figure 5) will provide professional hand-held aerial oblique photographs with maximum photographic detail. Figure 6 shows a typical low oblique photograph taken using a handheld Agiflite camera. Note the marginal data recorded at the time of exposure including the date, time, latitude, longitude and aircraft heading. Hand-held oblique photography might be taken as evidence, for example, that trucks left through a back gate of a facility at a particular time, or to document the appearance of an inspection site for reports.

If site maps must be prepared, vertical photographs will be more suitable than oblique photography. A survey camera, such as the Wild AVIOPHOT ™ RC-20 (as shown in Figure 7), can provide distortion-free photographs in a 9 x 9 inch (229 x 229 mm) format for photogrammetric measurements and high quality map production.

These cameras are expensive (about $300,000) and may provide more precision than would be required for BTWC-related overflights. A smaller tactical reconnaissance camera system such as the Vinten Type 360 70-mm camera (as seen in Figure 8) can provide low altitude photography for preparation of site maps at a fraction of the cost; a Vinten Type 360 camera costs about $33,000.

Thermal Infrared Systems

For night operations, thermal infrared sensors will be required. Forward-looking infrared (FLIR) systems can be used to acquire oblique thermal infrared imagery as shown in Figure 9. FLIR imagery can be used to monitor and record events in a similar manner to that in which oblique photography can be used during the day. In Figure 10, two Honeywell FLIRs have been mounted on an Ayres S2/R aircraft for nocturnal monitoring and reconnaissance missions. A gimballed FLIR allows an operator to image terrain anywhere ahead and all angles below, to the sides and to the rear of the aircraft. Most FLIR systems are used together with high resolution television displays to provide real-time data to the pilot and systems operator for navigation as well as surveillance.

An infrared linescanner can be used to acquire a strip of vertical thermal infrared imagery. Linescanners use a rotating mirror with optics to direct thermal radiation from a small ground surface area to a detector or detector array. The mirror rotates perpendicular to the line of flight so that with each cycle, a strip of ground normal to the flight direction is covered. The forward motion of the aircraft causes successive scan lines to cover adjacent strips on the ground, building a two-dimensional image. Figure 11 shows an infrared linescanner designed for reconnaissance missions.

Infrared sensors are generally more complex and expensive than photographic systems. A FLIR will cost about $450,000 and an infrared linescanner can be expected to cost about $500,000.

Radar

Radar systems can acquire imagery in almost any atmospheric conditions: haze, smoke, cloud cover, or even light rain and snow. In some areas, radar might be the only way to acquire imagery. Image acquisition might have to be completed during a specific period or it might have to be done on an urgent basis. In either case, cloud coverage could be a serious problem unless an imaging radar system is available. Furthermore, radar can be used during the night or day since it is an active sensor, providing its own illumination.

These systems produce continuous strips of imagery of the terrain adjacent to the flight path of the aircraft. A radar is mounted on the aircraft, pointing to the side. The antenna acts as a transmitter as well as a receiver of microwave energy pulses. It alternates between illuminating terrain adjacent to the flight path of the aircraft with pulses of microwave energy and recording the echoes which return. Returns reflected from targets at different ranges arrive back at the antenna at different times.

Modern airborne imaging radars are mostly synthetic aperture radars (SAR). SARs use the forward motion of the aircraft to create the effect of an antenna hundreds of metres long and thereby providing resolutions on the order of a few metres. A synthetic aperture radar is a complex sensor and also expensive: a SAR will cost from $5 to $6 million; $8 to $10 million with a ground-based data processing station. The data is recorded and processed digitally. Real time imagery may be produced on dry silver paper or the data can be downlinked to a ground receiving station.

Modern SAR systems can operate in wide-area surveillance or high resolution modes. Some systems are dual-sided, imaging swaths on both sides of the aircraft. In addition to the usual strip-map mode, modern digital SAR systems can offer a "spotlight" mode in which the radar antenna is steered to dwell on a particular target as the aircraft passes. This can be used to provide finer resolution or "speckle" reduction to provide a high quality image for interpretation purposes.

While the operational constraints controlling radar image acquisition do not initially appear as restrictive as those for other types of imagery, there are nonetheless a variety of factors which should be considered when planning radar overflights. The sensor might be able to operate in most weather conditions, but it is also necessary for the platform to be able to fly. Fog or severe weather can close an airport, grounding all aircraft. In the case of long range aircraft, they should be based at airports which are not prone to adverse weather conditions. Turbulence over the target site can also be detrimental. The attitude of the platform is usually measured and used for processing the data. Excessive changes in aircraft attitude can degrade image quality.

Radar imagery might often be required when any form of visual navigation will be impossible because of cloud cover. Any aircraft intended as an airborne radar platform must be equipped with the best navigation systems to operate successfully. The aircraft will need to be equipped with a precision altimeter providing a continuous flight record.

Data Processing and Interpretation

Image interpretation, also referred to as image analysis, is the process through which useful information is derived from remotely sensed imagery. Image interpretation involves the detection, identification and measurement of objects recorded in the imagery.

Image interpretation can be done manually, by a human interpreter, or using a digital image analysis system. For interpretation tasks requiring the interpretation of subtle clues or associations, the human interpreter is still necessary. When digital imagery is involved, the interpretation will likely be done using some combination of machine-based methods and human visual interpretation.

Manual interpretation techniques, using human interpreters with the necessary training and expertise, remains the most effective and reliable way to interpret remotely sensed imagery. Although the equipment has evolved, most of the techniques have remained basically the same for the past twenty years. Equipment required for manual interpretation of imagery includes equipment for viewing, measuring and transferring image detail to basemaps.

The simplest viewing instrument is the lens stereoscope, or pocket stereoscope. Lens stereoscopes have two lenses mounted in a metal or plastic frame with folding legs as seen in Figure 12. Lens stereoscopes usually provide two- or four-times magnification. The advantages of lens stereoscopes include their low cost, portability, and ease of operation and maintenance. The principal disadvantage is that matching points on the two photographs must be separated by a distance approximately equal to the eye base of the interpreter. For most image formats, including the most commonly used 23 x 23 centimetre format, this means that prints must be bent or folded to be viewed stereoscopically. Pocket stereoscopes also offer limited magnification compared to more expensive instruments.

Mirror stereoscopes eliminate these two major disadvantages. Two sets of mirrors, or a combination of prisms and mirrors, separate the lines of sight from each of the interpreter 's eyes. This permits 23 x 23 centimetre format prints to be viewed with full separation, removing the need to bend the prints as well as providing room for measuring instruments such as a parallax bar to be used under the stereoscope as shown in Figure 13. Under normal (zero) magnification, the entire coverage of the stereomodel can be viewed at once. Binocular lenses can be mounted to most models for magnification, with a consequent reduction in the field of view.

Other stereoscopes make it easier to scan over large areas or to enlarge areas of interest. The scanning mirror stereoscope allows the field of view to be moved around the entire overlap area of a stereopair at several magnifications without moving the photos or stereoscope. The zoom stereoscope provides continuously variable magnification, allowing an interpreter to easily zoom in on features of interest.

Working monoscopically with imagery can be as simple as looking at a photograph with a magnifying glass. There are sophisticated systems, however, which are designed for rapid display of imagery. The system shown in Figure 14 uses a closed circuit television system to display imagery. It can be used to magnify part of an image or to instantly present a negative image as a positive.

Once information has been interpreted from the imagery, it must often be transferred to a base map. Optical transfer devices may be used to match details on the imagery to maps of a different scale. Some instruments, called "camera lucida systems," superimpose views of the image and map through a special two-way viewing system. Inexpensive systems, such as the Sketchmaster, can be tedious to use, requiring many changes to the photo and base map positions. Zoom transferscopes provide all of the capabilities of camera lucida instruments as well as continuous zoom magnification of the image and a system to stretch the image, partially compensating for geometric image distortions. Optical projection instruments optically project the image onto a map. They are useful for transferring detail from near-vertical imagery. They provide a large work area and comfortable working position for the analyst.

A digital image analysis system will be necessary to work with imagery recorded in digital format. Digital image analysis systems vary in terms of capability and software, but share the same basic hardware. The computing is performed by a host computer. This can range from a personal computer to a supercomputer. Images are displayed on a screen which, typically, can display full colour images with graphics overlays. The user interacts with the image display using a graphics pad, mouse, track ball or joystick. Most systems allow the user to zoom in on specific locations in the image or roam around the image interactively. The software determines the kinds of analysis which may be done on a particular image analysis system. Digital image processing and analysis programs may be used for restoration, enhancement or interpretation of the imagery.

Costs for image processing equipment depends on the versatility and power of the computer equipment required, and the amount of software needed to perform data processing and analysis. For most applications, data processing can be accomplished adequately on either a personal computer or an image processing workstation with commercially available software. An image processing system consisting of personal computer with monitor, tape drive and software would cost approximately $ 15-20,000 CDN. The cost for an image processing workstation with monitor, tape drive and software would be approximately $ 25-35,000 CDN. Image production capabilities would be considerably more expensive, with digital printers costing approximately $50-100,000 CDN. Printing the processed imagery on a medium for later use can be done on a commercial basis, costing approximately $ 500 - 1000 per scene, depending on colour or black and white requirements.

Personnel

Personnel requirements may be divided into two groups: aircrew and interpretive staff. A minimum crew of two people, but more likely three people would be required. With a crew of two people, the pilot would do the navigation and the second person would manage the sensor operations. It is more likely, however, that a crew of three would be used with the third person acting as navigator. Additional personnel may be required if more than one sensor system is in operation during data acquisition.

The number of interpretive staff would be dependent upon the volume of imagery which would have to be interpreted. Most likely, only one or two people would be required. Furthermore, this interpretive work may not be their full responsibility: they might double as members of the aircrew or work at some other job within the organization.

LEGAL ASPECTS OF AERIAL OVERFLIGHTS

Any aerial activity contemplated as part of a verification regime would have to be established within a cooperative framework, in accordance with national air traffic rules and procedures, and institutionalized in order to provide an effective and coordinated approach to airborne surveillance. Under international law, the ultimate responsibility for all aerial overflights resides with the national government over whose territory the flight is taking place. The national authoritative body governing air traffic may authorize, limit or ban all and any flights within the navigable airspace of that country, although provision for aerial overflights would presume every effort at cooperation with the international body conducting the flights.

Three general principles apply to the conduct of overflights: treaty/operational considerations (e.g. timings including duration), the safety aspects of an overflight, and the intrusiveness (e.g. sensor suites and operation parameters) of a particular flight. In relation to an aerial inspection regime and the BTWC, only safety considerations would likely be considered as grounds to constrain the overflight. The operational considerations of flights and the level of intrusiveness allowed will have been established beforehand through negotiation. Intrusiveness issues would be dependent on the types and capabilities of sensors permitted within the operational framework of the aerial inspection regime. In the context of this paper, the use of commercially available imaging sensors with moderate to high spatial resolution would not constitute an overly intrusive regime, certainly not any more intrusive than that required for on-site inspections.

The issue of data sharing or data retention may have legal implications in that the data collected by the remote sensors must be controlled in a fashion to exemplify a supporting role to on-site inspections. Control of the data products acquired as a result of aerial overflights must be addressed in order to protect the informational aspects supplied as a result of overhead surveillance. One possibility may be a central databank contained within the operational body of such a regime.

The issue of compromising commercial or trade secrets of a particular facility may be of some concern. This paper has assumed, however, that all imagery collected during aerial overflights would fall under the jurisdiction of an internationally recognized organization such as a BTWC Secretariat or the United Nations, therefore reducing the risks of compromising commercial or trade secrets .

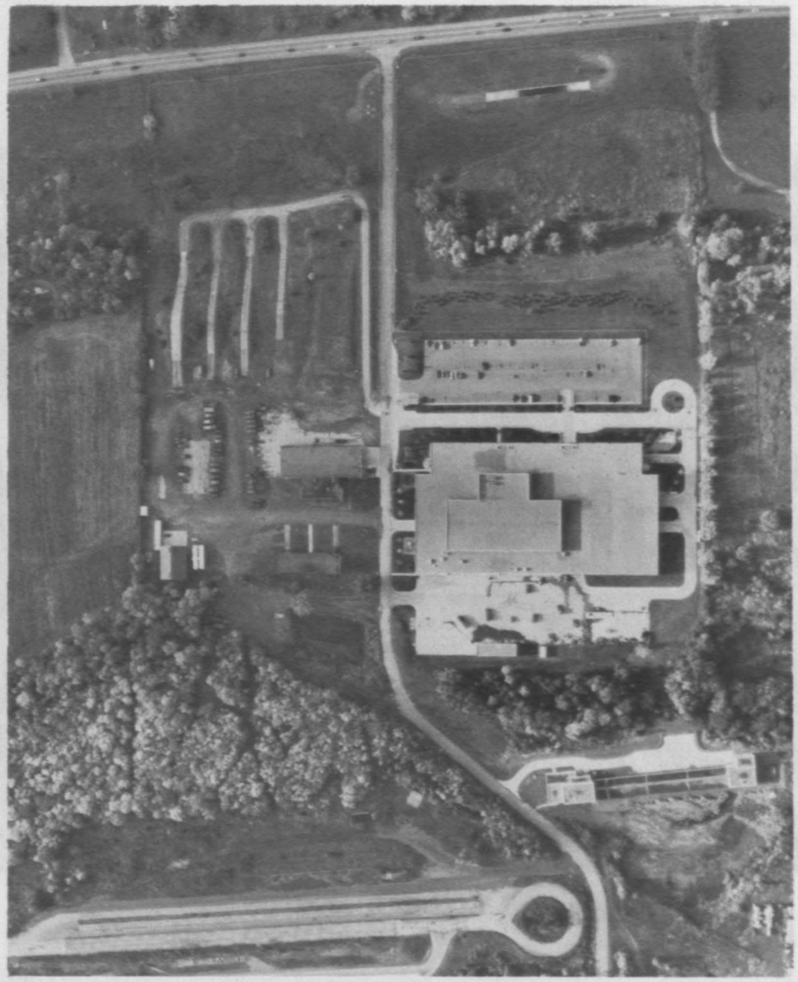

Figure 1. This simple vertical black and white aerial photograph was taken using a metric survey camera of a military facility. Information required to update or produce improved base maps of a facility can be gained from the image. Also, activity levels in and around the facility can be interpreted. The spatial resolution of the image is approximately 30 centimetres.

Figure 2. This thermal infrared linescanner image shows the utility of this sensor to map heat sources that are indicative of the level of human activity. Note the buried heating lines and the heat escaping from the hangar doors. The spatial resolution of this image is approximately 50 centimetres and the thermal resolution is 0.2 degrees Celsius.

Figure 3. This synthetic aperture radar image was acquired from an altitude of 11,000 metres. Note the broad area coverage provided by SAR and the reflective characteristics of the vehicles, perimeter fence and buildings. The spatial resolution of this image is approximately six metres.

Figure 4. Twin-engined Cessna Conquest equipped with a synthetic aperture radar. The Conquest is a cost-effective platform which delivers the altitude, range and speed capabilities required to operate a SAR. The Conquest provides a service ceiling of about 11,275 metres and has a maximum range of about 4,000 kilometres when flying at 10,000 metres. The aircraft would also make a good platform for an infrared linescanner and/or a camera system. (Courtesy Intera Technologies Ltd.)

Figure 5. The Boeing Dash 8 Series 300 provides a large volume platform, with room for 16 passengers or more as well as a full complement of sensors. The aircraft could be used to transport on-site inspection teams as well as being a sensor platform. (Courtesy of Boeing Canada, de Havilland Division)

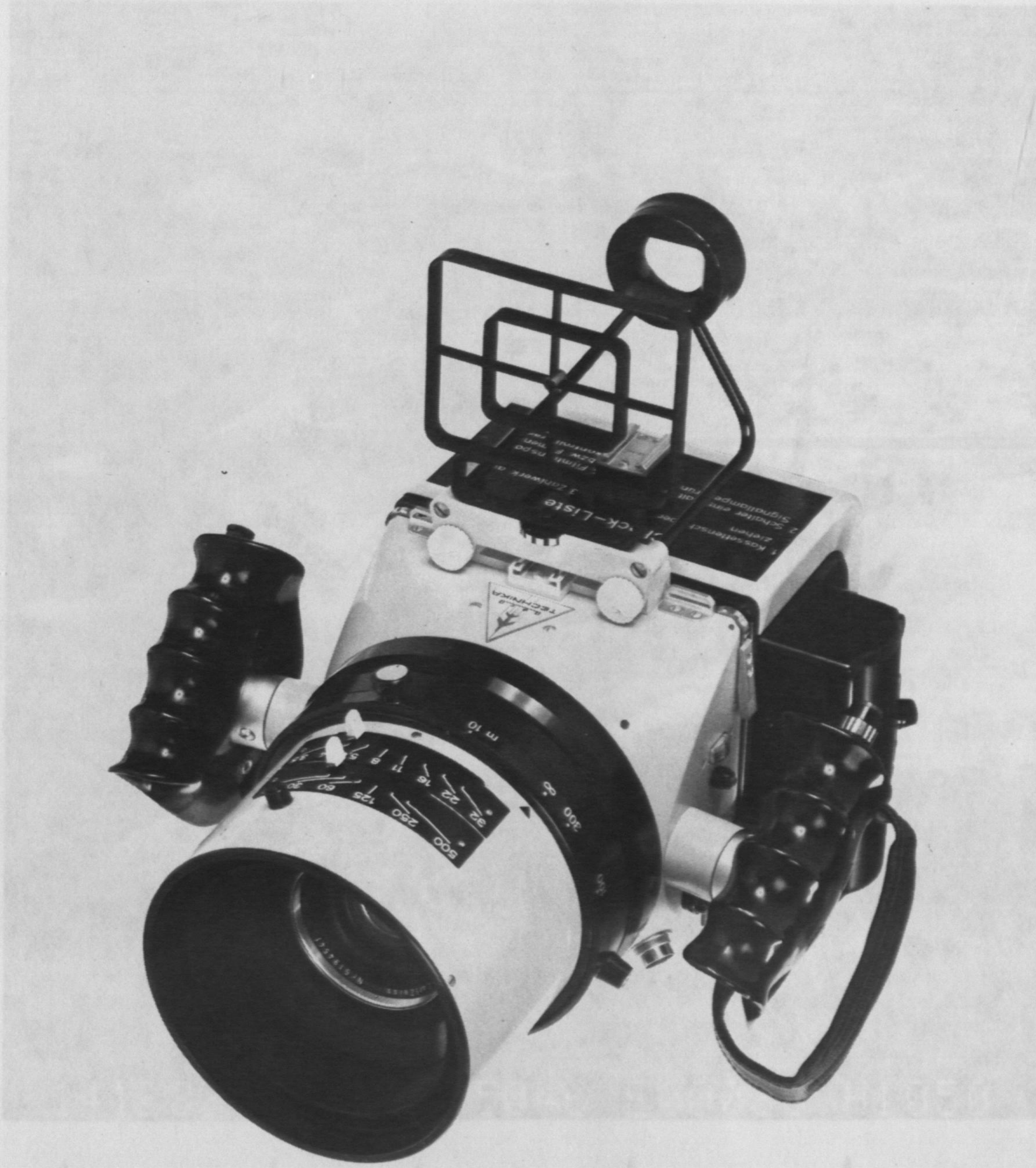

Figure 6. The Linhof aero Technika 45 EL 9 x 12 cm format hand-held aerial camera provides superior detail and information than smaller format cameras while, at the same time, is easily handled in an aircraft or helicopter. (Courtesy of Linhof Präzisions Kamera Werke GMBH)

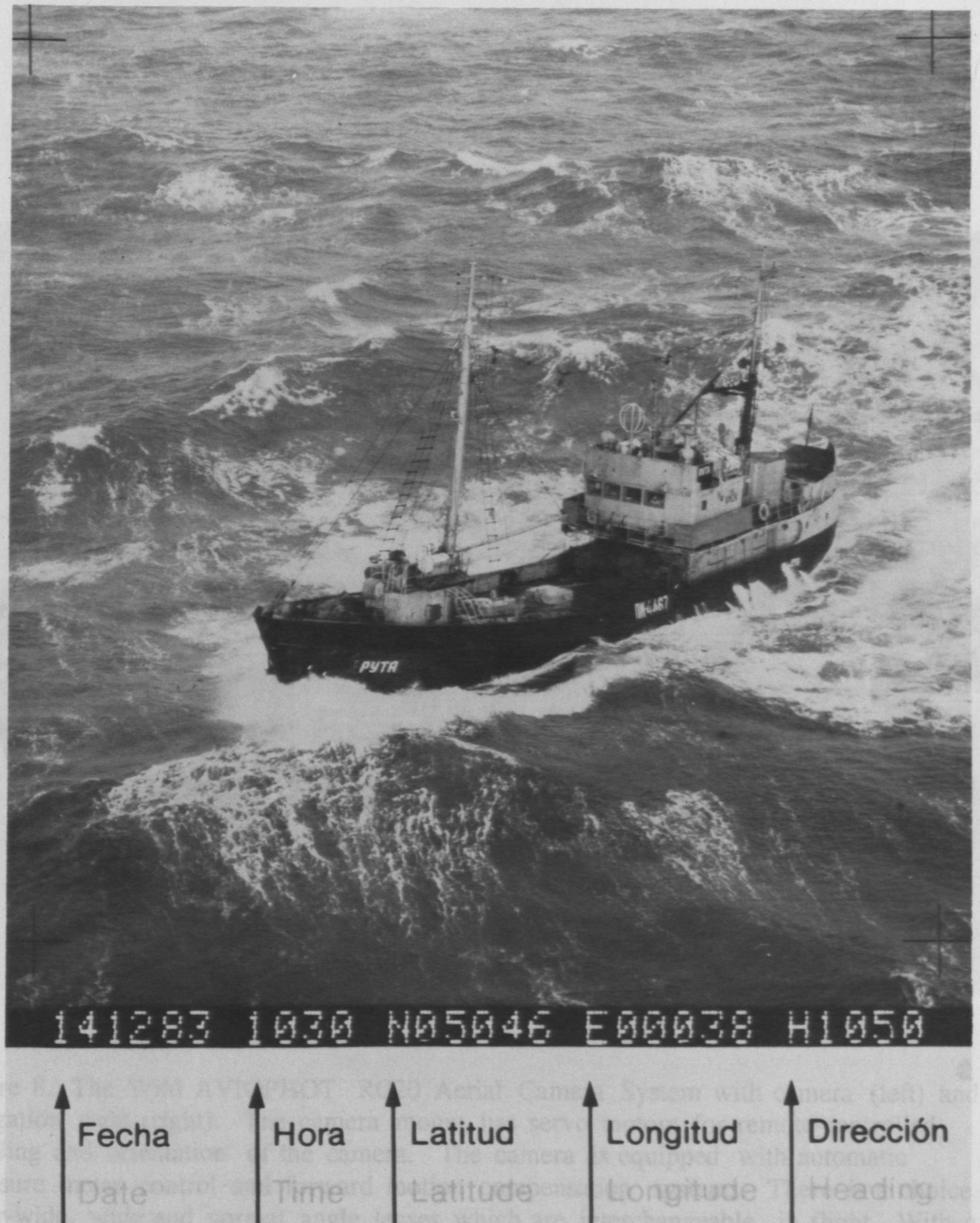

Figure 7. Oblique photograph taken using an Agiflite hand-held camera with time and position data recorded in the margin at the time of exposure. (Courtesy of Negretti Aviation)

Figure 8. The Wild AVIOPHOT RC20 Aerial Camera System with camera (left) and navigation sight (right). The camera mount has servo motors for remote-controlled levelling and orientation of the camera. The camera is equipped with automatic exposure meter control and forward motion compensation systems. There is a choice of super-wide, wide and normal angle lenses which are interchangeable in flight. With a plug-in interface, the RC-20 can be linked to and controlled by an air navigation system. The camera can record external real-time navigation data as well as the camera status data in the margin of every photographic exposure. (Courtesy of Wild Leitz Ltd.)

Figure 9. The Vinten Type 360 reconnaissance camera is rugged and reliable, providing high quality low and medium altitude photography with minimum cost and complexity. (Courtesy of Vinten Military Systems Ltd.)

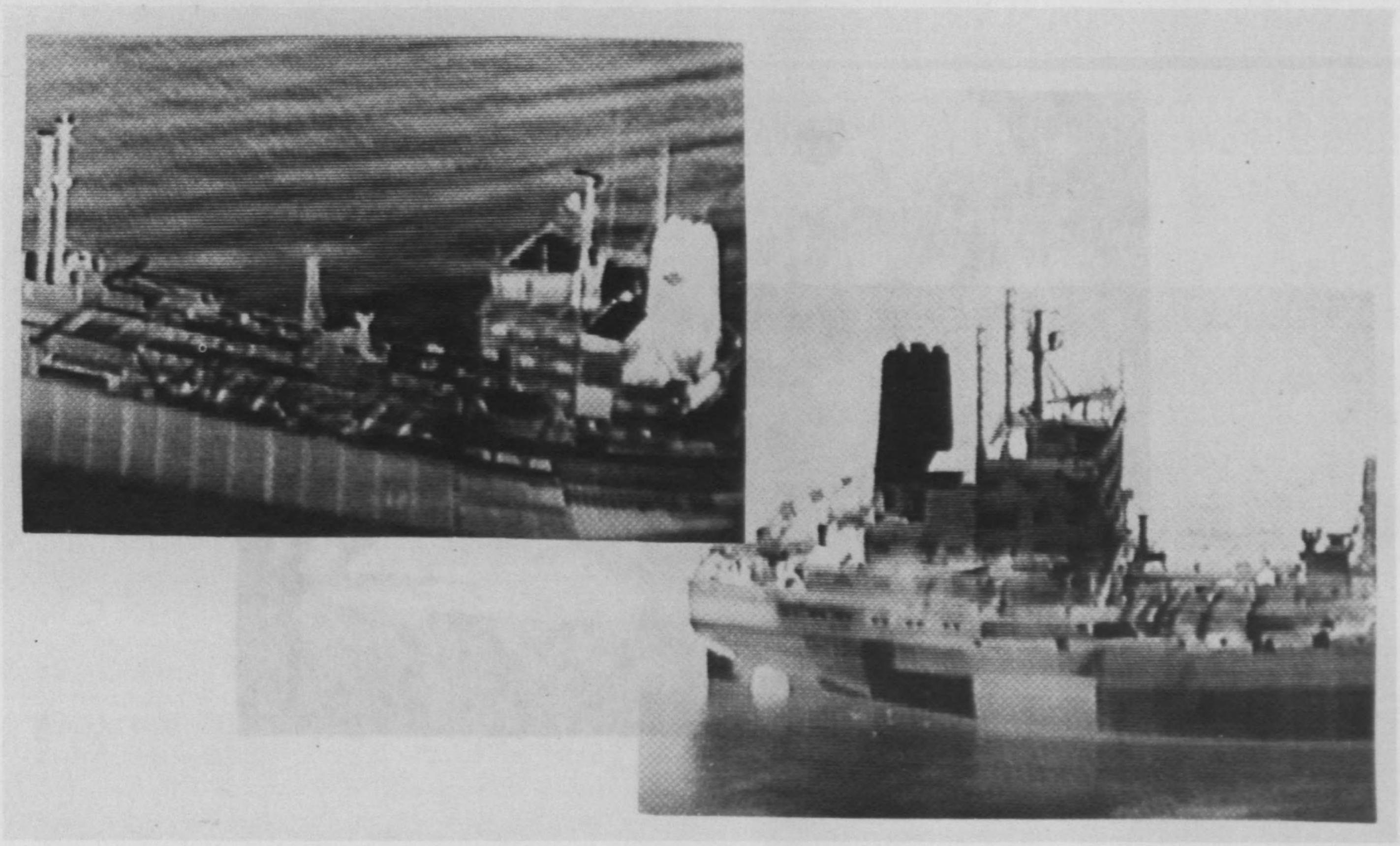

Figure 10. FLIR images of freighters. Notice the hot stack in the left image and the ability to "see through" the hulls because of differences in surface temperature resulting from contents of the holds. (Courtesy of David Dorschner, Aviation Resource Management.)

Figure 11. Two Honeywell Gimbaled Mark III FLIR systems mounted fore and aft under the fuselage of an Ayres S2/R Turbo Thrush aircraft. (Courtesy of Dave Dorschner, Aviation Resource Management.)

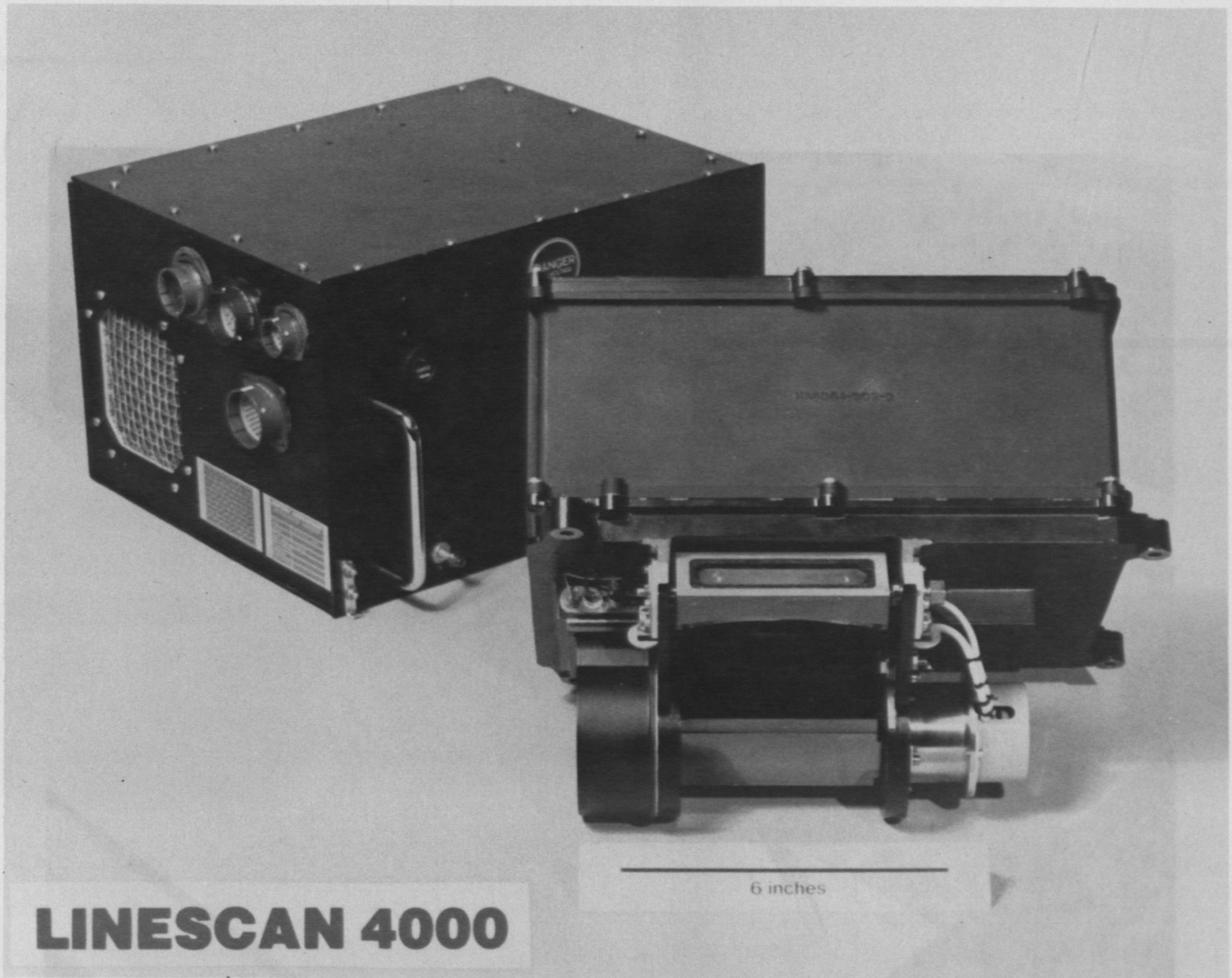

Figure 12. Linescan 4000 infrared linescan system. The system is compact and can be used on a wide range of platforms. It provides horizon-to-horizon coverage, electronic roll stabilization, real time video output and can be down-linked to a ground station. It has a multi-element mercury cadmium telluride detector operating in the 8 to 14 μm waveband and a closed cycle helium detector cooling system. (Courtesy of Vinten Military Systems Ltd.)

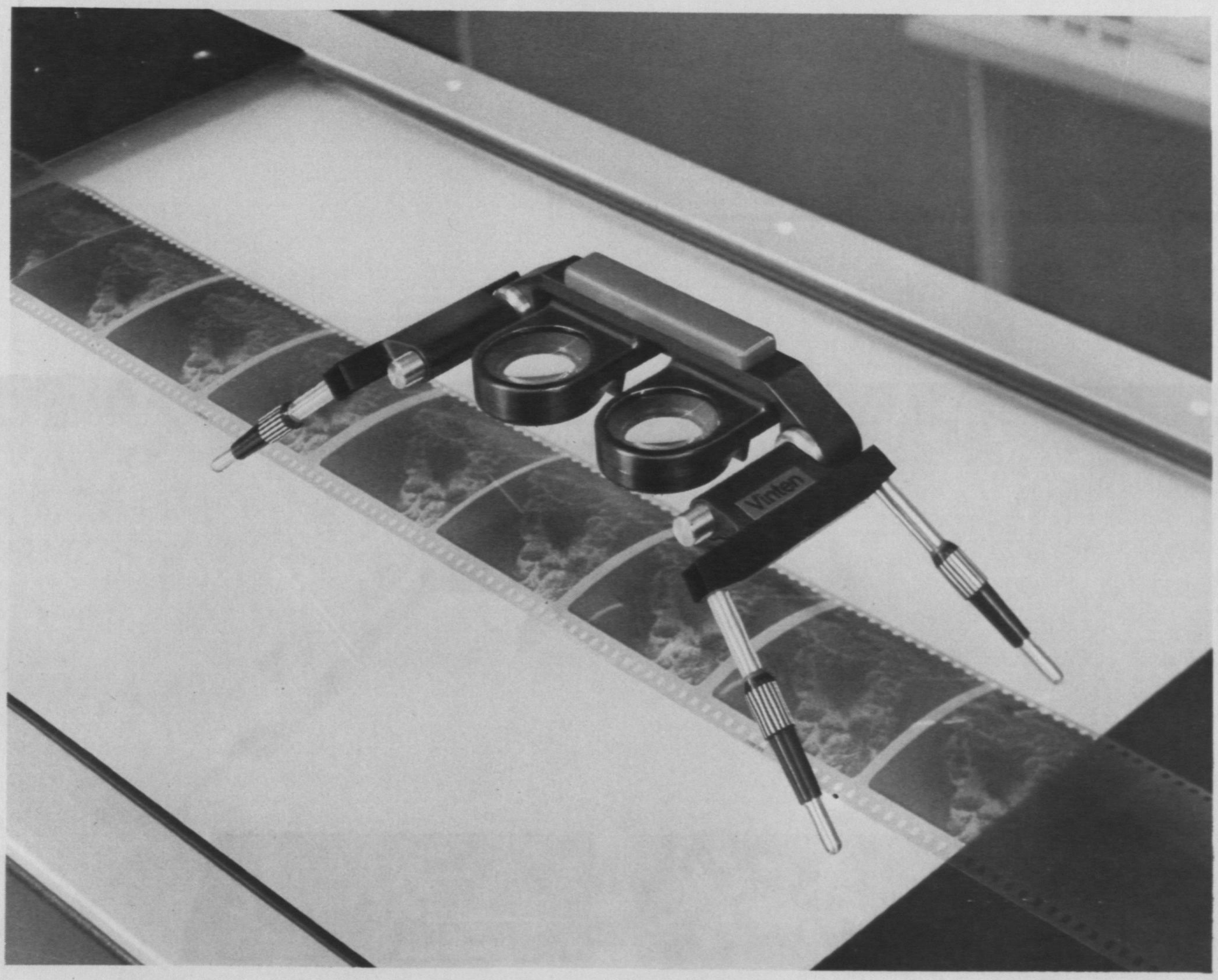

Figure 13. Lens stereoscope with 2x and 4x magnification lenses. (Courtesy of Vinten Military Systems Ltd.)

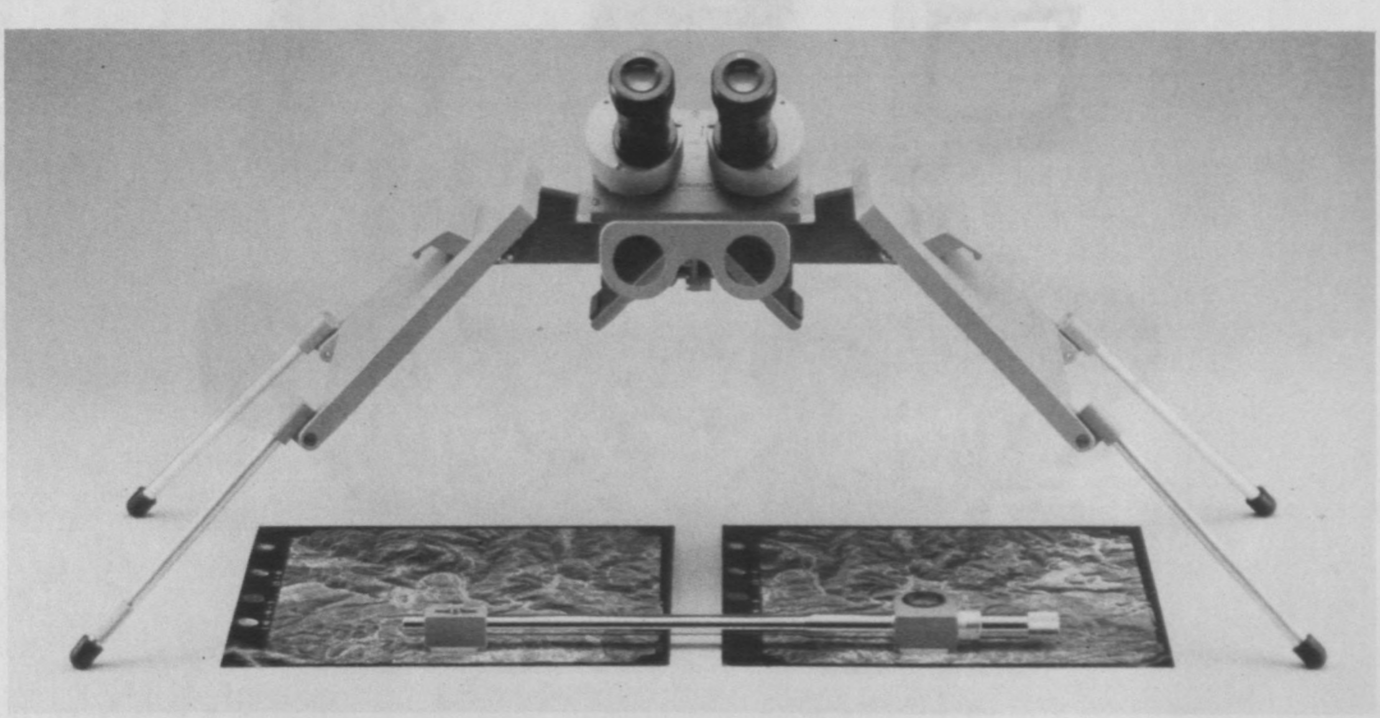

Figure 14. Sokkisha MS27 mirror stereoscope with a pair of aerial photographs prepared for stereo viewing together with a parallax bar. (Courtesy of Mark Lystiuk, Currie Engineering, and Sokkisha Co., Ltd.)

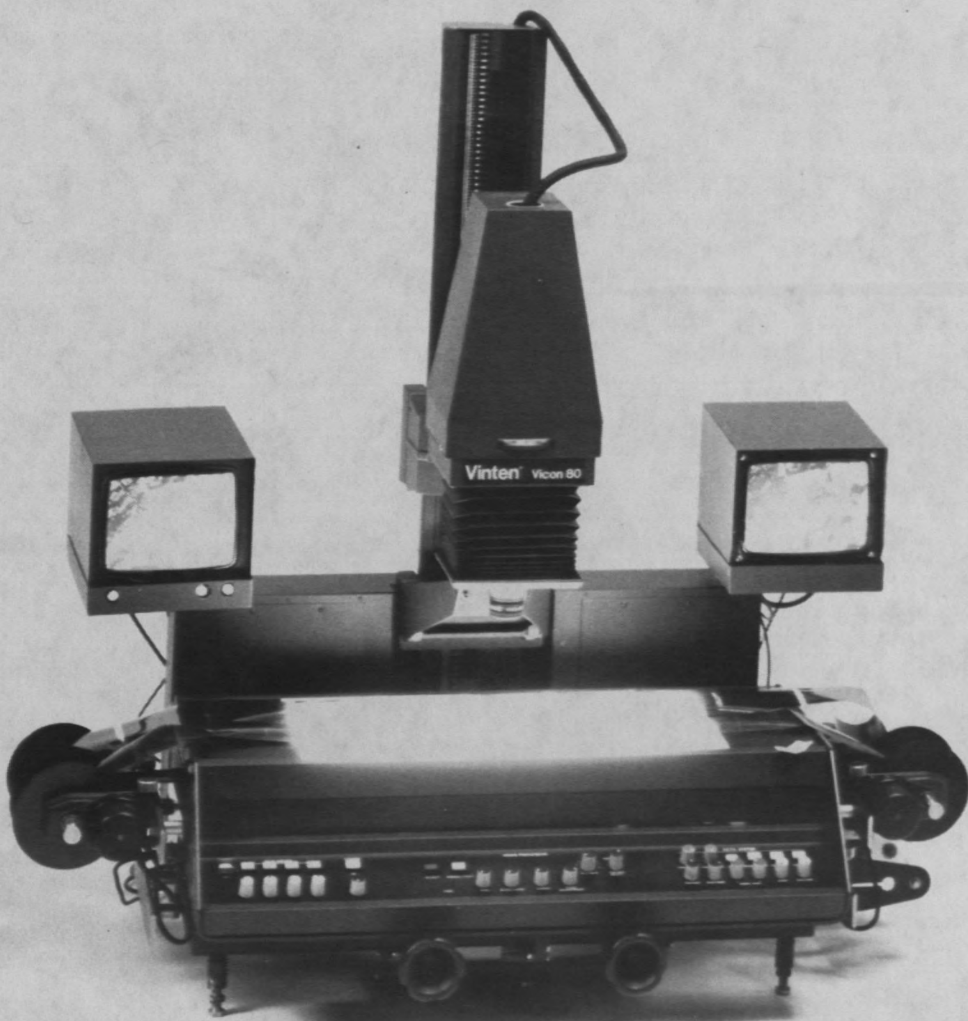

Figure 15. The Vinten Vicon 80 Imagery Interpretation and Reporting System. Based upon a closed circuit television system, the Vicon 80 provides a system for rapid presentation, enhancement and visual interpretation of film-based imagery. (Courtesy of Vinten Military Systems Ltd.)