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Aerial Reconnaissance for Verification of Arms Limitation Agreements

An Introduction

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PREFACE

One of the positive developments in the multilateral discussion and negotiation of disarmament issues in recent times has been the remarkable consensus that has been forged around the question of verification. In recognition of this fact and the importance of making further progress UNIDIR has implemented a number of research projects on the subject of verification. More research projects are currently in progress.

The UNIDIR Verification Research Programme has included on the one hand an analysis of the legal and political aspects and a description of national approaches to verification. On the other hand it has attempted to investigate technical aspects of verification so as to describe the present state of the art technology in this vital area and evaluate its potential and efficacy.

This research report on "Aerial Reconnaissance for Verification of Arms Limitation Agreements - An Introduction" by Allen Banner, Andrew J. Young and Keith W. Hall was actually conceived and begun as an UNIDIR research project before US President Bush's speech of 12 May 1989 renewed international interest in the 1955 "Open Skies" proposal of President Eisenhower. It was undertaken in co-operation with the Verification Research Unit, Arms Control and Disarmament Division of the Canadian Ministry of External Affairs and International Trade as a means of examining the potential of aerial reconnaissance in the verification of arms limitation and disarmament agreements. Although satellite observation continues to develop its verification technology its benefits are not yet universally available. In an area of global glasnost verification by airborne systems could therefore provide a complementary or an alternative means of verification depending on the circumstances. Aerial reconnaissance also has an important potential as a confidence building measures.

UNIDIR is gratified that subsequent international events have underscored the importance of this research project. The research report written by Messrs Banner, Young and Hall is intended for the lay reader as much as for the specialist. After describing the historical background and the legal issues involved the report examines the different systems applicable in aerial reconnaissance and their characteristics. It then describes the interpretation of aerial photographs and outlines the platforms used for aerial photography as well as the maintenance and safety aspects of the equipment used. A separate and important chapter is devoted to conducting international airborne operations and the possibilities of these operations being undertaken in the arms limitation context.

I would like to take this opportunity to thank the Verification Research Unit Arms Control and Disarmament Division of the Canadian Ministry of External Affairs and International Trade whose generous support made this research project possible.

The views expressed in this publication are of course the responsibility of the authors and not of UNIDIR. However we do assume responsibility for determining whether research reports merit publication and, consequently, we commend this report to the attention of its readers.

Jayantha DHANAPALA
Director, UNIDIR

UNIDIR

United Nations Institute for Disarmament Research

UNIDIR is an autonomous institution within the framework of the United Nations. It was established in October 1, 1980, by the General Assembly for the purpose of undertaking independent research on disarmament and related problems, particularly international security issues.

The work of the Institute, which is based on the provisions of the Final Document of the Tenth Special Session of the General Assembly, aims at:

(a) Providing the international community with more diversified and complete data on problems relating to international security, the armaments race and disarmament in all fields, particularly in the nuclear field, so as to facilitate progress, through negotiations, towards greater security for all States, and towards the economic and social development of all peoples;

(b) Promoting informed participation by all States in disarmament efforts;

(c) Assisting on-going negotiations on disarmament and continuing efforts to ensure greater international security at a progressively lower level of armaments, particularly nuclear armaments, by means of objective and factual studies and analyses;

(d) Carrying out more in-depth, forward and long-term research on disarmament so as to provide a general insight to the problems involved and stimulating new initiatives for new negotiations.

The contents of this publication are the responsibility of the authors and not of UNIDIR. Although UNIDIR takes no position on the view and conclusions expressed by the authors of its research report, it does assume responsibility of determining whether they merit publication.

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Keith W. Hall

- Keith Hall is an electronics technologist with fifteen years experience in airborne remote sensing surveys.
- During this time he has worked or travelled in over 30 countries, including most of Africa, Brazil, Thailand, Indonesia, the United States, Canada and the Arctic.
- His responsibilities included construction, debugging and installation of remote sensing equipment in many models of fixed wing and rotary aircraft in "field" conditions.
- He has also been responsible for arranging the import and export of the equipment and aircraft in countries where aerial surveys have been conducted.

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July 1990

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• AN INTRODUCTION •

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On May 12, 1989, U.S. President George Bush called upon the international community to explore once again the "Open Skies" plan proposed by President Eisenhower in 1955. Under Open Skies, aircraft from the NATO and Warsaw Pact countries would overfly each other's territory using aircraft equipped with cameras and other sensors to bring greater openness, or glasnost, to military activities in the territories of the two alliances. Aerial inspections will also play an important role in the verification of a Conventional Armed Forces in Europe (CFE) Treaty. Both alliances have included provisions for aerial inspections with no right of refusal in their proposals for a CFE compliance package.[1]

The use of aerial reconnaissance offers many potential benefits for verification and confidence building. Airborne systems are flexible. The types of platforms and sensors, timing and duration of overflights and the scale and coverage of the imagery can be tailored to meet the specific requirements of individual missions. They are also reliable. Aircraft and airborne sensors can be repaired or replaced more easily than more sophisticated satellite-based systems. Finally, airborne systems are cost-effective. The cost of an airborne capability to meet the Open Skies requirements for Central Europe has been estimated to be only 1/20 of what an equivalent space-based system would cost.[2]

Airborne reconnaissance systems would be particularly useful in a multilateral context. The options of restricting overflight coverage and allowing host country personnel to accompany the aircraft during overflights makes aerial reconnaissance more politically acceptable by ensuring that unauthorized data collection does not occur. Aerial surveillance is also within the technical and financial capabilities of a large number of countries. More nations are likely to be able to develop an indigenous airborne, rather than satellite-based, capability. Multilateral agreements will be made more verifiable and acceptable for all concerned by reducing the requirement for national satellite-based systems.[3]

Aerial reconnaissance systems would be useful for many applications. Aircraft could intensively monitor areas with treaty-relevant facilities or key transportation corridors. They can monitor a selected area more often than satellite-based systems and can also provide coverage of larger areas than would be possible using on-site inspections. Aerial imagery could be used to familiarize on-site inspectors with a site before their arrival and perhaps provide indications of where they should focus their attention once they arrive. Aircraft could be used to provide a rapid response capability to obtain coverage of an area within several hours of being notified. Finally, because airborne systems would not necessarily require sensitive monitoring technology, it might be possible to openly use the imagery in compliance discussions.

This study is an introduction to aerial reconnaissance, or remote sensing, and how this technology can be useful in an arms limitation context. It is intended for interested laypersons as well as professionals. The study will provide an introduction to the potential of aerial systems, with a review of the historical and legal background, the major sensors and potential platforms, and aspects of conducting international airborne operations.

Chapters 1 and 2 provide historical and legal background. Chapter 1 outlines the development of aerial reconnaissance and the extent to which it has been previously considered and used for verification-related purposes. Chapter 2 examines the airspace legal regime, aerial intrusion and State practices regarding arms limitation agreements and sovereignty.

Chapters 3 to 8 provide some technical background on airborne remote sensing systems. The major sensors - photographic, thermal infrared, multispectral and radar - are reviewed in Chapters 3 through 6. The characteristics of the sensors as well as the data they produce are described. Chapter 7 introduces the reader to some of the fundamentals of visual and digital image interpretation. In Chapter 8, the range of potential airborne platforms is outlined, from balloons to high altitude jets.

Chapters 9 and 10 review some operational aspects of the use of aircraft. Chapter 9 discusses maintenance of aircraft and sensors, and aircraft safety equipment. Chapter 10 considers some of the problems involved with international aircraft operations in the context of normal commercial operations, and then reviews some of the measures which have been used to help ensure efficient inspections in other agreements with intrusive inspection provisions.

Notes to Introduction

[1] Sloan, Stanley R. 1990. CFE Verification: Revolutionizing Relations. Arms Control Today 20(4), p. 21.
[2] Open Skies: Challenge for the 1990s Backgrounder. Arms Control and Disarmament Division. External Affairs and International Trade Canada. Ottawa, Canada. 15 September, 1989. p. 8.
[3] *Ibid*.

CHAPTER I

HISTORICAL BACKGROUND

1.1 The development of aerial reconnaissance

Aerial reconnaissance pre-dates aviation itself and began in the era of ballooning. A company of *aérostiers* was organized by France in April, 1794. One balloon was reportedly kept in the air for nine hours to make observations during the Battle of Fleurus.[1] The invention of the photographic camera in the late 1820's provided new opportunities for aerial reconnaissance, promising to provide detailed photographs which could be studied, rather than sketches and oral descriptions. The first known balloon photograph was taken in 1859 by Gaspard Felix Tournachon (later known as "Nadar") of the French village of Petit Becetre near Paris.[2] On October 13 of 1860, Samuel A. King and James W. Black took the first American aerial photograph when they photographed South Boston from the basket of the balloon *Queen of the Air* from an altitude of 365 metres.[3]

The early balloons and cameras were not ideally suited for reconnaissance. Balloon baskets were small and cameras were large. The cameras used glass plates which had to be coated in the field with a light-sensitive emulsion and then used and developed quickly, or the image would fade.[4]

Toward the end of the century, serious efforts were being made to improve the state of the art. A breakthrough came in 1871 with the development of a gelatin emulsion of silver halide grains which would allow the photographic image to be developed later. Only the camera and the photographic plates needed to be taken into the air, instead of the entire development apparatus as previously required.[5] Kites with remotely-controlled or timed-release cameras were used by the American and British armies into the beginning of the 1900's because they were less expensive than balloons, easier to transport, and less vulnerable to enemy fire.[6] An approach tried by the British used eight cameras arranged around the periphery of a balloon's basket, producing panoramic pictures of the surrounding terrain.[7] The most bizarre technique made use of pigeons, which would fly over the target area with cameras strapped to their breasts, taking automatically timed photographs of the ground below every thirty seconds.[8]

Introduction of the airplane greatly stimulated aerial photography. Unlike balloons or kites, airplanes did not have to be held captive by ropes. The first recorded photographs from an airplane were taken by Wilbur Wright on April 24, 1909, over Centocelli, Italy.[9] In January, 1911, the first American photograph from an airplane was taken of the San Diego waterfront using a Curtiss hydroplane.[10] That same year, the U.S. Army Signal Corps opened a flight training school at College Park, Maryland. Aerial photography was included in the curriculum from the outset.[11] The airplane's debut in war also came in 1911, when an Italian reconnaissance flight was used to make observations of Turkish positions during the Italian campaign in North Africa.[12]

Extensive use of aerial photography for military purposes dates from the early days of World War I. Aerial photographs were first taken of German-held territory by Lieutenant Laws of the Royal Air Force (RAF). He had difficulty convincing the authorities that aerial photographs could be useful until he brought back photographs which were obviously of intelligence value.[13] By the end of 1917, German reconnaissance planes were bringing back about four thousand photographs a day and in the process completely covering the entire western front every two weeks. In March 1918, Germany had 505 out of 2,047 aircraft on the western front dedicated to reconnaissance.[14] Combined British and French operations were probably about equal to those of the Germans.

Cameras weighed between thirty-five and a hundred pounds and were usually hand-held by the photographer. It was easier to take photographs at an angle while resting the camera on the rim of the cockpit than it was to lean out of the airplane to point it straight down. Hence, many of the photographs taken during World War I were "obliques" rather than "verticals." Camera lenses had focal lengths from 8.5 inches (21.6 cm) to about 40 inches (101.6 cm). Most film came as photo plates which had to be changed by hand, although some were attached in belts for quicker loading. Roll film was just beginning to appear. New analysis techniques were developed. Interpreters used stereoscopes for three-dimensional viewing, making it easier to find objects of interest and estimate their size. They learned how to assemble photographs into photomosaics showing entire areas at once.[15]

After the First World War, cameras were mounted inside the aircraft using specially-designed cushioned and vertically-stabilized mounts. Multilens cameras were tested throughout the 1930's which produced wide-angle photographs that were less distorted than those made by single lenses. Cameras were made that took interchangeable lenses. Roll film stored in magazines replaced plates. Film drives were operated by remote control mechanisms which could adjust the speed at which the film moved. Filmmakers were working on aerial films which were more light-sensitive and had finer emulsion grains. The finer-grained films combined with improved lenses produced photographs with steadily improving resolution.[16]

Photoreconnaissance was given another boost during the Second World War.[17] Knowledge of the spectral-reflectance properties of natural surfaces and the availability of practical infrared aerial photographic emulsions and field-developable colour films led to the development of false-colour "camouflage-detection" film. Col. Goddard, of the U.S. Army Air Corps, flew the first aerial tests of the new film between July 21 and August 7, 1942, near Rochester, N.Y.[18] By 1945, high resolution colour film was in widespread use. Dr. James Baker, a Harvard astronomer and optics expert developed cameras with 40, 60, 100, and finally 240 inch (100, 150, 250 and 600 centimetre) focal lengths and lenses which automatically compensated for changes in air temperature and atmospheric pressure.[19] World War II also spurred the development of other aerial reconnaissance devices, including thermal infrared and radar systems. During World War II, the United States, Great Britain, and Germany developed infrared sensing devices, but it was not until well after the war that sensitive detector elements with rapid response times were developed. The first successful airborne imaging radar, the "plan position indicator," was developed in Great Britain to assist nighttime and adverse-weather bombing.[20]

1.2 American aerial reconnaissance after World War II

Many countries have had active aerial reconnaissance programmes since World War II focussed on different targets. There is little documentation for most of these programmes. However, the use of aircraft by the United States for strategic reconnaissance has been comparatively well documented. An examination of the American programme on its own, while certainly not complete as a "history of aerial reconnaissance," is worthwhile in the present context for the information it can provide regarding how aircraft could be useful in a verification role.

For western countries, the Soviet Union became the major focus of interest after World War II. Initially, converted bombers such as the RB-36 Convair and RB-45 Tornado were used. One such converted bomber had a 240 inch (600 centimetre) focal length camera installed in its bomb bay.[21] These large and relatively slow aircraft quickly became vulnerable to improving Soviet air defences. More capable aircraft, such as the jet-powered RB-47, were adopted to enhance the survival of the aircraft but even these had a limited lifespan.

Lockheed Aircraft's Advanced Design Projects (ADP) group, headed by Clarence "Kelly" Johnson, prepared a design for a high altitude reconnaissance aircraft in response to a Design Study Requirement of March 27, 1953. Lockheed's U-2, as it became designated, was given approval on November 9, 1954.[22] The aircraft was simple in design, looking more like a glider than a conventional airplane. Every effort was made to minimize the weight of the aircraft. Construction of the first airframe began in January, 1955, and the first test flights were completed in July of the same year. With four aircraft in the programme by the end of the year, 70,000 foot (21,336 metre) altitudes became routine. There were sufficient airframes to enable the first pilots to begin training in early 1956.

Development of the aircraft was matched by similar progress in other technologies. New camera designs were produced. The Hycon Model 73B, or "B-camera," was designed to swing its lens from side to side, producing overlapping strips of photos for stereographic viewing.[23] Other camera systems included the Itek KA-102A LOROP system, the "A-3" and "A-4" units and the Wild RC-10 mapping camera.[24] A lightweight Mylar-based film was developed to allow large amounts of film to be loaded at once. The new acquisition capability was complemented by a new large-volume photo-interpretation facility.[25]

In this same period, U.S. President Eisenhower made his "Open Skies" proposal at the July, 1955 summit meeting in Geneva. Apparently concerned about the possible reaction of the Soviet Union to the U-2, the proposal would have provided a legal basis for aerial overflights if it had been accepted. Eisenhower's Open Skies proposal will be described further in Section 1.3.

With the rejection of the Open Skies plan, a programme of secret overflights was initiated, starting on July 4, 1956.[26] The U-2 overflights had a revolutionary impact. Within its first year, the U-2 program convincingly dispelled concerns over the purported Soviet "bomber gap." Later, U-2 overflights provided evidence indicating that the Soviet "missile gap" had also been overestimated. U-2 overflights reportedly provided "fully ninety percent" of the available hard data on Soviet military developments in this period.[27]

Initially, the U-2 was invulnerable to Soviet air defences. However, on May 1, 1960, a U-2 piloted by Francis Gary Powers was shot down by an SA-2 "Guideline" surface-to-air missile while over an airport near Sverdlovsk. The incident deeply embarrassed the United States. Overflights of the Soviet Union ceased and most of the 25 pilots were re-assigned to other posts.[28]

The U-2 came back to the forefront in 1962. Photos acquired by a U-2 in August, 1962, of the San Cristóbal area in Cuba revealed SA-2 sites deployed in a trapezoidal pattern. This matched deployment patterns of SA-2 sites used to protect ballistic missile complexes in the Soviet Union. Another U-2 overflight on October 14, 1962, acquired photographs of the first direct evidence of medium-range ballistic missiles (MRBM's) being installed, showing trailers, shelter tents and erector-launchers associated with MRBM's.[29] Using an interpretation technique dubbed "crate-ology," interpreters were able to deduce that IL-28 bombers were also being transported to Cuba, disassembled and in large crates lashed to the decks of freighters coming from the Black Sea.[30] In addition to the U-2 overflights, Navy P2V's and camera-carrying F8U Crusader fighters were used to monitor shipping lanes for freighters carrying military equipment. RF-101 Voodoos flew low-level photo missions of the deployment sites at San Cristóbal, Guanajay, Sagua la Grande and Remedios.[31]

Although reconnaissance satellites were available, they were not suited to acquiring imagery of Cuba which is long and narrow with an east-west orientation. The satellites orbited the earth in a north-south polar direction, overpassing Cuba quickly and at a right angle, thereby limiting the opportunity to acquire imagery.[32] Aircraft were considered more effective in providing the required intensive coverage.

Almost from the beginning, it was believed that a successor to the U-2 would be necessary because it would quickly become vulnerable to interception. Beginning in April of 1958, Lockheed submitted a series of proposals for an aircraft which would fly higher and faster. Their twelfth proposal was given limited approval on August 29, 1959.[33] The design was to eventually spawn four separate programmes, including the supersonic SR-71 which was operational for over two decades since its first flight on December 22, 1964.

The SR-71 holds the record as the world's fastest and highest flying aircraft. On July 27 and 28, 1976, it set a number of official world records, including the absolute world speed record of 2,193.167 miles per hour (3,529.56 km/hr) and the record for sustained altitude in horizontal flight at 85,069 feet (25,929.031 metres).[34] According to some reports, it's true ceiling may have been more than 100,000 feet (30,480 metres) with a top speed of more than Mach 4.[35]

Sensors on-board the SR-71 could reportedly image 100,000 square miles (259,000 square kilometres) of territory an hour.[36] Cameras were supplied by Itek, Fairchild and Chicago Aerial Industries (CAI) and were believed to be in the 24 to 110 inch (60 to 280 centimetre) focal length range.[37] The Loral synthetic aperture radar is "allegedly used as near standard kit" and reportedly could produce imagery with 3-metre resolution at ranges of at least 30 nautical miles (55 kilometres).[38]

Details regarding most SR-71 missions are not available in the open domain. However, accounts of some missions have been published.

In 1973, SR-71's operating from Griffiss AFB in New York and later from Seymour Johnson AFB in North Carolina, were used to monitor developments in the Middle East during and after the October War. About ten missions were flown, each one lasting 10 hours with five aerial refuellings and five hours of Mach 3 flying.[39] SR-71's reportedly also provided aerial photography to help verify the Sinai Disengagement Agreements of 1974 and 1975, and the Egypt-Israel Peace Treaty of 1979 until the end of the Withdrawal Period in 1982. This will be discussed in further depth in Section 1.3.

In January, 1978, an American reconnaissance satellite detected a number of crates being unloaded from a Soviet freighter in Havana which the "crate-ologists" believed to be MiG-23 aircraft. One version of the aircraft, the MiG-23E, is an interceptor, while another version, the MiG-23F, is a ground attack aircraft capable of delivering nuclear weapons. The Soviet Union insisted that the aircraft were MiG-23E's. If MiG-23F's were being delivered, it would have been a violation of a 1962 Soviet pledge not to deploy offensive weapons in Cuba. After the aircraft had been removed from their crates, SR-71 overflights were used to confirm that the aircraft which had been brought to Cuba were MiG-23E's.[40]

1.3 Airborne reconnaissance and arms limitation

Although the satellite-based reconnaissance systems of the United States and Soviet Union are most commonly associated with the verification of arms control agreements, airborne systems have figured prominently in some proposals and have actually been used to a limited extent.

The most familiar of these proposals was U.S. President Eisenhower's "Open Skies" proposal of 1955. The proposal was made at the July 1955 summit meeting in Geneva, attended by President Eisenhower, English Prime Minister Sir Anthony Eden, French Premier Edgar Faure and Soviet Prime Minister Nikolai Bulganin. On the fourth day of the summit, Eisenhower announced his proposal:

> "I propose ... that we take a practical step, that we begin an arrangement, very quickly, as between ourselves - immediately. These steps would include:
>
> To give each other a complete blueprint of our military establishments, from beginning to end, from one end of our countries to the other, lay out the establishments and provide the blueprints to each other.
>
> Next, to provide within our countries facilities for aerial photography to the other country - we to provide you the facilities within our country, ample facilities for aerial reconnaissance, where you can take all the photos you choose and take them to your own country to study; you to provide exactly the same facilities for us and we to make these examinations and by this step to convince the world that we are providing as between ourselves against the possibility of great surprise attack, thus lessening danger and relaxing tension. Likewise we will make more easily attainable a comprehensive and effective system of inspection and disarmament, because what I propose, I assure you, would be but a beginning."[41]

This was not the first time that the use of airborne overflights had been suggested. After the Baruch plan for control of atomic energy had been proposed by the United States in 1946, a United Nations commission reported that aerial surveys would be required for its implementation. Later, U.S. Secretary of State Dean Acheson made a general proposal for international "disclosure and verification" of all armed forces and weapons.[42]

In preparation for the July 1955 summit, Nelson Rockefeller had set up a panel of experts to study recommendations which the United States might propose. The Quantico Panel, as it became known, suggested that the President re-propose the plans for aerial inspection and exchange of military information.[43] It was estimated by Sherman M. Fairchild, the chairman of the board of Fairchild Camera, that thirty-four RB-47's would be needed to cover all of the Soviet Union. Eighteen would be needed for China and one for Eastern Europe.[44]

After the Geneva summit, the Soviet Union showed some willingness to consider the proposal. They proposed supplementing aerial inspection and exchange of military blueprints by stationing inspection teams in each country at control points such as at airfields, rail terminals and ports. The Soviets also inquired about the right to photograph overseas bases. While they were critical of the Open Skies plan, they did not dismiss it until the spring of 1956.[45]

Eisenhower still kept the Open Skies plan in mind. On May 25, 1960, Eisenhower went on national radio and television to discuss the U-2 incident and the aborted Paris Summit of May 16, and re-emphasized the interest of the United States in the plan:

> " ... I offered five years ago to open our skies to Soviet reconnaissance aircraft on a reciprocal basis. The Soviets refused. That offer is still open. At an appropriate time America will submit such a program to the United Nations, together with the recommendation that the United Nations itself conduct this reconnaissance. Should the United Nations accept this proposal, I am prepared to propose that America supply part of the aircraft and equipment required.
>
> This is a photograph of the North Island Naval Station in San Diego, California. It was taken from an altitude of more than 70 thousand feet. You may not perhaps be able to see them on your television screens, but the white lines in the parking strips around the field are clearly discernible from 13 miles up. Those lines are just six inches wide.
>
> Obviously most of the details necessary for a military evaluation of the airfield and its aircraft are clearly distinguishable.
>
> I show you this photograph as an example of what could be accomplished through United Nations aerial surveillance.
>
> Indeed, if the United Nations should undertake this policy, this program, and the great nations of the world should accept it, I am convinced that not only can all humanity be assured that they are safe from any surprise attack from any quarter, but indeed the greatest tensions of all, the fear of war, would be removed from the world. I sincerely hope that the United Nations may adopt such a program."[46]

Although the 1955 "Open Skies" proposal did not come to fruition, airborne reconnaissance has been used for verification-related activities. Airborne systems are one element of the "National Technical Means" (NTMs) of the United States and Soviet Union and are used with other systems to verify bilateral agreements.

Under the Sinai I Disengagement Agreement of January 18, 1974, it was agreed that the deployment of Egyptian and Israeli forces would be monitored regularly by American reconnaissance aircraft.[47] In the second Agreement of September 4, 1975, the United States agreed to become directly involved. According to the terms of the Annex of the Agreement, the United States formally agreed to undertake aerial reconnaissance missions over the areas covered by the Agreement.[48] The reconnaissance was reportedly done by an American Lockheed SR-71 from an altitude of 70,000 feet (21,336 metres).[49] Missions were flown several times per month[50] or when a special request was received from Egypt, Israel or the United Nations Emergency Force (UNEF).[51]

Under the second Agreement, UNEF was provided equal access to the aerial reconnaissance data. This was a great improvement over the system under the first Agreement, when UNEF did not have access to the photos, except from one side in support of a complaint. The accuracy of the ground inspection reports reportedly improved greatly with the cooperation between UNEF and the American aerial reconnaissance units.[52] In addition to the American reconnaissance missions, Egypt and Israel were permitted to fly their own reconnaissance aircraft freely to the border of the buffer zone and to fly up to the middle line of the buffer zone according to an agreed schedule.[53]

Once the Egypt-Israel Peace Treaty of 1979 was in effect, and until the end of the Withdrawal Period (April, 1982), the United States provided aerial reconnaissance as before.[54] The Sinai Field Mission (SFM) undertook low-level reconnaissance flights over a two day period, prior to a scheduled on-site inspection. Aircraft normally flew at altitudes of 244 to 305 metres but inspection teams also undertook "close look" surveillance of various military formations and installations.[55] After the Withdrawal Period (from April, 1982 to present), the Multilateral Force and Observers (MFO) took over the responsibilities of the SFM. Verification flights are carried out by MFO aircraft cleared with the authorities of the respective parties.[56]

Another example of airborne inspection being used, albeit in a very limited way, is for inspections conducted according to the Stockholm Agreement on Confidence- and Security-Building Measures in Europe. The 1986 Stockholm Agreement permits the use of aircraft and helicopters for inspections. However, they are used primarily as platforms for human observers, not sensors. Inspectors are permitted to use their own "photo cameras" and own binoculars, but there is no provision for actual aerial cameras or other reconnaissance sensors.[57] Nevertheless, the provisions of the Stockholm Document outlining the use of aircraft set important precedents with regards to how airborne inspections should be conducted.[58]

The role of airborne systems may be expanded in the next round of talks on CSBM's in Vienna. Measure six of the opening NATO proposal calls for improvements to "observation modalities" including possibilities for an aerial survey of the activity area. Measure eight calls for, amongst other things, permitting a pre-inspection aerial survey.[59] In the Warsaw Pact proposal, part three contains provisions to "develop and amplify" the previous Stockholm measures such as improving observer opportunities, including aerial survey and observation from helicopters. The fifth section proposes, amongst a number of measures, employing "modern technology" for verification.[60]

On May 12, 1989, prospects for expanded use of airborne systems for verification-related activities were enhanced when U.S. President George Bush made his first major foreign policy speech at Texas A & M University:

> "Thirty-four years ago, President Eisenhower met in Geneva with Soviet leaders who, after the death of Stalin, promised a new approach toward the West. He proposed a plan called 'Open Skies,' which would allow unarmed aircraft from the United States and the Soviet Union to fly over the territory of the other country. This would open up military activities to regular scrutiny and, as President Eisenhower put it, 'convince the world that we are ... lessening danger and relaxing tension.'
>
> ... Let us again explore that proposal, but on a broader, more intrusive and radical basis — one which I hope would include allies on both sides. We suggest that those countries that wish to examine this proposal meet soon to work out the necessary operational details, separately from other arms control negotiations."

Some of the initial reaction within the United States was less than enthusiastic, thinking that the proposal was primarily intended for public relations. Raymond L. Garthoff, a former U.S. Government official, said that aerial reconnaissance was less important now than during the Eisenhower Administration, when the United States had no reconnaissance satellites.[61] Although it was primarily intended as a confidence building measure, some specialists have indicated that aerial surveillance could be useful for verification of a conventional arms agreement in Europe.[62]

The Canadian Government strongly supported the initiative, and quickly indicated that Canada would be willing to join in an "Open Skies" arrangement that would allow for short notice overflights of Canadian territory by unarmed aircraft. The Prime Minister noted, that "an 'Open Skies' agreement could lead to an important increase in confidence between East and West. It could provide major benefits in the verification of arms control agreements, especially for states which do not possess satellite monitoring capabilities."[63] As Mr. Joe Clark, Canada's Minister of State for External Affairs, wrote,

> "Open Skies would let all members of NATO and the Warsaw Pact participate fully in arms control verification and monitoring.

Only large countries have satellites in the skies. Yet, if we are to have conventional arms control in Europe, it is essential that all parties to the agreement have the ability to assure their publics, on the basis of their own judgements, that these agreements are being adhered to, and that their security is intact."[64]

Airborne inspections will also likely be one of the verification components of the CFE Treaty. Verification of the treaty will be accomplished using a number of complementary layers, including NTMs, aerial and ground inspections. To a limited extent, ground inspection teams will be able to get an overhead perspective through the use of helicopters provided by the *inspected* country. These overflights will primarily be useful for relatively small areas as support for ground inspection teams. The aerial inspection provisions will probably involve the use of aircraft owned by the *inspecting* country equipped with remote sensing instruments. Overflights by these aircraft will provide more extensive overhead coverage than the helicopter overflights associated with the ground inspections.

Notes to Chapter I

[1] Burrows, William E. 1986. Deep Black: Space Espionage and National Security. Random House. New York. p. 28.
[2] Simonett, David S. (author/editor), Robert G. Reeves, John E. Estes, Susan E. Bertke, Charlene T. Sailer. (contributing authors) "The Development and Principles of Remote Sensing." IN: Colwell, Robert N. (editor-in-chief) 1983. Manual of Remote Sensing. Second Edition. Volume I. Theory, Instruments and Techniques. American Society of Photogrammetry. Falls Church, Virginia. p. 2.
[3] Burrows, op. cit., p. 29.
[4] *Ibid.*
[5] Fischer, William A. (author/editor), Peter Badgley, Donald G. Orr, George J. Zissis (coauthor/editors), Abraham Anson, John F. Cronin, William R. Hemphill, John H. Hopkins, David Landen, Paul D. Lowman, Jr., Leonard J. Porcello, Robert S. Quackenbush, Jr., J. Robert Quick, Donald S. Ross, G. Carper Tewinkel, Sondra G. Wenderoth and Edward F. Yost. "The History of Remote Sensing." IN: Reeves, Robert G. (editor-in-chief), Abraham Anson and David Landen (associate editors-in-chief). 1975. Manual of Remote Sensing. First Edition. Volume I. Theory, Instruments and Techniques. American Society of Photogrammetry. Falls Church, Virginia. p. 27.
[6] Burrows, op. cit., p. 30-31.
[7] *Ibid.*
[8] *Ibid.*
[9] Fischer et al., op. cit., p. 30.
[10] Burrows, op. cit., p. 31-32.
[11] *Ibid.*
[12] *Ibid.*, p. 32.
[13] Fischer et al., op. cit., p. 31.
[14] Burrows, op. cit., p. 34-35.
[15] *Ibid.*
[16] *Ibid.*, p. 39.
[17] A detailed first-hand account of aerial reconnaissance and photo intelligence during the Second World War is given in Babington-Smith, Constance. 1957. Air Spy. Harper & Brothers Publishers. New York. 266 pp.
[18] Fischer et al., op. cit., p. 37.
[19] Burrows, op. cit., p. 51.
[20] Simonett et al., op. cit., p. 3.
[21] Crickmore, Paul F. 1986. Lockheed SR-71 Blackbird. Osprey Publishing Limited. London. p. 10.
[22] Thornborough, Anthony M. and Peter E. Davies. 1988. Lockheed Blackbirds. Ian Allan Ltd. London. p. 12.
[23] Moser, Don. 1977. "The time of the angel: the U-2, Cuba, and the CIA." American Heritage 28(6), p. 9.

[24] Thornborough and Davies, op. cit., p. 33.
[25] Moser, op. cit., p. 9.
[26] Thornborough and Davies, op. cit., p. 30.
[27] Prados, John. 1982. The Soviet Estimate. Princeton University Press. Princeton, New Jersey. p. 102.
[28] Thornborough and Davies, op. cit., p. 33.
[29] Burrows, op. cit., p. 125.
[30] *Ibid*., p. 120.
[31] *Ibid*., p. 129.
[32] *Ibid*., p. 117.
[33] Thornborough and Davies, op. cit., p. 15.
[34] Crickmore, op. cit., p. 155.
[35] Burrows, op. cit., p. 160.
[36] Young, Susan H.H. and John W.R. Taylor. "Gallery of USAF Weapons: Reconnaissance and Special-Duty Aircraft." Air Force 71(5) (May, 1988), 180.
[37] Thornborough and Davies, op. cit., p. 100.
[38] *Ibid*.
[39] Crickmore, op. cit., p. 164.
[40] *Ibid*.
[41] Vexler, Robert I. (editor) and Howard F. Bremer (series editor). 1970. Dwight D. Eisenhower 1890-1969. Chronology - Documents - Bibliographic Aids. Oceana Publications, Inc. Dobbs Ferry, New York. p. 98-99.
[42] Donovan, Robert J. 1956. Eisenhower: The Inside Story. Harper & Brothers, Publishers. New York, N.Y. p. 345.
[43] *Ibid*. p. 345-346.
[44] Peebles, Curtis. 1987. Guardians: Strategic Reconnaissance Satellites. Presidio Press. Novato, CA p. 14.
[45] Donovan, op. cit., p. 349-350.
[46] Branyan, Robert L. and Lawrence H. Larsen. 1971. The Eisenhower Administration 1953-1961. A Documentary History. Random House, Inc. New York, N.Y. p. 1250-1251.
[47] Mandell, Brian S. 1987. The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management. Arms Control Verification Studies No. 3. Department of External Affairs, Canada. p. 5
[48] *Ibid*., p. 8.
[49] Siilasvuo, Ensio. "Verification Activities in UNEF II in Sinai." Symposium on Verification of Disarmament in Europe. Swedish National Defence Research Institute. Stockholm, 1985. p. 71.
[50] Mandell reports the frequency of overflights as "once every seven to ten days" whereas Siilasvuo reports a frequency of "twice per month."
[51] Mandell, op. cit., p. 13.
[52] Siilasvuo, op. cit., p. 71.
[53] Mandell, op. cit., p. 13.
[54] *Ibid*., p. 17.
[55] *Ibid*., p. 22.
[56] *Ibid*., p. 17.
[57] Article (87), Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe Convened in Accordance with the Relevant Provisions of the Concluding Document of the Madrid Meeting of the Conference on Security and Co-operation in Europe. Stockholm, 1986.
[58] These provisions will be discussed further in Chapter 11, Section 2.
[59] Borawski, John. 1989. "From Stockholm to Vienna: Confidence- and Security-Building Measures in Europe." Arms Control Today 19(4) p. 12, 13.
[60] *Ibid*., p. 15.
[61] Gordon, Michael R. "2 Suitors for Europe: Bush and Gorbachev Try to Impress NATO Allies With Offerings of Peace." The New York Times. Saturday, May 13, 1989. p. 7.
[62] *Ibid*.; Henry Trewhitt with Brian Duffy, Andy Plattner, Douglas Stanglin, Kenneth T. Walsh, Robin Knight and Jeff Trimble. "Bush's bold bid to rescue NATO" U.S. News & World Report. June 12, 1989. p. 27.
[63] "Prime Minister Welcomes President Bush's Call for 'Open Skies' and Offers to Include Canada." Press release. Department of External Affairs, Government of Canada. May 12, 1989; Smith, R. Jeffrey. "Bush Openness Plan a Bow to Symbolism." The Washington Post. May 13, 1989. p. A14.
[64] Clark, Joe. "Don't Dismiss Open Skies." The New York Times. June 5, 1989. p. A17.

CHAPTER II

LEGAL CONSIDERATIONS

The powerful influence of aircraft in warfare and their revolutionary effect upon transportation precipitated a number of international agreements regulating them. Almost every aspect of aviation is governed either by treaties, national legislation, rules and regulations or a combination thereof. This all pervasive legal intervention mandates a detailed consideration of the law governing aerial reconnaissance, particularly since this is one of the more politically sensitive uses to which aircraft can be put.

Arms control is by definition international. Even unilateral measures have extra-territorial application. The vast majority of arms limitation activity, whether bilateral or multilateral, is premised upon international agreement.

2.1 The Airspace Legal Regime

The basic principle, accepted ever since the 1919 Paris Convention,[1] is that each State "has complete and exclusive sovereignty over the airspace above it's territory."[2] By the time the 1944 Chicago Convention came into force, the Contracting States thereto "recognized," in article 1 thereof, the existence of the customary international law principle of airspace sovereignty. The Chicago Convention, accompanied by it's amplifying eighteen annexes, governs the complex field of international civil aviation today.[3] Sovereignty was, perhaps, best defined by Arbitrator Max Huber in the landmark Island of Palmas case[4] where he wrote of it in the following terms:

> "Sovereignty in the relations between States signifies independence. Independence in regard to a portion of the globe is the right to exercise therein, to the exclusion of any other State, the functions of a State. The development of the national organisation of States during the last few centuries and, as a corollary, the development of international law, have established this principle of the exclusive competence of the State in regard to it's own territory in such a way as to make it a departure in settling most questions that concern international relations."

Thus, territorial sovereignty extends fully to the airspace superjacent to each State which has "exclusive competence" to legislate concerning activities to be carried out there. This national airspace must be distinguished from it's international counterpart.

International airspace is sub-divided into two categories, that found over the high seas (*territorium extra commercium*) and that above "lands without a master"[5] (termed *terra nullius*) which have yet to be made amenable to a sovereign claim, such as

Antarctica.[6] The legal regime for international airspace over the high seas is that prescribed under the Chicago Convention,[7] while that governing Antarctica is contained in the Antarctic Treaty, to be discussed in more detail later in this section of the report.[8]

The essential distinction between national and international airspace lies in the extent of their respective overflight rights. Although the parties to the Paris Convention accorded "freedom of innocent passage" in time of peace over each other's territory, this was curtailed by the Chicago Convention which stipulates several conditions to overflight. Article 5 accords civil aircraft not engaged in scheduled international air services a

> "right ... to make flights into or in transit non-stop across it's territory and to make stops for non-traffic purposes without the necessity of obtaining prior permission, and subject to the right of the State flown over to require landing. Each contracting State reserves the right ... to require aircraft to follow prescribed routes, or to obtain special permission for such flights." (Emphasis added).

This is further restricted by article 9 which permits contracting States "for reasons of military necessity or public safety, [to] restrict or prohibit uniformly the aircraft of other States from flying over certain areas of it's territory" provided there is no discrimination between States and such prohibited areas are of "reasonable extent." The criterion of reasonableness is assessed subjectively by the State exercising it's right to establish a prohibited zone. A temporary prohibition "over the whole or any part of it's territory" may be imposed by a contracting State if it perceives the existence of exceptional circumstances, an emergency, or an overriding public safety interest.[9] Furthermore, article 68 of the Convention empowers States to designate the routes to be followed and the airports to be used by any international air service operating within it's territory. Thus, the freedom of overflight may be more accurately described as a privilege rather than a right. It is a limited freedom subject to removal or curtailment at any time by the State overflown upon it's terms, subject only to a requirement of reasonableness. This limitation, well recognized during the 1944 Chicago conference, led to the production of two agreements in addition to the Convention just discussed. Commercial imperatives militated against a general freedom of overflight. A piecemeal approach was adopted in order to extend it to scheduled international services. The Transit Agreement[10] accorded the "privilege" both of overflight and landing for non-traffic purposes and was widely ratified. However, the Transport Agreement[11] which tried to extend this to cover three additional "freedoms"[12] was generally ignored and rendered academic by the dynamic network of bilateral air transport agreements which is still the norm today.

Another aspect of international airspace was codified in the 1958 Geneva Convention on the High Seas which provided in article 2 that the high seas were "open to all nations" and that "no State may validly purport to subject any part of them to it's sovereignty." This "freedom of the high seas" was stipulated to comprise *inter alia* the freedom of overflight.[13] Of course, there is the concomitant responsibility to exercise this freedom "with reasonable regard to the interests of other States in their exercise of the freedom of the high seas." The air defence identification zone (ADIZ) illustrates the true extent of this freedom.

The ADIZ has been defined as "an area of airspace over land or water in which the ready identification, location, and control of civil aircraft is required in the interest of national security."[14] Since the 1950's a number of nations, including the United States, Canada, France and the Philippines have employed ADIZ's of up to 300 miles, although this is often expressed in enabling municipal legislation in terms of hours of cruising time from territorial airspace, rather than actual mileage.[15] This of course extends the ADIZ well out over the area recognized as high seas. Essentially, an ADIZ regulation requires foreign aircraft intending to fly into a State's airspace to file a special flight plan with an appropriate air traffic control unit in that State.[16] This leads to the situation where an aircraft flying through international airspace *en route* to a country which imposes an ADIZ must comply or lose it's right to land there and possibly jeopardize it's safety while in transit through ostensibly free airspace. The legal justification for an ADIZ is claimed to flow from the doctrine of self-protection, as exemplified by the U.S. Monroe Doctrine of 1823, applied under other names by other nations. That doctrine envisages the right of a State to take action to protect itself before events render the exercise of such right impossible.[17] Although there has been some dispute as to it's legitimacy, it's virtually unchallenged (at the diplomatic level) existence since 1950 may well have rendered the ADIZ a legitimate legal instrument.[18] In any event, it may be fair to describe it as a confidence-building measure which has generally contributed to increased security and stability by limiting dangerous opportunities for surprise.

Freedom of the high seas may be seen as further affected by the ability of nations to use them and their superjacent airspace for the conduct of military activities, such as naval manoeuvres and weapons testing.[19] This will often involve the issuance of Notices to Airmen (NOTAM's) and Notices to Mariners to avoid certain sections of the high seas during such manoeuvres.[20] Although by no means an attempted appropriation of the high seas, it results in the temporary exclusion of all other users from a specified area in which they are entitled to be, for they enter at their peril. The principle of reciprocity ameliorates this situation to a certain extent. However, there is a considerable disparity between the number of nations who would customarily (and with some frequency) avail themselves of this option and the potential number of seafaring and aviation-capable nations.

The Chicago Convention distinguishes between civil and state aircraft. Article 3 specifies that the Convention is not applicable to state aircraft, which are defined as those used in "military, customs and police services." These activities go to the essence of a State's expression of it's sovereignty and could not be transferred to ICAO in 1944, or now for that matter. This is augmented by article 89 of the Convention, which stipulates that

> "[i]n case of war, the provisions of this Convention shall not affect the freedom of action of any of the contracting States affected, whether as belligerents or as neutrals."

The 1923 Hague Draft Rules of Aerial Warfare,[21] although never adopted in a legally binding form, "largely corresponded to customary rules and general principles underlying the laws of war on land and at sea."[22] A similar distinction between categories of aircraft is contained within the Hague Rules except that it is between private (civil) aircraft and public (state) aircraft. Military aircraft and those non-military aircraft employed exclusively in the public service are deemed to be public aircraft, while all others are private aircraft.[23] Article 11 of the Hague Rules specifies that "outside the jurisdiction of any State, belligerent or neutral, all aircraft shall have full freedom of passage through the air and of alighting." In addition, article 12 recognizes the right of any State, "whether belligerent or neutral" to "forbid or regulate the entrance, movement or sojourn of aircraft within it's jurisdiction." This parallels the distinction in time of peace in the Chicago Convention, whereby state aircraft are not permitted to overfly foreign national airspace without authorization and only subject to the terms of such authorization.[24]

If an aircraft engaged in reconnaissance for verification of arms limitation were classed as a state/public aircraft, it would appear to require permission for it's overflight from the subjacent State. If such an aircraft were classed as civil/private, it would still be limited by the restrictions, including prohibited zones, which a subjacent State is entitled to impose upon overflight within it's territorial airspace.

The Charter of the United Nations[25] expresses it's primary purpose as being maintenance of international peace and security. To that end, the United Nations is empowered

> "... to take effective collective measures for the prevention and removal of threats to the peace, and for the suppression of acts of aggression or other breaches of the peace, and to bring about by peaceful means, and in conformity with the principles of justice and international law, adjustment or settlement of international disputes or situations which might lead to a breach of the peace."[26]

This is qualified by article 2(7) of the Charter whereby the United Nations is not authorized to intervene in matters essentially within a State's domestic jurisdiction, subject to a right to apply the enforcement provisions of the Charter contained in it's Chapter VII. The latter outlines the powers of the Security Council with respect to action it may take to ameliorate threats to the peace, breaches of the peace and acts of aggression. Article 43 of the Charter is especially relevant here and provides in it's first paragraph that

> "[a]ll Members of the United Nations, in order to contribute to the maintenance of international peace and security, undertake to make available to the Security Council, on it's call and in accordance with a special agreement or agreements, armed forces, assistance, and facilities, including rights of passage, necessary for the purpose of maintaining international peace and security." (emphasis added)

Since the Security Council determines the existence of a threat to or breach of the peace, this would appear to be a very significant power to request and obtain rights to overflight. However, until very recently, the actions of the Security Council were hampered by the exercise of the power of veto by one or other of the five permanent members.[27] Nevertheless, the successful passage of Resolution 598 pursuant to the Iran-Iraq war on July 20, 1987, and it's activation a year later by Iran's acceptance thereof, may presage a more dynamic Security Council performing on the world stage as originally envisaged in 1945.[28]

It has been averred that there are two exceptions to the "inviolability of territorial airspace ... (1) consent; and, (2) self-defence."[29] A State can at all times specifically consent to the overflight of even military aircraft belonging to another State. The other exception would envisage the exercise of overflight rights by State A without the consent of the subjacent State B, where State A believes it's self-defence demands a derogation from the sovereignty of State B. An alternative means to realise this notion would be the legitimate exercise of the powers of the U.N. Security Council in article 43 of the Charter to require a right to overflight. However, in the present context, the consent exception is the only relevant option.

2.2 Aerial Intrusion

There is nothing illegal *per se* in aerial reconnaissance. In time of peace it's legality depends upon whether it is being conducted in national or international airspace. If a reconnaissance aircraft of State A is flying in international airspace, at no time entering the territorial airspace of State B whose territory it is photographing or otherwise monitoring, then State A commits no offence. This is termed "peripheral reconnaissance."[30] In contrast, should the aircraft of State A stray into the territorial airspace of State B, although it performs the same act, it's locus converts this into an illegal activity, provided it has not obtained the prior consent of State B. The latter is termed "penetrative reconnaissance."[31] This dichotomy can best be illustrated by counterpointing two incidents which occurred in 1960. On May 1st of that year, a United States U-2 high altitude reconnaissance aircraft piloted by a civilian, Francis Gary Powers, was shot down *in flagrante delicto* some 1200 miles within Soviet territorial airspace. Powers was convicted in the Soviet Union of espionage.

> "During the subsequent debates in the United Nations Security Council, the fact that the U-2 program of penetrative reconnaissance violated the territorial sovereignty of the Soviet Union was emphasized by several delegations and never denied by the United States."[32]

In contrast, two months after the U-2 incident, a U.S. military RB-47 reconnaissance aircraft was shot down over the Barents Sea by a Soviet fighter. The United States claimed that the RB-47 had at all times remained outside the territorial sea of the Soviet Union and that it's destruction was a clear breach of international law. This was implicitly admitted by the U.S.S.R. which repatriated the survivors without charging them with espionage, following strenuous protestations by the United States in the Security Council.[33]

> "The most significant legal feature of the RB-47 incident is that neither the United States nor the Soviet Union claimed or admitted the right of a State to shoot down a foreign aircraft over the high seas, even though it flies close to foreign territory and even though it is a military aircraft engaged in military reconnaissance."[34]

There have been some 34 cases of aerial intrusion by civilian aircraft since 1947,[35] many of which have ended tragically. In an attempt to outlaw the use of such extreme force against civil aircraft, ICAO met in extraordinary session in April-May, 1984 and produced an amendment to the Chicago Convention, article 3 *bis*. In essence the latter seeks to enshrine the principle that

> "every State must refrain from resorting to the use of weapons against civil aircraft in flight and that, in case of interception, the lives of persons on board and the safety of aircraft must not be endangered."

There are those who contend that this is merely declaratory of existing customary international law[36] and those who would accept that the use of weapons against civil aviation, whilst deplorable, will not be absolutely banned until article 3 *bis* has been ratified by a two-thirds majority of ICAO member States.[37] If the latter belief is the correct one, which appears likely given State practice in this area, there are, nevertheless, two limitations in international law which are operative (if somewhat less than concrete). One is the principle of Proportionality, as expressed by the arbitral tribunal in the Naulilaa Incident[38] which held that in order for a reprisal to be legitimate in international law, it must be in proportion to the original offence and "reprisals out of all proportion to the act that inspired them ought certainly to be considered as excessive and illegal." The second, is the principle of the observance of "elementary considerations of humanity, [which are] more exacting in peace than in war," as noted in the Corfu Channel case.[39] However, these fall clearly short of a prohibition such as that envisaged by article 3 *bis*. Hence the necessity for it's promulgation. Unauthorized aircraft, be they engaged in reconnaissance or civilian air transportation impinge upon controlled national airspace at their peril, at least until article 3 *bis* becomes law. In that event, the ultimate sanction would not be destruction, but a recognized right

> "... that every State, in the exercise of it's sovereignty, is entitled to require the landing at some designated airport of a civil aircraft flying above it's territory without authority ... To this end each contracting State shall establish all necessary provisions in it's national laws or regulations to make ... compliance mandatory for any civil aircraft registered in that State ..."[40]

Some States, such as Sweden and the Soviet Union, already make illegal intrusion into it's airspace a criminal violation subject upon conviction to a custodial sentence.[41]

There are additional limitations contained within the Chicago Convention which are relevant to this discussion. Thus, article 8 provides in part that

> "[n]o aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without authorization ..."

This would outlaw reconnaissance drones which are becoming an increasingly sophisticated adjunct to military operations. In addition, article 36 of the Convention accords each contracting State the right to "prohibit or regulate the use of photographic apparatus in aircraft over it's territory."

To engage in aviation is to be subjected to a plethora of rules and regulations both municipal and international. Although they are of differing importance, the neglect to comply with even an apparently minor one, may have devastating consequences. The abiding impression is that for a system of aerial reconnaissance for verification to succeed, it must have the full agreement of all the nations to be overflown. In particular, States must not exercise their rights regarding prohibited zones, which may surround the very areas in which the reconnaissance overflights would be required. Reliance upon principles of customary international law for protection would be reckless. A treaty duly ratified by all the relevant nations in which they permit overflight pursuant to a "verification for arms limitation" scheme is the only safe and incontrovertibly legal means to proceed.

2.3 Airborne Verification - The Arms Limitation Context

This section deals with a number of international agreements which may prove instructive of State practice regarding their willingness to limit territorial sovereignty to facilitate verification of an arms limitation agreement. Comprising as they do the actions of various States clearly contemplating binding legal relations, both of the requirements (State practice and *opinio juris*, ie the belief that a rule of law is involved) laid down by the International Court of Justice for the existence of customary international law are present.[42]

The Antarctic Treaty[43] imposes a 30 year moratorium on the territorial claims to Antarctica,[44] which is thus *terra nullius* as discussed earlier. To ensure that no State does anything inconsistent with the aims of the Treaty, such as engage in military activities,[45] the Contracting Parties may appoint observers to monitor each other. Observers have "complete freedom of access at any time to any or all areas of Antarctica."[46] In addition,

> "[a]ll areas of Antactica, including all stations, installations and equipment within those areas, and all ships and aircraft at points of discharging or embarking cargoes or personnel in Antarctica, shall be open at all times to inspection by any observers designated ..."[47]

In order to maximize the effectiveness of the observers, "aerial observation may be carried out at any time over any or all areas of Antarctica."[48] Thus, there is a clear precedent for unlimited aerial reconnaissance, albeit over *terra nullius*.

The 1972 U.S.-Soviet Prevention of Incidents at Sea Treaty[49] can be seen as a compromise by each of the superpowers of their freedom of navigation on, and overflight of, the high seas (*territorium extra commercium*). This was in order to prevent a confrontation from developing and followed a series of incidents resulting from the excess zeal of naval commanders and their aviators. Article 3(1) of the Treaty provides that

> "[i]n all cases ships operating in proximity to each other, except when required to maintain course and speed, <u>shall remain well clear to avoid risk of collision</u>." (emphasis added)

This applies specifically to ships engaged in "surveillance" operations of other ships, which are to "stay at a distance which avoids the risk of collision" and also to avoid manoeuvres which might embarrass or endanger such shipping.[50] Furthermore, article 4 directs aircraft commanders to

> "use the greatest caution and prudence in approaching aircraft and ships of the other party operating on and over the high seas, in particular, ships engaged in launching or landing aircraft, and in the interest of mutual safety shall not permit: simulated attacks by the simulated use of weapons against aircraft and ships, or performance of various aerobatics over ships, or dropping various objects near them in such a manner as to be hazardous to ships or to constitute a hazard to navigation."

In addition, article 6 establishes a three to five day period for the issuance of warnings to mariners "of actions on the high seas which represent a danger to navigation or to aircraft in flight."

The Conference on Security and Co-operation in Europe commenced work in 1973 and concluded it's first phase at Helsinki in 1975. The Helsinki Final Act,[51] while recognizing the "inviolability of frontiers,"[52] provided in it's Document on confidence-building measures for the prior notification of major military manoeuvres. Such manoeuvres are defined as those exceeding 25,000 troops made up of army, navy, air force or any combination thereof. Notification is to be given at least 21 days in advance of the start of such manoeuvres. If the latter extend beyond the European land mass to adjoining sea areas and air space, this fact must also be notified. Most importantly, the Helsinki Final Act permits the exchange of observers in the following manner:

> "The participating States will invite other participating States, voluntarily and on a bilateral basis, in a spirit of reciprocity and goodwill towards all participating States, to send observers to attend military manoeuvres.
> The inviting State will determine in each case the number of observers, the procedures and conditions of their participation, and give other information which it may consider useful ...
> The invitation will be given as far ahead as is conveniently possible through usual diplomatic channels." (emphasis added)

This is augmented by a commitment to promote exchanges of military personnel and visits by military delegations. The Helsinki Final Act can be seen as a tentative derogation from territorial sovereignty to a limited but significant extent, with both it's strength and weakness inherent in the voluntary nature of such confidence building measures.

The 1976 Peaceful Nuclear Explosions Treaty[53] seeks to introduce on-site inspection into superpower nuclear research to ensure that various limits on the yield (or destructive power) of underground nuclear tests would not be exceeded. The tests envisaged are underground explosions conducted for "peaceful purposes." Article V of the Protocol containing the Treaty's verification provisions permits "designated personnel in the exercise of their rights and functions" to "have access along agreed routes" to the test location and it's environs within a radius of 10 kilometres of the site of the explosion.[54] The party carrying out the explosion is to notify the other party at least 30 days prior to the explosion[55] and observers may be present between 5 and 20 days in advance of the event and between 2 and 8 days thereafter, depending upon the yield of the nuclear device used.[56] The host nation is to

> "assure for designated personnel telecommunications with their authorities, [and] transportation and other services appropriate to their presence and to the exercise of their rights and functions at the site of the explosion." (emphasis added)[57]

Such designated personnel are specifically permitted to enter the territory of the host nation through an agreed port, which will usually be an airport given the time constraints involved, and to remain in such territory in order to carry out their purpose.[58] Thus, observers are not prohibited from having aerial access to and around test sites and may be permitted to do so when this is considered "appropriate ... to the exercise of their rights and functions" in each other's territory on a basis of reciprocity, whilst having explicit permission to carry out ground inspections.

Throughout the 1970's a number of agreements were reached between Egypt and Israel in order to bring about peace between them. The first was the 1973 Cease-Fire Agreement[59] which committed the two belligerents to the negotiation of a framework for the "disengagement and separation of forces under the auspices of the United Nations."[60] This was followed up by the first Disengagement Agreement in 1974.[61] This Agreement established a "zone of disengagement" between the combatants in which a United Nations Emergency Force (UNEF) was to be stationed.[62] The second Disengagement Agreement, negotiated a year later, affirmed the "buffer zone" to which access was controlled by the UNEF.[63] It elaborated provisions regarding aerial surveillance in an incorporated Annex to the Agreement which stipulated that there was to be

> "a continuation of aerial reconnaissance missions by the United States over the areas covered by the Agreement ... following the same procedures already in practice. The missions will ordinarily be carried out at a frequency of one mission every 7-10 days, with either party or the United Nations Emergency Force empowered to request an earlier mission. The United States Government will make the mission results available expeditiously to Israel, Egypt and the chief co-ordinator of the United Nations peace-keeping missions in the Middle East."[64]

The results of the U.S. aerial reconnaissance, both high altitude and "close look," were collated and supplied to both Egypt and Israel by the U.S. Sinai Field Mission.[65] In addition, UNEF personnel carried out bi-weekly inspections and manned check-points and observation posts. This was augmented by automatic early-warning stations, also provided by the United States in it's role as a neutral third party facilitating peace, and surveillance stations set up by Israel and Egypt themselves.[66] Highly specific provisions were included in a Protocol to the second Disengagement Agreement regarding flights generally over Sinai and aerial reconnaissance in particular. Thus, article V states in part that:

> "1. Aircraft of either Party will be permitted to fly freely up to the forward line of that Party.
> 2. Reconnaissance aircraft of either Party may fly up to the Median Line of Buffer Zone 1 [see Figure 2.1] ... in accordance with the following principles:
> a) Reconnaissance flights will be carried out by planes at a height of not less than 15,000 feet and on a straight course (along the median line of Buffer Zone 1). No manoeuvre should occur in the Buffer Zone that may involve the crossing of the lines of the other Party.

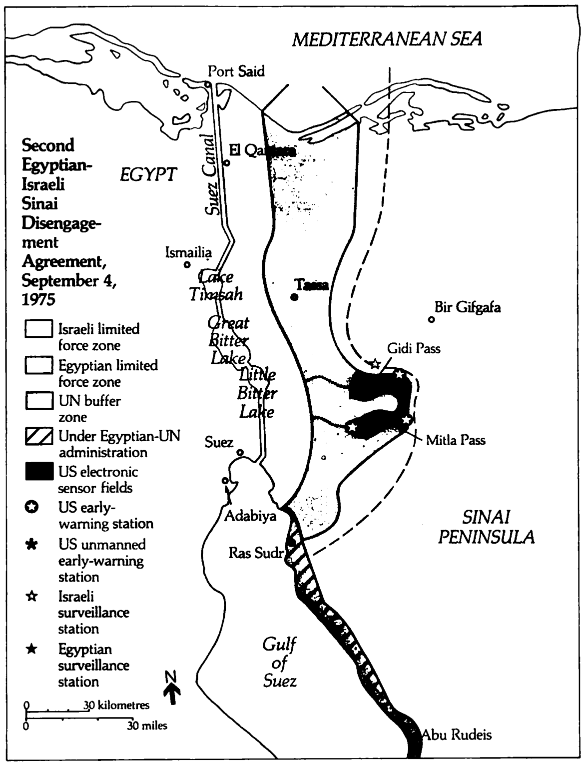


Figure 2.1 Second Egyptian-Israeli Sinai Disengagement Agreement, 4 September, 1975. (Reprinted, by permission of the Arms Control and Disarmament Division, External Affairs and International Trade Canada, from B.S. Mandell, The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management, op. cit., p. 7)

b) Each reconnaissance flight shall not be made by more than two (2) planes.
c) There shall be seven (7) reconnaissance flights every week for each Party.
d) For these flights each Party will have at it's exclusive disposal periods of 24 hours beginning at 12:15 until 11:45 the following day. The Parties will alternate in the use of the allocated periods. No flights will be carried out between 11:45 and 12:15 daily ...
f) Notice shall be given to a representative of the Chief Co-ordinator (of UNEF) not less than six (6) hours before each reconnaissance flight ..."

The final agreement in this sequence, the Egypt-Israel Peace Treaty of March 26, 1979,[67] *inter alia* perpetuated the aerial reconnaissance flights of the U.S. Sinai Field Mission under the same terms as the previous agreements had. The "Aerial Military Regime" is specified in Annex I to the Treaty in the following terms (see Figure 2.2):

"1. Flights of combat aircraft and reconnaissance flights of Egypt and Israel shall take place only over Zones A (Western Sinai) and D (Israel to the East of the International Boundary) respectively.
2. Only unarmed, non-combat aircraft of Egypt and Israel will be stationed in Zones A and D, respectively.

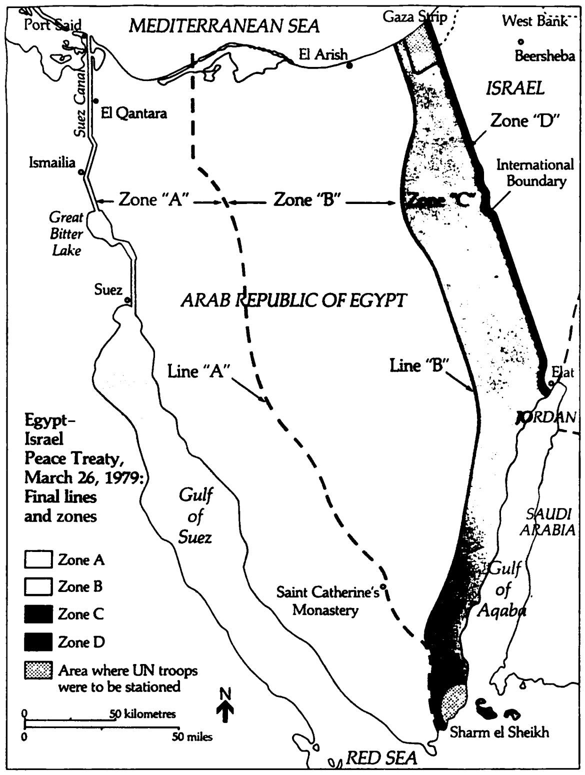


Figure 2.2 Egypt-Israeli Peace Treaty, 26 March, 1979: Final lines and zones. (Reprinted, by permission of the Arms Control and Disarmament Division, External Affairs and International Trade Canada, from B.S. Mandell, The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management, op. cit., p. 20)

3. Only Egyptian unarmed transport aircraft will take off and land in Zone B (central Sinai) and up to eight such aircraft may be maintained in Zone B. The Egyptian border units may be equipped with unarmed helicopters to perform their functions in Zone B.
4. The Egyptian civil police may be equipped with unarmed police helicopters to perform normal police functions in Zone C (Eastern Sinai to the west of the International Boundary).
5. Only civilian airfields may be built in the Zones.
6. Without prejudice to the provisions of the Treaty, only those military aerial activities specifically permitted by this Annex shall be allowed in the Zones and the airspace above their territorial waters."

Regarding U.S. aerial reconnaissance, article VII of the Appendix to Annex I provides that:

"1. Aerial surveillance activities during the withdrawal will be carried out as follows:
a. Both Parties request the United States to continue airborne surveillance flights in accordance with previous agreements until the completion of final Israeli withdrawal.

> b. Flight profiles will cover the Limited Forces Zones to monitor the limitations on forces and armaments, and to determine that Israeli armed forces have withdrawn from the [specified] areas and that these forces thereafter remain behind their lines. Special inspection flights may be flown at the request of either Party or of the United Nations ...
> 2. Both Parties request the United States operated Sinai Field Mission to continue it's operations in accordance with previous agreements until completion of the Israeli withdrawal from the area east of the Giddi and Mitla Passes. Thereafter, the Mission will be terminated."

This marks a considerable derogation from the traditional notion of territorial sovereignty and indicates that nations are prepared, albeit *in extremis*, to permit third party intervention over territory which each would claim to be it's own. Such intervention has included aerial reconnaissance and may be seen as a direct precedent for it's use for verification in other contexts.

The continuing activity of the Conference on Security and Co-operation in Europe, which produced the Helsinki Final Act mentioned above, succeeded in developing a document at Stockholm on September 19, 1986, elaborating "Confidence and Security-Building Measures."[68] These measures included prior notification of certain military activities, observation of such activities and compliance and verification provisions. The prior notification provisions are much more detailed than those of Helsinki, and include the total numbers of troops, tanks, artillery pieces, helicopters and the "envisaged number of sorties by aircraft,"[69] the "purpose of air missions,"[70] and the "categories of aircraft involved."[71] The notification period is extended to 42 days[72] whereupon the invited State may send up to two observers (either civilian, military, or a combination) to the notified manoeuvres.[73] The host State is to provide the observers "with appropriate means of transportation in the area of the military activity,"[74] which necessarily includes air transport and concomitant overflight rights for foreign personnel. The compliance and verification provisions are particularly relevant here. Each participating State may restrict to three the annual number of inspections by all other participating States of it's territory, no observing State being entitled to more than one inspection per year of the same host State.[75] A State requesting an inspection is permitted to designate a "specified area" in the territory of another State comprising terrain where notifiable military activities are to be conducted.[76] However, this may be limited by the host State which may permit

> "access, entry and unobstructed survey, <u>except for areas or sensitive points to which access is normally denied or restricted, military and other defence installations, as well as naval vessels and aircraft</u>. The number and extent of the restricted areas should be as limited as possible."[77] (emphasis added)

Both ground and aerial inspection are specifically permitted,[78] the aircraft being chosen to provide the inspection team with "a continuous view of the ground during the inspection." In practice, the inspectors fly into the point of entry using their own aircraft, but the inspections are conducted using aircraft provided by the host State. The procedure for aerial inspections is detailed in paragraph 90 of the Stockholm Document in the following terms:

> "After the flight plan, specifying, *inter alia*, the inspection team's choice of flight path, speed and altitude in the specified area, has been filed with the competent air traffic control authority the inspection aircraft will be permitted to enter the specified area without delay. Within the specified area, the inspection team will, at it's request, be permitted to deviate from the approved flight plan to make specific observations provided such deviation is consistent with [the provision concerning restricted areas] as well as flight safety and air traffic requirements ..."

The final treaty to be considered herein is the 1987 INF Treaty.[79] It's verification provisions are contained in article XI of the Treaty and permit on-site inspection of specified facilities in the United States and Soviet Union for a period of 13 years, during which time numerous inspections may be made to ensure intermediate-range nuclear weapons are progressively eliminated by the year 2001.[80] In addition, continuous monitoring of missile final assembly facilities at Utah and Votkinsk is permitted.[81] The second Protocol to the INF Treaty concerning inspection procedures provides in part that

> "[w]ithin 30 days after entry into force of the Treaty, each Party shall inform the other Party of the standing diplomatic clearance number for airplanes of the Party transporting inspectors and equipment necessary for inspection into and out of the territory of the Party or basing country in which an inspection site is located. Aircraft routings to and from the designated point of entry shall be along established international airways ..."[82]

Thus, there is no general freedom of overflight, but a controlled access through designated airports for inspectors to perform their function on the ground at the specified sites. Instead, the on-site inspections, which may be said to be the highest or most intrusive form of verification available, are explicitly to be supported by "national technical means of verification," which are familiar in the nuclear arms control context and include surveillance satellites.[83] The combination of satellite reconnaissance, assisted by specified co-operative measures, with on-site inspections was apparently judged to be adequate to fulfill the verification requirements of the Treaty. It is likely that this, together with the traditional use of satellite reconnaissance data by the United States and Soviet Union, precluded serious consideration of any role for aerial reconnaissance.

Clearly, there is considerable precedent for the use of aerial reconnaissance for verification of arms limitation. Even where on-site inspection is permitted, aerial reconnaissance has a role to play in areas of difficult terrain or to obtain coverage for large areas, such as in the Sinai peninsula and, for example, the borders between Iran and Iraq or that separating East and West Germany.

2.4 Other relevant treaties in a security context

There are several additional categories of treaty which may be instructive to this presentation. One category is that of bilateral overflight agreements, whereby State A accords the right to State B to fly over it's territorial airspace. An example of this is the US-USSR Protocol on Expansion of Air Services[84] which permits fourth freedom rights[85] of air transport for PanAm and Aeroflot into each other's country through designated airports and via specified intermediary points. In a security context, there are a number of examples of bilateral agreements according the military aircraft of one nation the right to overflight above the territory of the other.[86] It will be recalled that there is no right to overflight for military aircraft and they must always have the permission of the subjacent State.

Another important category of security treaty, is the mutual defence variety. One of the best known, The North Atlantic Treaty,[87] established in it's article 5 that the Parties considered an armed attack against one or more of them in Europe or North America as being against them all and, in the event of such an attack,

> "each of them, in exercise of the right of individual or collective self-defence recognized by Article 51 of the Charter of the United Nations, will assist the Party or Parties attacked by taking forthwith, individually and in concert with the other parties, such action as it deems necessary, including the used of armed force, to restore and maintain the security of the North Atlantic area." (emphasis added)

This is mirrored in the Warsaw Pact[88] by it's article 4, with the addition of an agreement to "establish a Unified Command, to which certain elements of their armed forces" would be allocated by subsequent agreement.[89] A number of bilaterals have been concluded between the Soviet Union and it's Eastern bloc members reiterating the general provisions of the Warsaw Pact.[90] As a further example of a mutual security agreement, the 1981 Israel-United States: Memorandum of Understanding on Strategic Co-operation[91] envisages "joint military exercises, including naval and air exercises in the Eastern Mediterranean Sea, as agreed upon by the Parties."[92] Such co-operation is explicitly to extend to the defence trade.[93]

The final category of security treaty to be dealt with herein is that concerning the granting of military base rights. Thus, in article I of the 1952 US-Japan Security Treaty[94] the right is given "to dispose United States land, sea and air forces in and about Japan." This was amplified in a 1960 Treaty of Mutual Co-operation and Security between Japan and the United States of America.[95] Article VI of the latter states that

> "[f]or the purpose of contributing to the security of Japan and the maintenance of international peace and security in the Far East, the United States of America is granted the use by it's land, air and naval forces of facilities and areas in Japan."

This is similar to two other treaties concluded by the United States in South East Asia. Thus, both a US-Korea treaty[96] and a US-Taiwan treaty[97] provide for the right of the United States to dispose it's land, sea and air forces on relevant asian territory by mutual agreement. What these treaties represent is a clear derogation from territorial sovereignty by the stationing of foreign personnel in the host State, which will involve considerable freedom of action on such bases and in the airspace surrounding them.

The unifying feature of all the treaties discussed in this part of the report, is the flexibility which nations can exhibit regarding overflight rights and the concomitant presence on the ground of the armed forces of an allied State where security interests are deemed to require it.

Notes to Chapter II

[1] Convention Relating to the Regulation of Aerial Navigation (The Paris Convention) 1919. No longer in force as superseded, see infra note 9.
[2] *Ibid.* article 1.
[3] Convention on International Civil Aviation signed at Chicago on 7 December, 1944, 15 UNTS 295 (1947).
[4] The Netherlands v. The United States of America, 2 R.I.A.A. 829 (1928).
[5] *Ibid.* Arbitrator Huber at 839.
[6] See this classification explained in: Bin Cheng "The Legal Regime of Airspace and Outer Space: The Boundary Problem Functionalism Versus Spatialism: The Major Premises," V Ann. Air & Space Law 323, 336-337 (1980) where an additional category, the Common Heritage of Mankind, is averred to have been "officially introduced" into international law.
[7] Article 12 of the Chicago Convention provides in part that "[o]ver the high seas, the rules in force shall be those established under this Convention."
[8] see infra section 3.3
[9] Article 9(b), Chicago Convention.
[10] "International Air Services Transit Agreement" signed at Chicago on 7 December, 1944, also called the "Two Freedoms Agreement."
[11] "International Air Transport Agreement" signed at Chicago on 7 December, 1944, also called the "Five Freedoms Agreement."
[12] *Ibid.*, article 1, section 1 provides in part that:

> "Each contracting State grants to the other contracting States the following freedoms of the air in respect of scheduled international air services:
> (1) The privilege to fly across its territory without landing;
> (2) The privilege to land for non-traffic purposes;
> (3) The privilege to put down passengers, mail and cargo taken on in the territory of the State whose nationality the aircraft possesses;
> (4) The privilege to take on passengers, mail and cargo destined for the territory of the State whose nationality the aircraft possesses;
> (5) The privilege to take on passengers, mail and cargo destined for the territory of any other contracting State and the privilege to put down passengers, mail and cargo coming from such territory ..."

[13] The other three freedoms specifically mentioned were those to navigate, to fish and to lay submarine cables and pipelines. This was reiterated in article 87(1)(b) of the 1982 Law of the Sea Convention U.N. Doc. A/CONF. 62/122, 7 October, 1982. Article 87 added both the freedom to construct artificial islands and other installations permitted under international law, and the freedom to conduct scientific research, to the high seas freedoms specifically mentioned.
[14] J.M. Denaro "States' Jurisdiction in Aerospace Under International Law." 36 J. Air L. & Comm. 688 (1970).
[15] R. Hayton "Jurisdiction of the Littoral State in the Air Frontier." 3 Philippine Int. L. J. 369, 381 (1964).

[16] For example, the Canadian ADIZ (CADIZ) regulations, contained in the Transport Canada Civil Aeronautics Flight Information Manual 1977/78 at 5-13, stipulate several conditions which must be complied with before an aircraft may fly into its area *viz*.

> "No person shall operate an aircraft into or within the domestic CADIZ unless he has filed an IFR (Instrument Flight Rules) flight plan, a DVFR (Visual Flight Rules) or a Defence flight notification with an appropriate air traffic control unit."

In addition to position reports

> "a pilot in command of an aircraft that will operate within a coastal CADIZ toward the land mass of Canada shall
> (a) file an IFR flight plan, a DVFR flight plan or a defence flight notification before take-off from his last location prior to his operation within the coastal CADIZ; and
> (b) provide an appropriate air traffic control unit with position reports or estimates required by the instrument flight rules."

[17] I.L. Head "ADIZ, International Law and Contiguous Airspace." 3 Alberta L. Rev. 182, 191 (1964).

[18] However, in 1961, a Soviet civil aircraft transporting Leonid Brezhnev from Moscow to Rabat, Morocco penetrated a French ADIZ surrounding Algeria while still over the high seas above the Mediterranean Sea. A strenuous protest was lodged by the Soviet Union at the necessity for compliance with this ADIZ whose legality was disputed. Hayton, op. cit.

[19] D.J. Harris Cases and Materials on International Law. (3rd Ed.) 322 (1983).

[20] *Ibid*. p. 323.

[21] Reproduced in A. Roberts and R. Guelff (Eds.) Documents on the Laws of War 121 (1982).

[22] *Ibid*.

[23] *Ibid*. article 13.

[24] Chicago Convention, op. cit., article 3(c).

[25] 16 UST 1134 signed 26 June, 1945, entered into force 24 October, 1945.

[26] *Ibid*. article 1(1).

[27] The five permanent members are the United States, Soviet Union, Peoples Republic of China, France and the United Kingdom.

[28] For text of Resolution 598 see The Times (London) 19 July, 1988, 9.

[29] F. Fedele "Overflight by Military Aircraft in Time of Peace." 9 JAG L. Rev. 8,17 (1967).

[30] *Ibid*. p. 22.

[31] *Ibid*. p. 20.

[32] *Ibid*. p. 21.

[33] Bin, op. cit. p. 348.

[34] Fedele, loc. cit.

[35] See G. Richard "KAL 007: The Legal Fallout." IX Ann. Air & Space L. 147, 148 (1984).

[36] M. Milde "Interception of Civil Aircraft vs. Misuse of Civil Aviation." XI Ann. Air & Space L. 105, 113 (1986).

[37] Richard, op. cit. 152. 102 ratifications are required out of a total of 152, with 48 Nations having done so by mid-July, 1988.

[38] Special Arbitral Tribunal: Germany-Portugal (1928) 2 R.I.A.A. 1012, 1019.

[39] The Corfu Channel Case (Merits) (United Kingdom v. Albania) (1949) I.C.J. 4.

[40] Article 3 *bis*, paragraphs (b) and (c).

[41] J. Sundberg "Legitimate Responses to Aerial Intruders - The View from a Neutral State." X Ann. Air & Space L. 251, 254 (1985). The custodial sentence prescribed by Soviet law is 3 years.

[42] North Sea Continental Shelf Cases (Federal Republic of Germany v. Denmark) (Federal Republic of Germany v. Netherlands). I.C.J. (1969); 8 Int. Leg. Mat. 340 (1969).

[43] 402 UNTS 71, opened for signature 1 December, 1959, entered into force 13 June, 1961.

[44] *Ibid*., Article XII 2.(a) entitles any contracting State to call a conference of all the contracting Parties to discuss a variation of the moratorium, such as to permit the exercise of territorial claims and begin the task of mineral extraction, after the expiry of 30 years from the date of the treaty's coming into force. The earliest date for such a conference would be 23 June, 1991.

[45] Article 1(1) of the treaty provides that

> Antarctica shall be used for peaceful purposes only. There shall be prohibited, *inter alia*, any measures of a military nature, such as the establishment of military bases and fortifications, the carrying out of military manoeuvres, as well as the testing of any type of weapons.

[46] Article VII(2).

[47] Article VII(3).

[48] Article VII(4).

[49] The text is reproduced in the New York Times, 26 May, 1972, A-4.

[50] *Ibid*. article 3(4).

[51] Concluded on 1 August, 1975, 14 Int. Leg. Mat. 1292 (1975).
[52] *Ibid*. Part I(a)III.
[53] "Treaty between the USA and the USSR on Underground Nuclear Explosions for Peaceful Purposes," signed at Moscow and Washington, 28 May, 1976; 15 Int. Leg. Mat. 891 (1976). Revitalized by protocol at Moscow summit in May, 1988. In anticipation of its ratification, a test was conducted in Nevada in August, 1988, which was attended by Soviet scientists; "US and Russia in joint nuclear test." The Times (London). 18 August, 1988, 1.
[54] *Ibid*. Protocol article V 1.
[55] *Ibid*. article V 2.
[56] Article V 3.
[57] Article V 8.
[58] Article VII.
[59] "Agreement regarding the implementation of United Nations Security Council Resolution 338 (1973) & 339 (1973)," U.N.S.C. Doc. S/11056/Add.3, Annex, 11 November, 1973, 12 Int. Leg. Mat. 1312 (1973).
[60] *Ibid*. article B.
[61] "Egypt-Israel: Agreement on the Disengagement of Forces," U.N.S.C. Doc. S/11198, 18 January, 1974, 13 Int. Leg. Mat. 23 (1974).
[62] *Ibid*. article B2. In addition, article B6 permits the "Air forces of the two sides ... to operate up to their respective lines without interference from the other side" but not to cross over into the zone of disengagement.
[63] Egypt-Israel: Agreement on the Sinai and Suez Canal," done at Geneva, 4 September, 1975, U.N.S.C. Doc. S/11818/ Add.1. 2 September, 1975, 14 Int. Leg. Mat. 1450 (1975).
[64] *Ibid*. Annex article 4.
[65] See B.S. Mandell "The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management," Publication of the Arms Control and Disarmament Division, Department of External Affairs, Canada, September 1987, 13.
[66] "Protocol to Agreement between Egypt and Israel," op. cit. 1458 *et seq*. A number of different sub-zones or "Areas" are specified within the overall disengagement zone, each such sub-zone having its own provisions. For example, in the Southern Area

> [a]ccess to the airspace and the coastal area shall be limited to unarmed Egyptian civilian vessels and unarmed civilian helicopters and transport planes involved in the civilian activities of the area. (article II 1.d)

Additional provisions for this Area define the UNEF responsibilities in the following terms in article II 2.:

> b. UNEF will assure that no military or para-military forces of any kind, military fortifications and military installations are in the area. The UNEF shall allow entry to and exit from the area by land, by air or by sea, through UNEF checkpoints to authorized persons and cargoes only.
> c. In order to perform its functions, UNEF
> (i) will establish checkpoints and observation posts
> (ii) will patrol throughout the area by land, coastal and air patrols.
> d. UNEF will carry out verification at the checkpoints through the Egyptian civilian police in the presence and under the supervision of UNEF personnel.

[67] "Treaty of Peace Between the Arab Republic of Egypt and the State of Israel," done at Washington, 26 March, 1979, 18 Int. Leg. Mat. 362 (1979).
[68] "Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe Convened in Accordance with the Relevant Provisions of the Concluding Document of the Madrid Meeting of the Conference on Security and Co-operation in Europe," Stockholm, 1986.
[69] *Ibid*. para. 35.1.6.
[70] Para. 35.1.7.
[71] Para. 35.1.8.
[72] Para. 29.
[73] Para. 41.
[74] Para. 53.6.
[75] Paras. 65-68.
[76] Para. 73.
[77] Para. 74.
[78] Para. 76.
[79] "Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of their Intermediate-Range and Shorter-Range Missiles" done at Washington on 8 December, 1987.
[80] Article XI 5. permits each Party to conduct 20 inspections annually in the first 3 years, 15 inspections per year in the next 5 years and 10 per year in the final 5 years.
[81] Article XI 6.
[82] "Protocol Regarding Inspections Relating to the Treaty between the USA and USSR on the Elimination of their Intermediate-Range and Shorter-Range Missiles," article III 8.

CHAPTER III

PHOTOGRAPHIC SYSTEMS

The wavelength range from 0.3 to 0.9 μm is known as the photographic remote sensing region. Wavelengths in this region may be imaged by photographic methods. An image is recorded on photographic film which must be developed to be seen. Electro-optical systems are being increasingly used because the imagery can be seen immediately using a suitable display device. But photography remains the optimal remote sensing system if collecting imagery with maximum spatial detail is required. Photographic systems are likely to play a significant role in any multilateral verification regime because of the importance of spatial information for tasks related to verification.

3.1 Vertical photography

The major photographic system is the frame camera. This type of camera comes in a wide range of formats, from the standard 35-mm cameras (25 x 37 mm format) commonly used for hand-held photography on the ground to specialized aerial cameras using 240 mm film and providing a 229 x 229 mm (9 x 9 inch) format. Survey (or cartographic) cameras, such as the Wild AVIOPHOT™ RC20 in Figure 3.1, are primarily designed for medium altitudes and "average" conditions. They are built to provide distortion-free photographs for map production. Reconnaissance cameras must provide high resolution imagery and are designed to meet the requirements of specific photographic missions.

Tactical military reconnaissance cameras must often take photographs from aircraft flying at low altitudes, high air speeds and under adverse photographic conditions. Tactical military reconnaissance cameras typically supply forward motion compensation, automatic exposure control and take up to 12 frames per second. The Vinten Type 360 70-mm camera (Figure 3.2) is a rugged and dependable system providing frame rates of 4 frames per second (fps) with a shutter speed of 1/1000 second or 8 fps with a shutter speed of 1/2000 second.

Vertical photographs provide a maplike, overhead view of the ground. However, they are seldom truly vertical. Aircraft motion and other factors usually introduce a few degrees of tilt. As well, vertical photographs do not show objects in their true "map

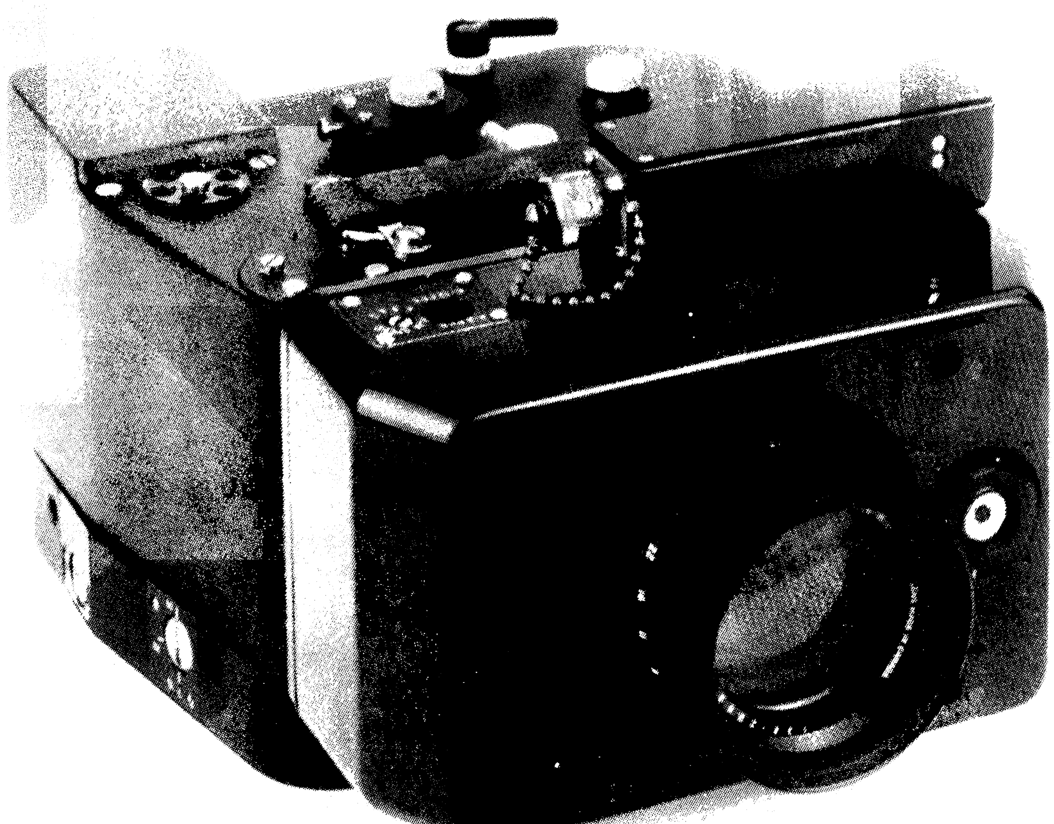


Figure 3.1 (on facing page, top) The Wild AVIOPHOT RC20 Aerial Camera System with camera (left) and navigation sight (right). The camera mount has servo motors for remote-controlled leveling and orientation of the camera. The camera is equipped with automatic exposure meter control and forward-motion 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 RC20 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 3.2 (on facing page, bottom) The Vinten Type 360 reconnaissance camera was originally designed for the Royal Air Force as an alternative for larger format cameras which could not be fitted into small tactical reconnaissance aircraft. It is rugged and reliable, providing high quality low and medium altitude high-speed tactical aerial photography with minimum cost and complexity. The cameras can be fitted with manual click stop lenses, remote control lenses or automatic exposure control lenses. (Courtesy of Vinten Military Systems Ltd.)

position." A map is an orthographic projection, which shows objects as though each were viewed from directly above. A photograph is a perspective projection. All objects are viewed from a single, common point (in the camera lens). Figure 3.3 shows a portion of a vertical aerial photograph of an airfield. Using photographs such as this, different kinds of aircraft may be distinguished based upon measures such as fuselage length, wing span, wing shape, stabilizer design, and the number and position of engines.[1]

Figure 3.3 Typical vertical panchromatic aerial photograph of an airfield. Several different kinds of aircraft can be distinguished. (Courtesy of David M. Dorschner, Aviation Resource Management)

The scale of vertical aerial photographs is determined by the relationship

$$\text{Scale (S)} = \frac{\text{distance on the photo (ab)}}{\text{distance on the ground (AB)}}$$

Usually the scale is expressed as a representative fraction, such as 1:10,000 or 1:40,000. A representative fraction of 1:10,000 means that one unit of linear distance measure (centimetre, inch, etc.) on the photo represents 10,000 equivalent units of horizontal distance on the ground. A 1:10,000-scale photograph has a larger scale than a 1:40,000 photo. Objects will measure larger, thereby providing more detail, in the 1:10,000 photo than they do at the 1:40,000 scale. Figure 3.4 includes 70-mm photographs with scales ranging from 1:5,000 to 1:40,000.

Figure 3.5 shows the geometric relationships involved in the calculation of photographic scale. Using the similarity of triangles *AOL* and *aoL*, the scale may be expressed in a form

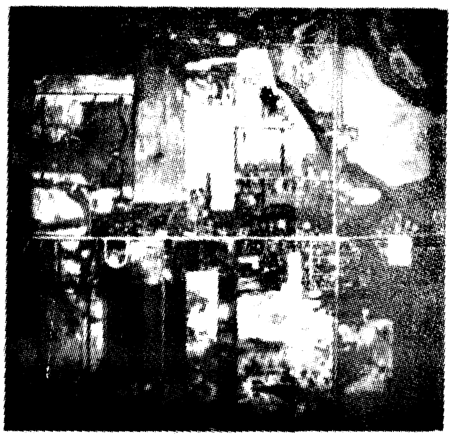
$$\text{Scale (S)} = \frac{\text{Camera focal length}}{\text{Flying height above terrain}} = \frac{f}{H'}$$

There are different combinations of focal length and flying height which will provide photography at a particular scale. Selecting the right combination is a matter of balancing constraints.

The focal length of a camera lens affects the photo geometry and quality in a number of significant ways. Longer focal length lenses provide a more vertical view of objects situated toward the edges of camera's field of view. This reduces "dead ground," areas near the edges of photo frames which are hidden from view behind hills or tall objects (Figure 3.6). Long focal length lenses would be better for looking through openings in a forest canopy to check for vehicles parked beneath the trees.

The type of aircraft determines the maximum ceiling for flying.[2] Oxygen equipment or a pressurized aircraft is required at altitudes above 10,000 feet (3048 metres) ASL. In some locations, persistent haze or low cloud may set limits on the maximum flying height.[3] On the other hand, there is often turbulence below 5,000 feet ASL, particularly in the tropics, and urban areas have minimum flying height restrictions.

If the terrain is perfectly flat, features in a vertical photograph will be positioned exactly as they would on a topographic map of the same scale. For most photographs, however, distance and area measurement are complicated by scale variation, relief



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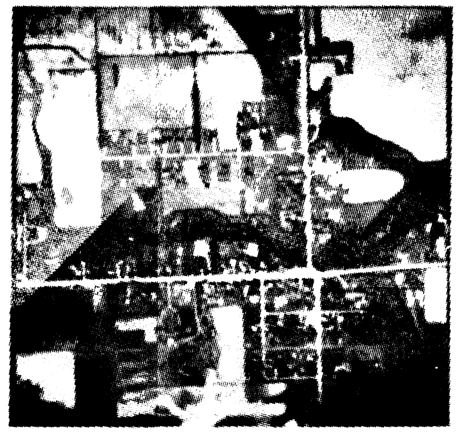

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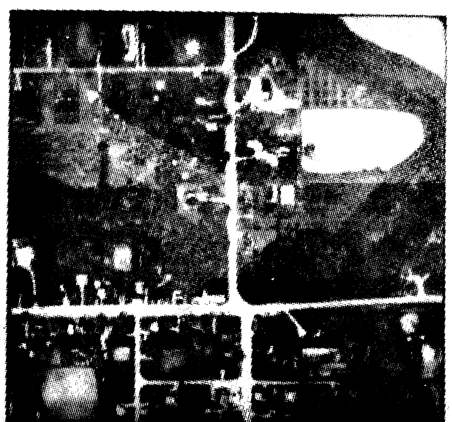

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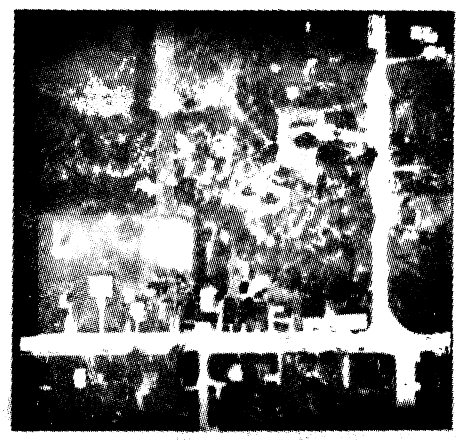


1:5,000

Figure 3.4 Aerial photographs at different scales:

1:5,000	(largest scale)
1:10,000	
1:20,000	
1:40,000	(smallest scale)

Note the extent to which small detail can be interpreted at each scale and the relationship between the total area covered by each photograph and its photographic scale. Large scale photographs are better for interpreting small features but each photograph covers a smaller physical area. (Courtesy of E.M. Senese, Ontario Centre for Remote Sensing.)

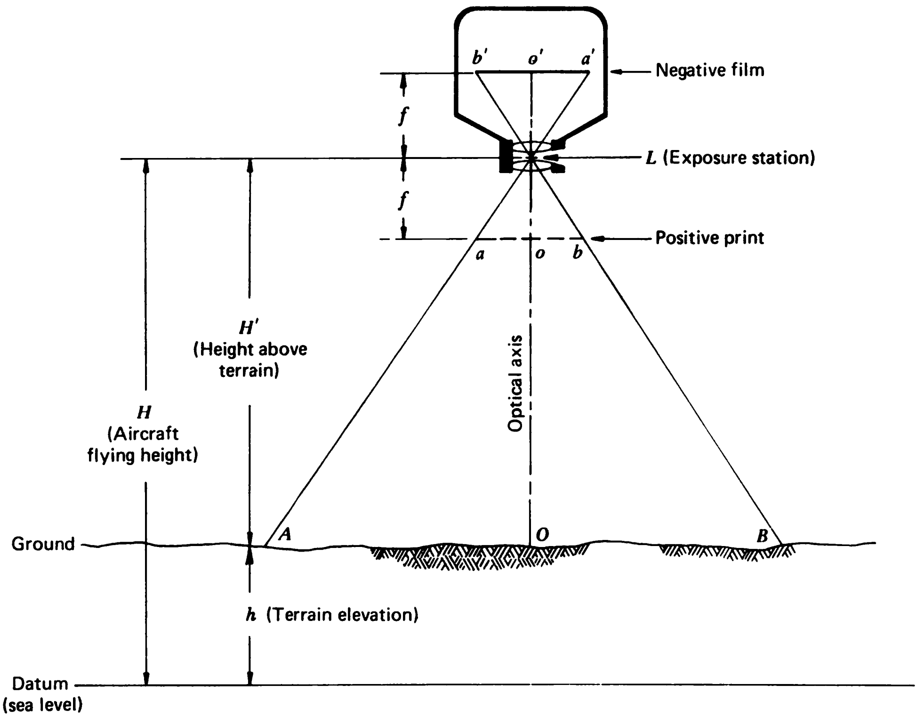


Figure 3.5 Geometric relationships associated with scale calculations for a vertical photograph. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 83, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

displacement and tilt.

Photographs taken over hilly terrain exhibit continuously varying image scales associated with changes in terrain elevation (Figure 3.7). Areas with higher elevations are closer to the camera, and therefore appear larger in the photograph, than those at lower elevations. For general orientation purposes, the average scale can be used based upon an estimated average terrain elevation. For accurate measurements, however, the actual terrain elevation or flying height above ground must be known.[4]

Relief displacement results from the perspective projection of photographs. It causes the tops of objects to be imaged further from the center of the photograph than

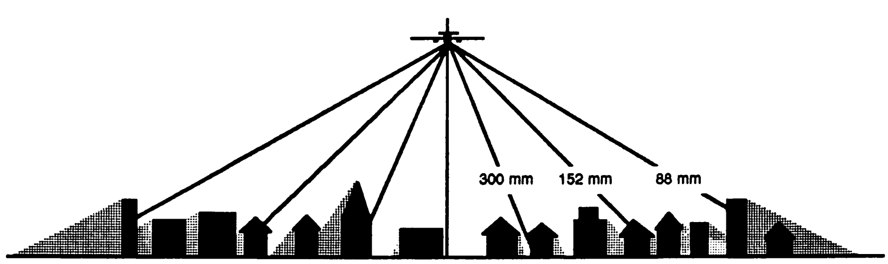


Figure 3.6 Effects of different lens angles on the sizes of dead zones toward the edges of photo frames. (Redrawn from Ron Graham and Roger E. Read, Manual of Aerial Photography, p. 215, by permission of Focal Press.)

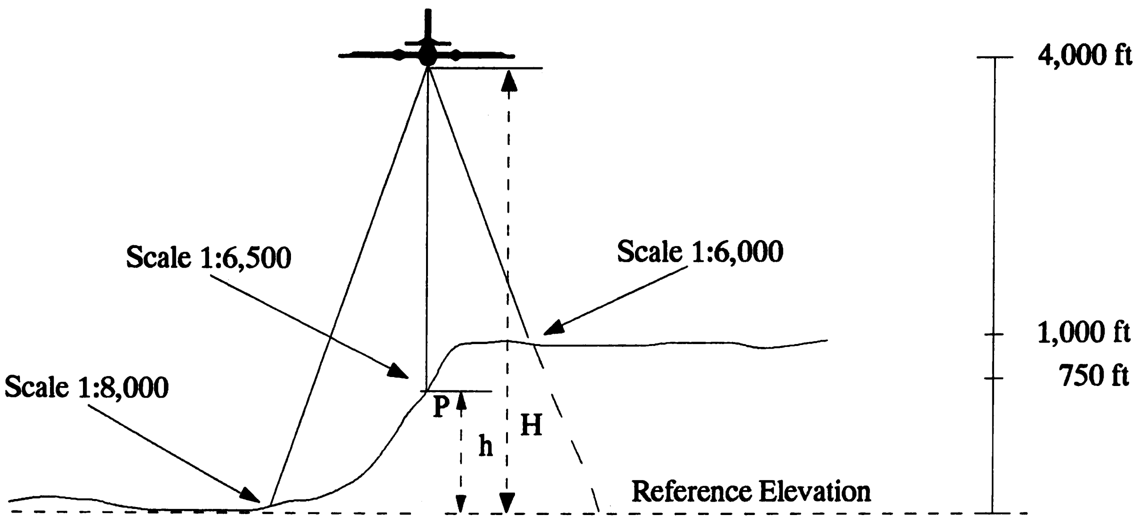


Figure 3.7 Scale and coverage differences over variable terrain. (Redrawn from Ron Graham and Roger E. Read,Manual of Aerial Photography p. 227, by permission of Focal Press.)

their bases, making them "lean" away from the center It also causes straight line features such as roads or power lines to appear crooked in hilly terrain. Figure 3.8 illustrates the geometry of relief displacement.This effect is most pronounced for tall

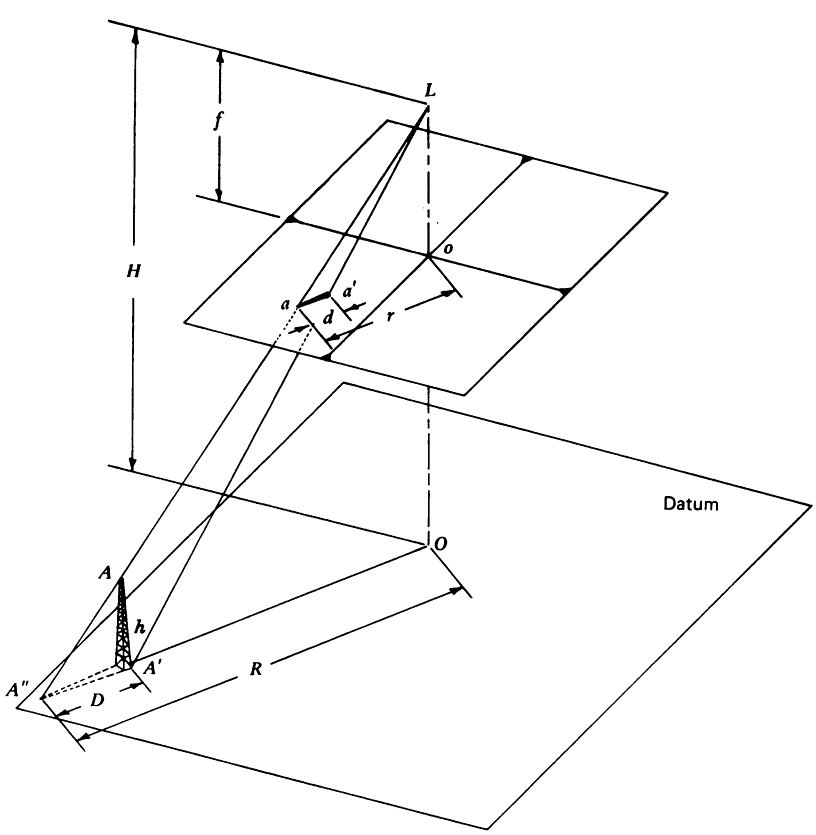


Figure 3.8 Geometric components of relief displacement. (From Thomas M. Lillesand and Ralph W. Kiefer,Remote Sensing and Image Interpretation p. 298, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

objects or areas of high relief, at the edges of photographs, and for photographs taken from a low flying height above terrain. The use of longer focal length lenses flown at higher altitudes will reduce the effects of relief displacement and scale variation in areas of high relief.

Tilted photographs present slightly oblique, rather than truly vertical, views of the terrain. Along the "hinge" formed by the tilted photograph and an imaginary horizontal plane, objects are imaged in the same positions as they would in an untilted photograph. Objects are displaced radially inward on the upper side of a tilted photograph and radially outward on the lower side. In practice, virtually all aerial photographs are tilted to some degree. Tilt of less than 2 or 3 degrees can be ignored even for photogrammetric survey work without serious measurement errors.

The ground coverage of a photograph is a function of the camera format size and scale of the photograph. If the camera format is held constant, there is a tradeoff between the ground area covered and the detail provided by a photograph. An increase in the scale of photography (by increasing the focal length of the lens or by reducing the flying height) will reduce the area which is covered by a single photographic frame.

Most vertical photography is taken as a series of overlapping flight strips. Two adjacent overlapping photographs, called a stereopair, can be viewed as a three-dimensional stereomodel using a stereoscope. A minimum overlap of 50 per cent is required from one photograph to the next along a strip to provide complete stereoscopic

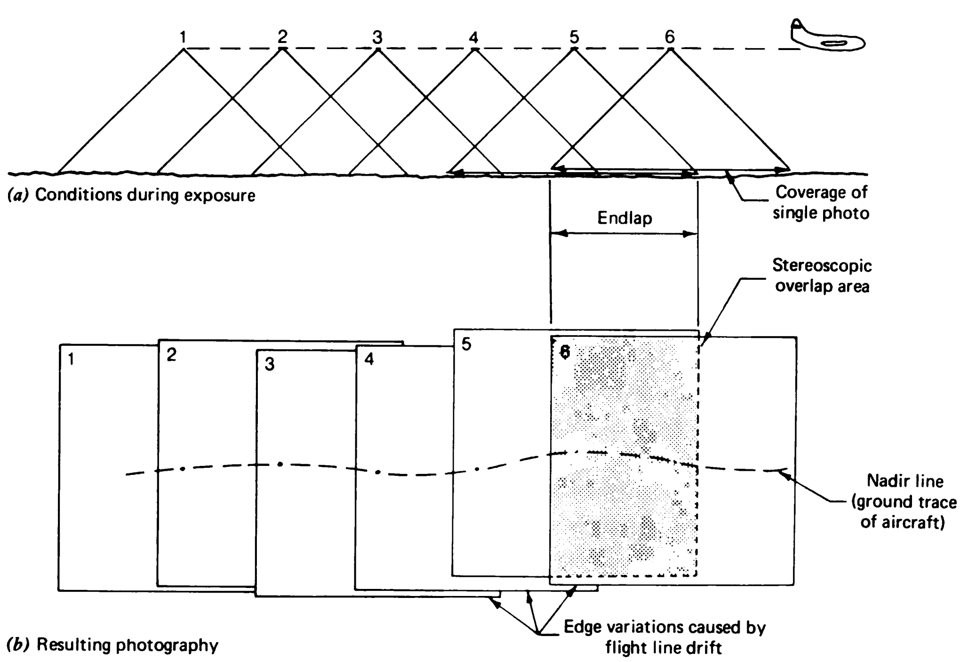


Figure 3.9 Acquisition of overlapping photographic coverage along a flight strip to provide stereoscopic coverage. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 78, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

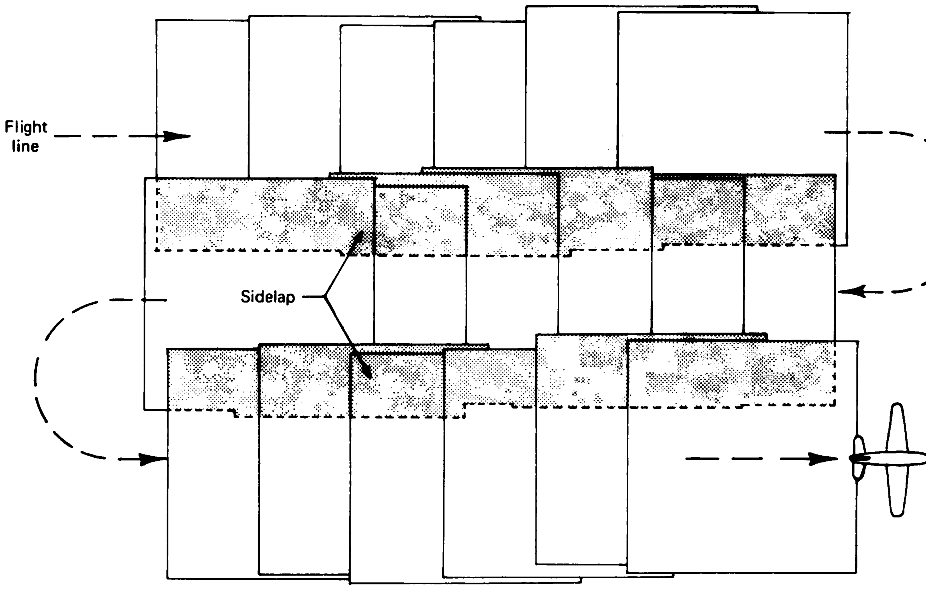


Figure 3.10 The use of sidelap between adjacent flight lines to obtain contiguous coverage of an area. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 80, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

coverage of an area. However, it is possible to inadvertently fail to get stereoscopic coverage along a flight line because of camera tilt, variation in the flying height or variation in terrain elevation. For this reason, 60 per cent overlap is the generally accepted standard. Figure 3.9 illustrates the acquisition of overlapping photographs for stereoscopic coverage.

The entire area of interest cannot always be photographed using a single flight line. If the photography is required to cover a large area, the photos will be obtained using a block coverage pattern. Adjacent flight lines are flown with a sidelap, usually of 30 per cent. Figure 3.10 shows the use of adjacent flight lines with sidelap to ensure contiguous block coverage of an area.

Drift and crab are the two primary causes of unsatisfactory block coverage (Figure 3.11). Drift is a displacement of the aircraft from its intended flight line due to crosswinds. This can result in gaps in coverage between adjoining strips of photography. Crab is caused by a failure to orient the camera with respect to the intended flight line.[5]

Maintaining the required sidelap may be a problem where the terrain elevation changes. As the terrain elevation increases, sidelap may be reduced to the point where gaps in coverage could occur (Figure 3.12a). To compensate, the line spacing could be reduced (Figure 3.12b) or, assuming the terrain is known in advance, the flying height could be altered from one flight line to the next to match the changes in terrain elevation (Figure 3.12c).

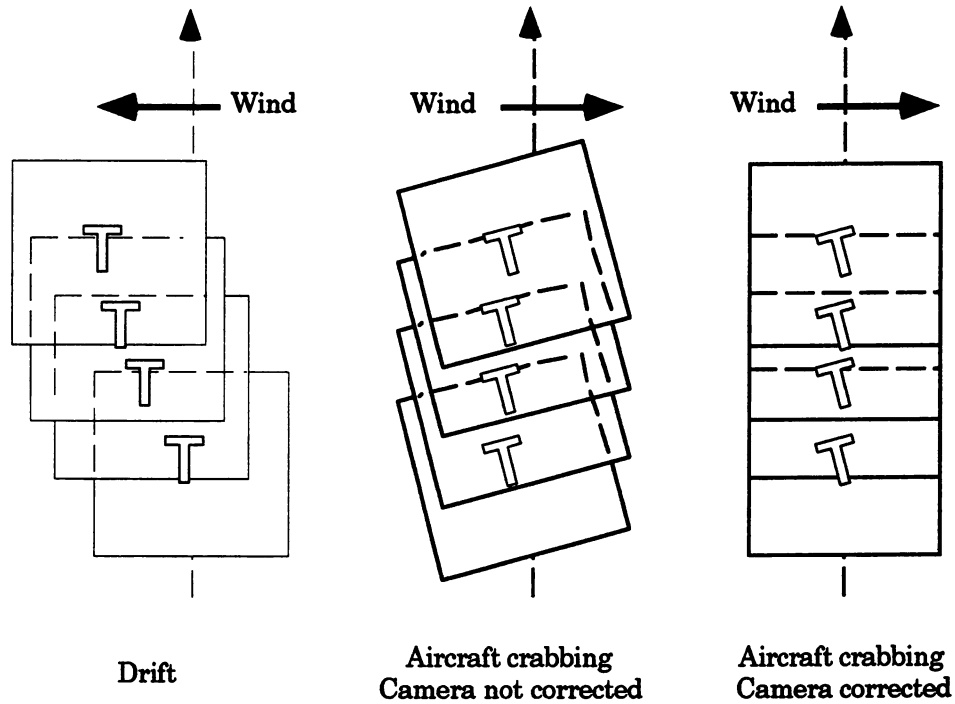


Figure 3.11 Drift is the result of an aircraft being carried off the intended flight line by a crosswind. Crab is the result of the pilot of the aircraft compensating for a crosswind but the camera not being properly oriented to be parallel to the flight line. (Courtesy of Morrie Konick, Consultant, Vinten Military Systems Limited.)

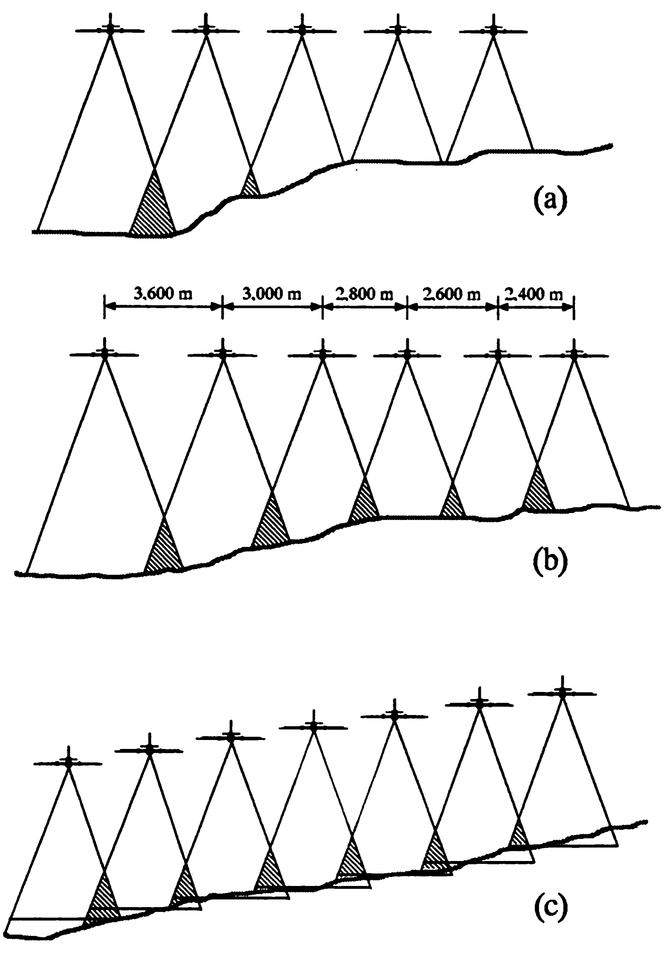


Figure 3.12 Regular line spacing, as used over flat terrain, will not meet sidelap requirements in areas where elevation increases from one line to the next (a). The line spacing could be reduced to maintain the required sidelap while allowing photo scale to change with changes in terrain elevation (b), or a steadily increasing flying altitude could be used to maintain the required sidelap and approximate photo scale (c). (Redrawn from Ron Graham and Roger E. Read, Manual of Aerial Photography, p. 227 & 228, by permission of Focal Press.)

Another form of survey is the feature line survey in which a terrain feature such as a river or road is followed (Figure 3.13a). Such a survey requires more planning and in-flight effort than block patterns. Each flight line has a unique heading. Crosswinds will have different effects upon each flight line, necessitating drift checks for each line (Figure 3.13b). Unlike block flying, the runs to be flown may not be in any order, and there is a danger of runs being overlooked. It is important to include margins around the area of interest to allow for navigation errors. If coverage of the whole area, complete with margins, cannot be guaranteed with single-line coverage, then parallel lines should be added.

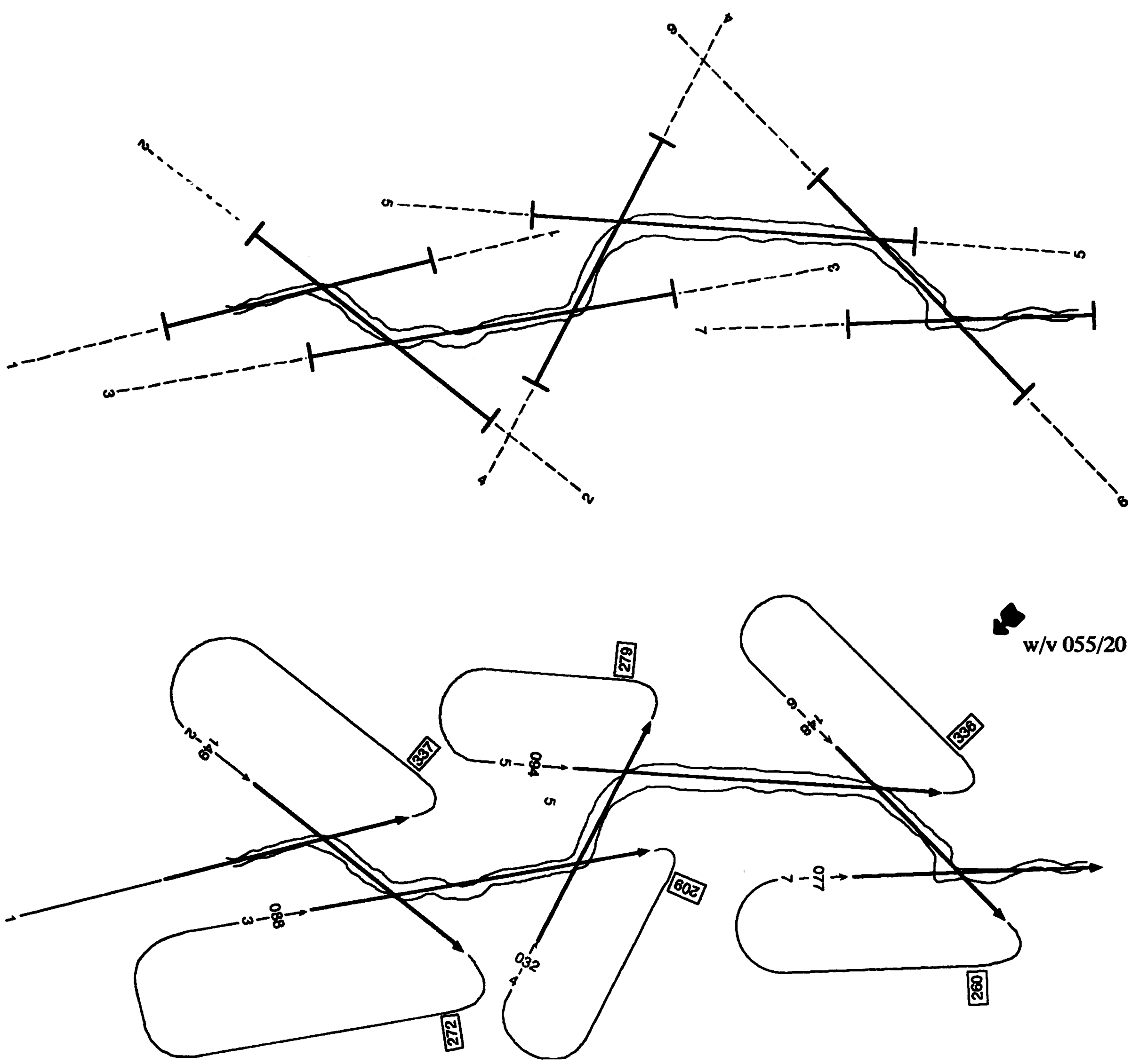


Figure 3.13 Arrangement of flight lines for a feature line survey (top) and the flight pattern to check for crosswinds and drift for each line (bottom). (Redrawn from Ron Graham and Roger E. Read, Manual of Aerial Photography, p. 243 & 244, by permission of Focal Press.)

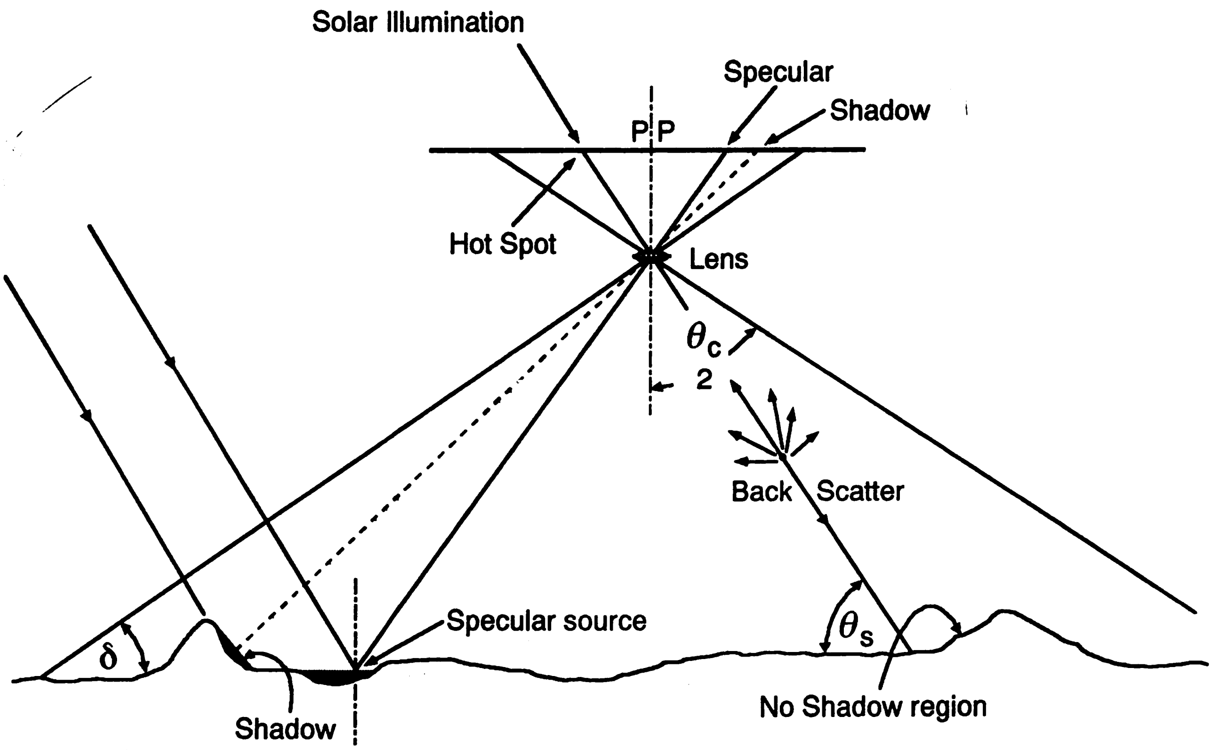


Figure 3.14 Geometry of hot spot and sun spot formation in wide-angle photography. To minimize these effects, flying should be restricted to periods when the solar angle (θ_S) is less than δ. (Redrawn from Ron Graham and Roger E. Read, Manual of Aerial Photography, p. 134, by permission of Focal Press.)

The timing of aerial photo missions is dependent, for several reasons, upon the solar altitude.[6] The solar altitude, in turn, is determined by the time of day, season of the year as well as latitude of the project area. Solar altitude nomograms may be used to calculate when the sun will be above a particular altitude and when photos will have a hot spot or sun spot.[7] Both kinds of "spot" are associated with high solar altitudes and are more of a problem for wide-angle photography.

The hot spot, or "no shadow point," in a photograph appears as a bleached out or overexposed area resulting from the reflection of the sun within the angle of view of the camera lens. The sun spot, or "specular reflection zone," is caused by a water surface reflecting sunlight directly toward the camera, overexposing a large area of the photograph and potentially obscuring features such as a ship. Figure 3.14 shows the effects of these two phenomena.

The solar altitude also influences shadow length. Maximum solar angles occur in the summer season and close to solar noon. Long shadows are usually undesirable because important features can be obscured. In areas of rough terrain at high latitudes, steep-sided valleys running from east to west can remain in shadow for most of the day or even for entire seasons. However, long shadows can also be useful, for example, to measure the dimensions of objects using their silhouettes. If the photography is to be used for multitemporal analysis, the orientation of shadows, as well as their extent, might be important.

The season can have a great influence on the acquisition and usefulness of photography. In addition to the influence of the season upon the sun mentioned above, the season has a pronounced effect upon the ground! The ability to detect vehicles or signs of activity in forested areas, and the photographic overflight parameters needed to do so, is clearly going to be influenced by whether or not the trees have any leaves on them or if there is snow on the ground.

Certain times of year can bring problems with persistent cloud cover. In south-western Canada, there are about ten suitable days for survey photography[8] in July, August and September and about two days per month from November to March. In western Britain, reasonably long cloudless periods are uncertain and usually only occur in February, November, June and September.[9]

Scattered clouds can be worse than a complete cloud cover. It is sometimes possible to fly under a complete and even cloud cover to obtain low contrast photographs with few shadows which provide greater detail. Scattered cloud cover is accompanied by cloud shadows which unavoidably obscures ground detail. Cloud cover is always more of a problem for high altitude photography than for low altitude work.

3.2 Oblique photography

Oblique photographs could be defined simply as photographs which are intentionally not vertical. Camera systems used for oblique photography range from standard 35-mm cameras to specialized LOROP (long range oblique photography) systems for reconnaissance involving large stand-off distances.

The smaller, 35-mm format cameras can be used to take photographs through an open window or door of a small plane. Camera equipment, film and processing services are easily obtained and relatively inexpensive. However, these cameras are not suitable as a primary camera system for most aerial photographic missions. A 35-mm camera with a suitable lens provides a good backup system in case of a failure of the primary system and if space limitations dictate that a larger format camera cannot be used as a backup.

Some "medium format" cameras are designed for reconnaissance missions involving oblique or vertical photography, such as the Vinten Type 360 70-mm camera shown in Figure 3.2. It can be mounted or, if it is equipped with the type 716 adaptor, it can be used as a hand-held applications. Systems such as the Linhof aero Technika 45 EL

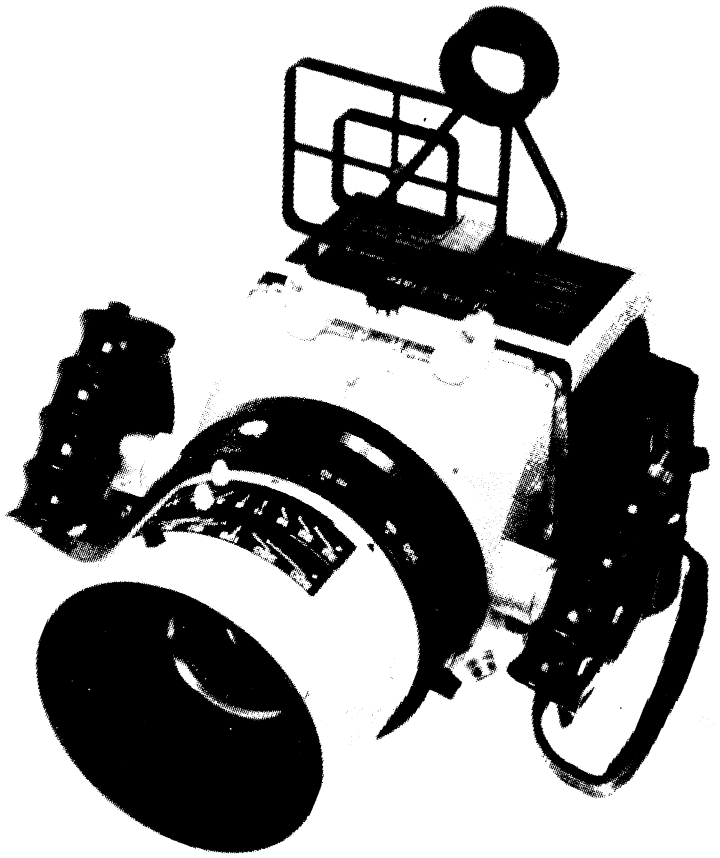


Figure 3.15 The Linhof aero Technika 45 EL 9 x 12 cm format hand-held aerial camera. (Courtesy of Linhof Präzisions Kamera Werke GMBH)

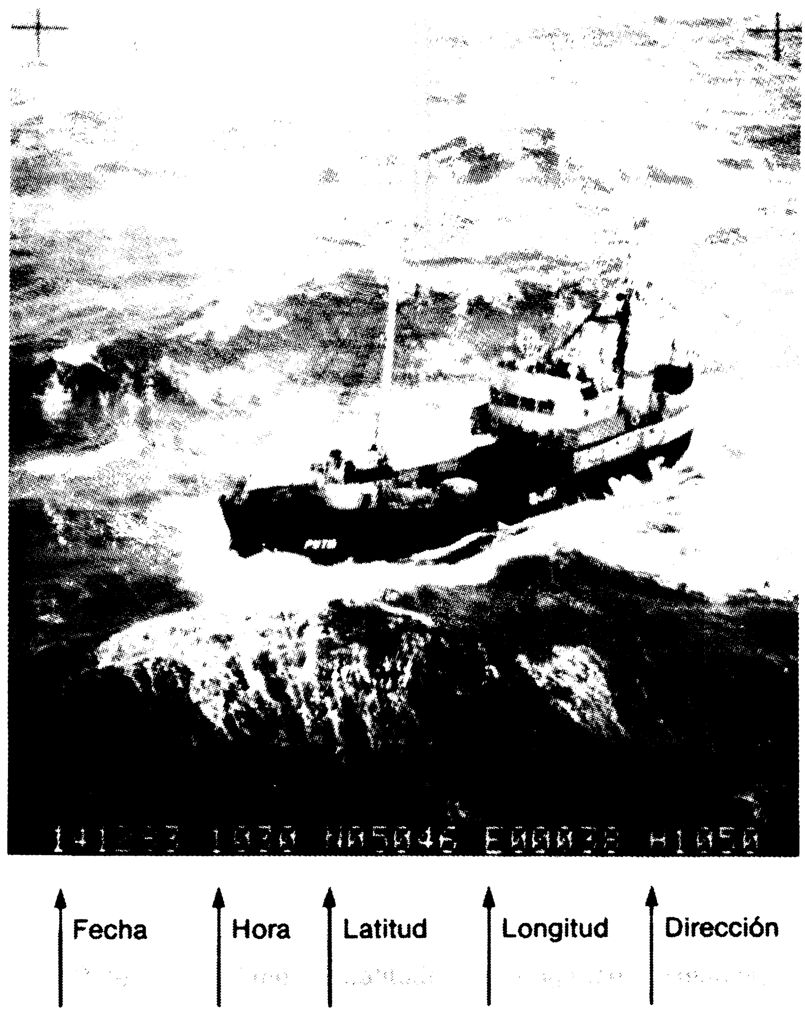


Figure 3.16 Oblique photograph taken using an Agiflite hand-held camera with time and position data, recorded in the margin at the time of exposure. (Courtesy of Negretti Aviation)

(Figure 3.15) are specially designed for professional hand-held aerial oblique photography. The 9 x 12 cm format provides photography with superior detail and information than that from smaller format systems. The camera system has been used for a wide range of applications, including during a NASA space shuttle mission in April, 1984. Figure 3.16 shows a typical low oblique photograph taken using a hand-held Agiflite camera. Note the marginal data recorded at the time of exposure includes the date, time, latitude, longitude and aircraft heading.

Long range oblique photography (LOROP) systems are highly specialized to provide high resolution oblique photographs from large stand-off distances. LOROP systems may be mounted internally or in external pods. The CAI KS-127A LOROP system (Figure 3.17) is a 66-inch (168 cm) focal length, 5-inch (12.7 cm) format frame camera designed for reconnaissance over extremely long ranges. It can provide a ground resolution capability of 22 inches (56 cm) at a slant range of 20 nautical miles (37 km) for medium and high contrast targets.[10] Figure 3.18 illustrates the high-resolution capabilities of LOROP reconnaissance systems. This photography was taken

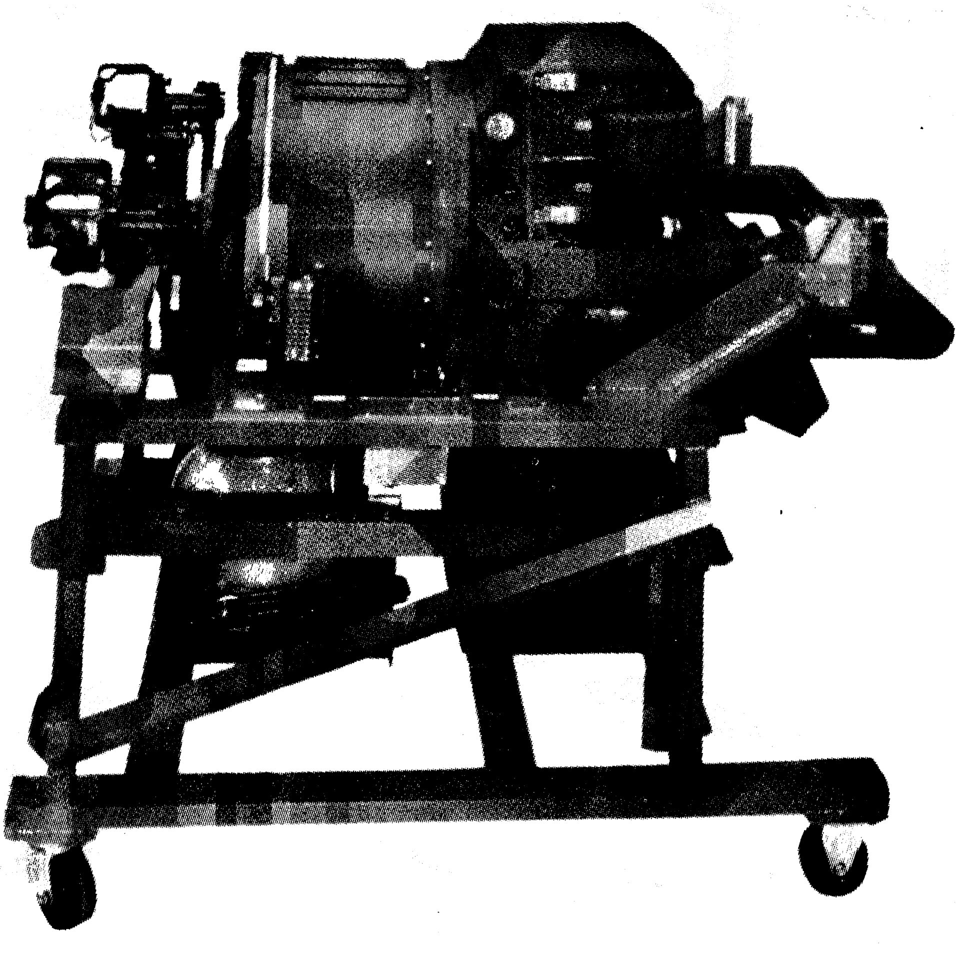


Figure 3.17 The CAI KS-127A, equipped with a 66-inch (1680 mm) focal length, f/8 lens, is a high performance LOROP system designed for photo reconnaissance from long range standoff distances. (Courtesy of CAI, a Division of RECON/OPTICAL, Inc.)

12X enlargement

Contact print

Figure 3.18 (on facing page) Contact print and 12X enlargement of oblique photography acquired using the CAI KS-127A LOROP camera. The aircraft was at an altitude of 35,500 feet (10,820 metres). The photo was taken from a standoff range of 22 nautical miles (40.8 kilometres). (Courtesy of CAI, a Division of RECON/OPTICAL, Inc.)

from an altitude of 35,500 feet (10,820 metres) from a standoff distance of 22 nautical miles (40.8 km). The standoff operating range for such a system depends upon the targets of interest and required level of photo interpretation. Imagery for precise identification of tanks would require a much smaller standoff distance than that for detection-level interpretation.

Oblique photographs may be categorized as either high obliques or low obliques. Low oblique photography does not show the horizon and is commonly taken using a depression angle of about 45 degrees. High oblique photographs include the horizon and are acquired using smaller depression angles. Figure 3.19 compares the geometries of vertical, low oblique and high oblique photographs.

Oblique photographs provide the potential advantage of recording large areas in a single photograph. They also permit imagery to be acquired without directly overflying the target. They have the disadvantage of variations in scale from the foreground to background of the photograph. The variable scale makes photo measurements more difficult and spatial detail in the smaller-scale background portions of the photograph is reduced. Low obliques have smaller scale changes than high obliques since they are taken at depression angles closer to vertical photography. Perspective grids are shown in Figure 3.20, illustrating typical scale variation for high and low oblique photographs.

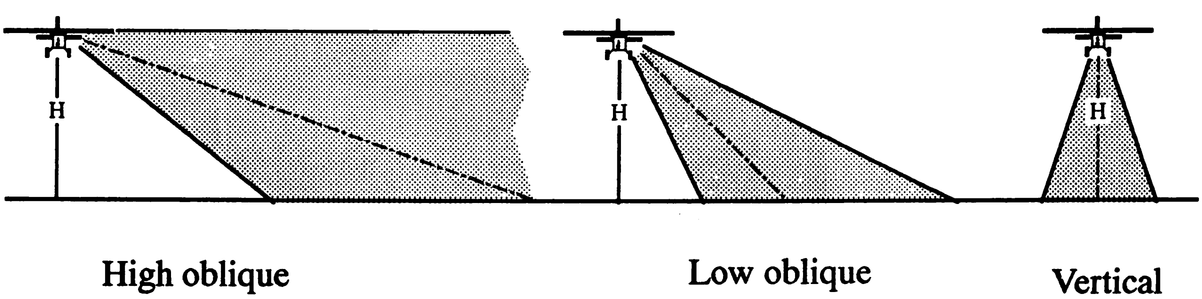
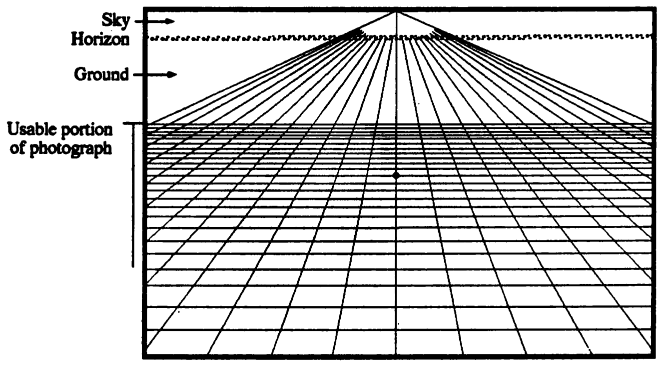
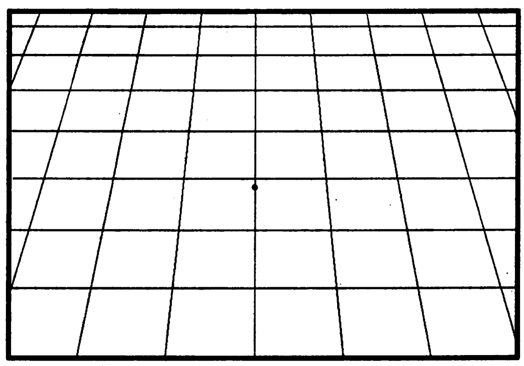


Figure 3.19 Geometries of vertical, low oblique and high oblique photographs. (Redrawn from Barry M. Evans and Larry Mata. 1984. "Acquisition of 35-mm oblique photographs for stereoscopic analysis and measurement." Photogrammetric Engineering and Remote Sensing 50(11), p. 1589-90, by permission of American Society of Photogrammetry and Remote Sensing.)



High oblique perspective grid.



Low oblique perspective grid.

Figure 3.20 Perspective grid for high and low oblique photographs. (Redrawn from Evans and Mata. "Acquisition of 35-mm oblique photographs for stereoscopic analysis and measurement," p. 1589-90, by permission of American Society of Photogrammetry and Remote Sensing.)

3.3 Panoramic and multi-lens cameras

Panoramic and multi-lens cameras are intended to provide a wide swath of photographic coverage from a single overpass. Both types of cameras were developed, and have been used, primarily for military reconnaissance missions.

Panoramic cameras are designed to provide horizon-to-horizon photographic coverage either by rotating the camera lens or rotating a prism in front of the lens. During each exposure, the terrain is scanned from side to side, perpendicular to the direction of flight. Modern panoramic cameras can also be "sectored" to record photography of one specific part of the total scan. A sector can be selected while in flight. Panoramic cameras can be used as a stand-alone camera system or as part of a multi-camera package, providing horizon-to-horizon coverage to complement the photography of other frame cameras. Figure 3.21 provides an example of stereo panoramic photography. Stereo viewing and measurements can be done over most of the frame with the exception of the extreme ends.

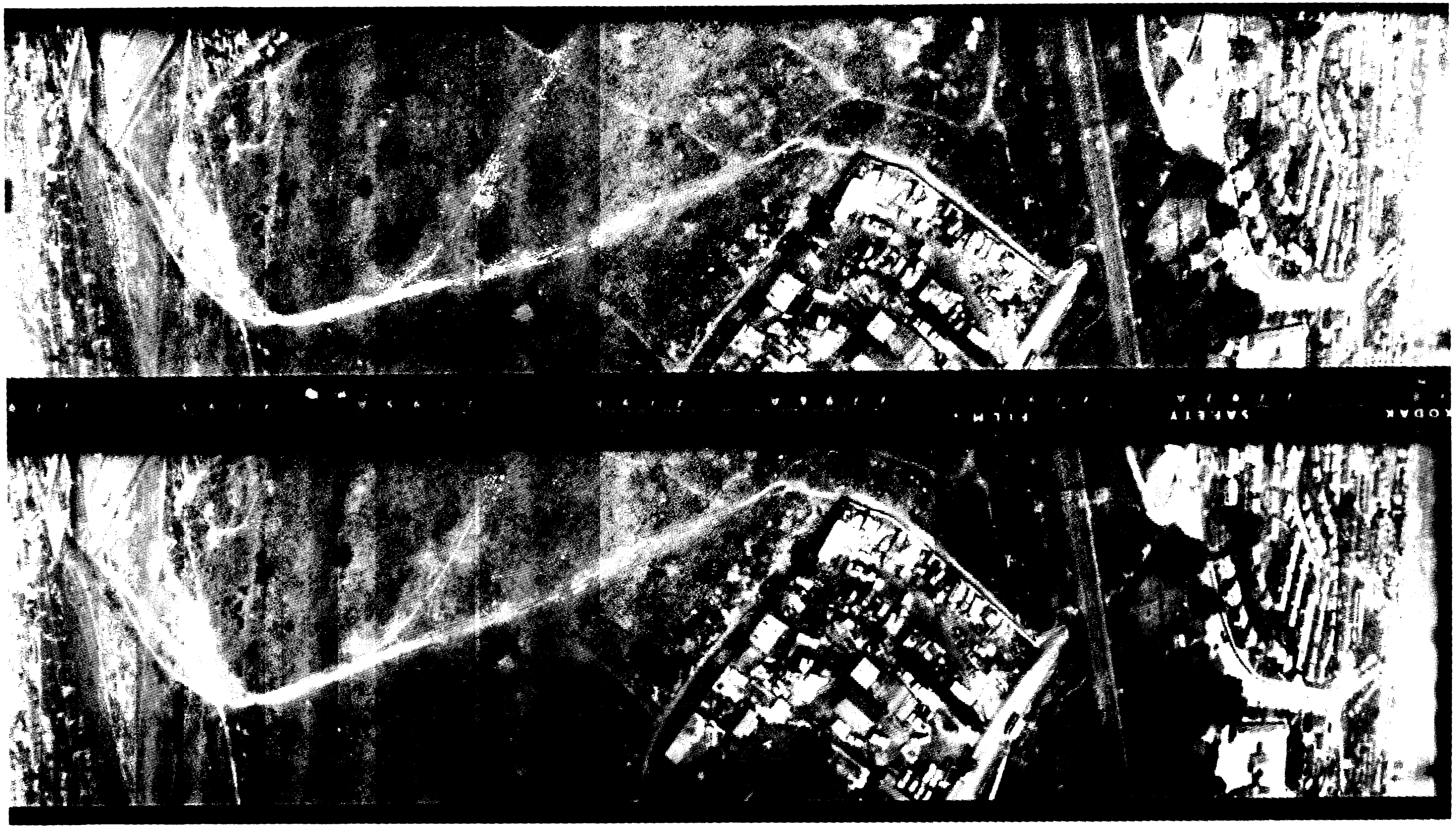


Figure 3.21 Stereo panoramic photography showing horizon-to-horizon coverage in a perpendicular direction to the line of flight. This photograph was taken using a Vinten 751 panoramic camera fitted with a 3-inch (76 mm) automatic exposure control lens. (Courtesy of Vinten Military Systems Ltd.)

Direction of travel

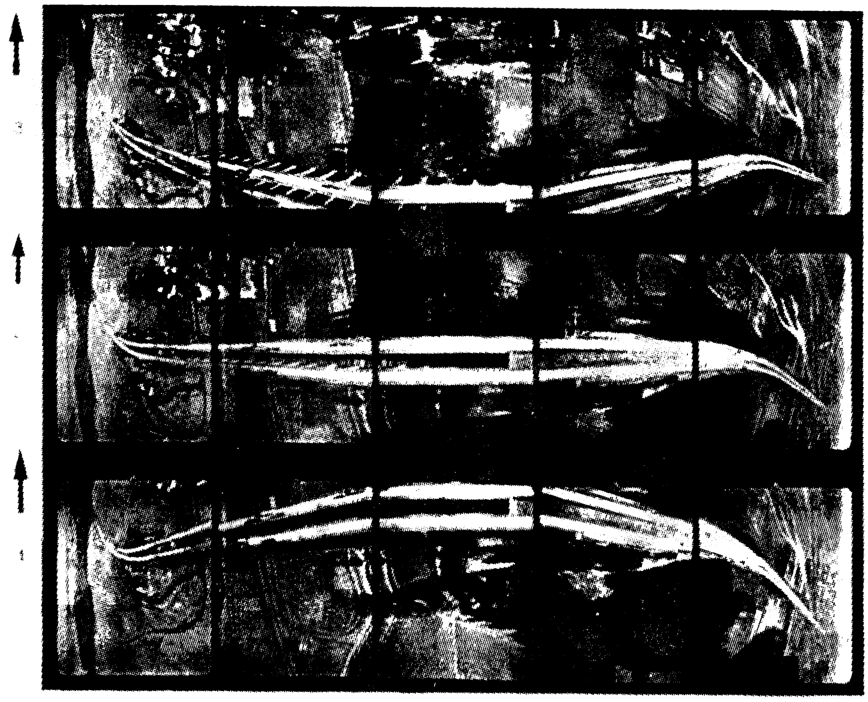


Figure 3.22 A sequence of three along-track frames from the five-lens Zeiss KRb 6/24. (Courtesy of Ron Graham, AIS Ltd., and Carl Zeiss Ltd.)

The multi-lens camera produces multiple (usually 3 or 5) small, across-track images for each photographic "frame" (Figure 3.22). Stereoscopic interpretation is possible using matching images of adjacent along-track frames. Unlike multi-camera or fanned camera systems which produce multiple across-track images using separate cameras, the multi-lens camera produces only one film to be processed, interpreted and stored.

3.4 Aerial films

Aerial films share the same basic structure as films used for hand-held 35-mm cameras. A transparent, polyester film base is coated with a light-sensitive photographic emulsion. For black and white films, the emulsion consists of crystals of silver halide suspended in gelatin. The silver halide grains which have been exposed to light are reduced to metallic silver when the film is developed. For colour films, there are three separate emulsions, each with a particular spectral sensitivity.

The characteristics of the silver halide crystals has an important influence upon the performance of the film. The finer the size of the grains, the greater the detail that can be recorded on the film. Coarser grains, however, produce a film with greater sensitivity to light. The grain size also influences the contrast, or range of gray tones

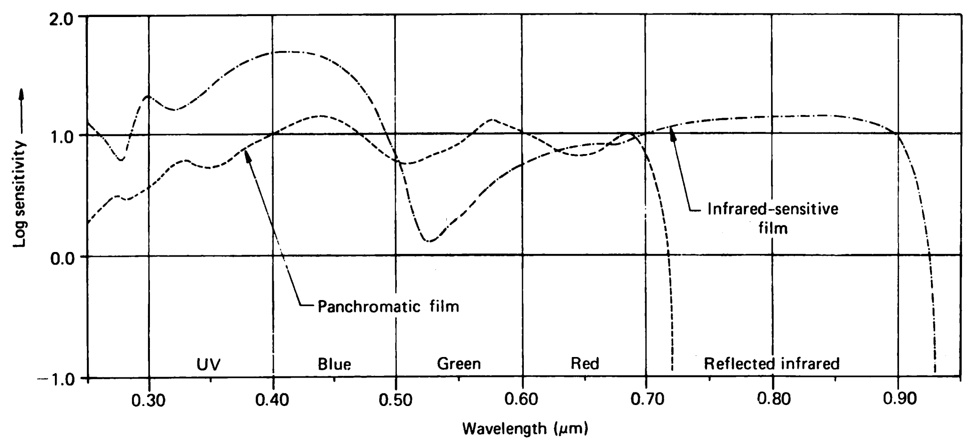


Figure 3.23 Spectral sensitivities for black and white panchromatic and infrared-sensitive films. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 46, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

recorded by a film. Fine grained emulsions tend to have a lower contrast, often enabling the film to record more gray tones than higher contrast and higher speed films. The net result is that slower speed films tend to have higher spatial resolution and can often record more graytone information than the coarser-grained, faster speed films.

a) *Black and white films*

Black and white aerial film is usually either panchromatic or infrared-sensitive. Figure 3.23 outlines the spectral sensitivities of the two film types.

Panchromatic film is the "standard" film used for commercial aerial survey work. It is a black and white negative film with a sensitivity similar to that of the human eye. It is sensitive throughout the visible spectrum (0.4 to 0.7 μm) and to ultraviolet light (0.3 to 0.4 μm). For higher altitude work, the film is usually used with a "minus blue" filter to exclude the ultraviolet and blue light which is responsible for atmospheric haze and the loss of fine detail in aerial photographs. The photo shown in Figure 3.3 was taken using panchromatic film.

The sensitivity of black and white infrared film is similar to that of panchromatic film but is somewhat depressed in the green region and extends into the near infrared to 0.92 μm. It is usually exposed through a red or dark red filter to isolate the infrared portion of its sensitivity. The exclusion of most visible wavelengths makes this film particularly useful for haze penetration. The ability of infrared film to penetrate haze is an important feature for high-oblique photography, particularly LOROP systems. Infrared film can also be used for detection of military equipment which has been camouflaged with non-infrared reflective green paint or cut vegetation.

b) *Colour films*

The human eye can distinguish more than 20,000 hues, values and chromas of colour compared to about 200 shades of gray.[11] This capability can be invaluable for interpretive tasks.

Colour films may be divided into normal colour[12] and colour infrared[13] films. Figures 3.24 and 3.25 outline the spectral sensitivities for the two film types. Normal colour film is made of a "tripack" of dye layers sensitive to blue, green and red light. Colour infrared film also has three dye layers but they are sensitive to green, red and near infrared light. Once the film has been developed, green-coloured surfaces in the scene are represented as blue, red-coloured surfaces in the scene are represented as green, and objects which reflect strongly in the near infrared are represented as red:

Colour in the scene:	Blue	Green	Red	Infrared
Colour reversal film:	Blue	Green	Red	—
Colour infrared film:	—	Blue	Green	Red

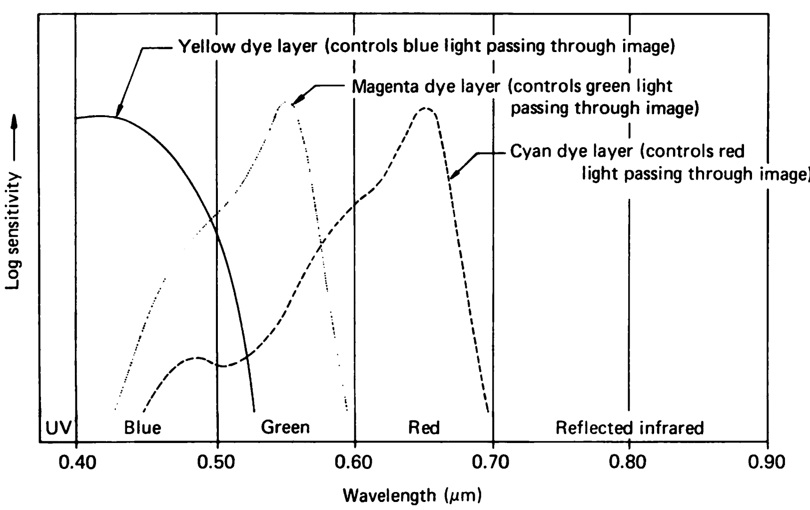


Figure 3.24 Spectral sensitivities for colour film. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 51, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

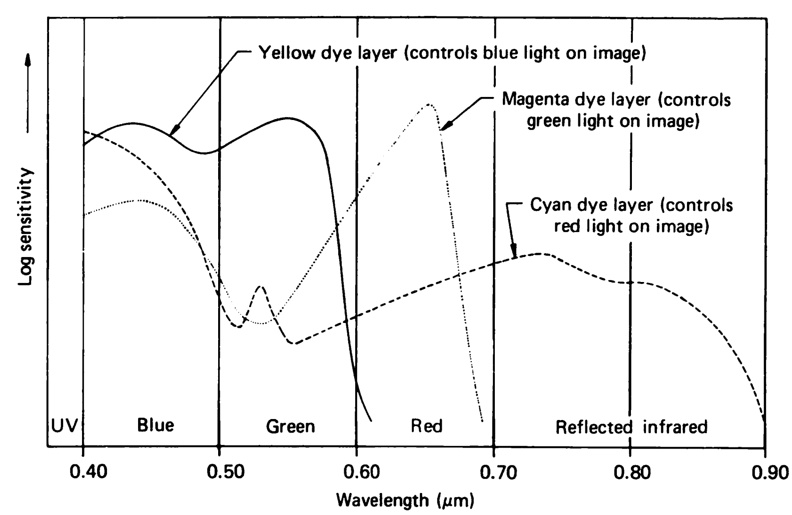


Figure 3.25 Spectral sensitivities for colour infrared film. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 56, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

The exclusion of shorter wavelength blue light gives colour infrared film better haze penetration capabilities than normal colour film. Colour infrared film is also useful for detection of crudely camouflaged equipment.

c) *Very high resolution films*

Aerial films with much higher resolution than those commonly in use for commercial aerial photography are available. The films were developed to meet the needs of high altitude reconnaissance and space missions. Panatomic-X offers improved spatial resolution. The High Definition Aerial Colour Film SO-242 has improved detail definition and colour saturation. The High Definition Infrared Film SO-131 has greatly improved colour definition in the infrared range but less improvement in spatial resolution than the other films.[14]

The major operational disadvantage of these films is their reduced film speed. The longer exposure times required for these films necessitate the use of cameras with Forward Motion Compensation (FMC) and restricts the use of the films, particularly the colour films, to high altitude use. As well, the films are not as readily available as the more conventional films and usually must be ordered in relatively large quantities.[15]

Notes to Chapter III

[1] Avery, T. Eugene. 1968. Interpretation of Aerial Photographs. Second Edition. Burgess Publishing Company. Minneapolis, Minnesota. p. 304.

[2] For a discussion of the range of platforms available for aerial photography, see Chapter 8.

[3] In some cases, it is possible to fly under a haze or cloud cover provided it is an even cover which does not cause cloud shadows on the ground.

[4] One exception to this rule is fixed-base camera systems, used for large-scale photography with scales from 1:200 to 1:1500. Two cameras are attached at either end of a boom, typically six or more metres in length, which is then attached beneath a helicopter. Alternatively, cameras may be attached to the end of each wingtip of a light aircraft. Photos are taken simultaneously with each camera. With the separation between the cameras kept constant, it is possible to make accurate photogrammetric measurements without knowing the precise altitude of the helicopter or aircraft.

[5] To compensate for a cross-wind which would otherwise cause drift, a pilot will point the aircraft into the wind so that the plane will follow the intended flight line. The plane, therefore, will not be oriented in the same direction as the flight line, requiring the camera to be aligned.

[6] solar altitude is the angular elevation of the sun above the horizon.

[7] Fleming, E.A. 1968. "Solar altitude nomograms." IN: Smith, John T. (editor-in-chief). Manual of Color Aerial Photography. American Society of Photogrammetry. Falls Church, VA. pp. 67-75.

[8] A maximum of 5 percent cloud cover (evident in the photographs) is usually allowed for commercial survey photography. In the context of arms control verification, missions might be conducted at times with more cloud cover even though parts of the photographs will be obscured by clouds and cloud shadows.

[9] Howard, John A. 1970. Aerial Photo-Ecology. American Elsevier Publishing Company, Inc. New York. pp. 79.

[10] "KS-127A Long Range Oblique Camera ." Product Information Sheet. TD-468/3M/7-86. CAI, a Division of RECON/OPTICAL, Inc.

[11] Evans, R.M. 1948. "An Introduction to Color." p. 1083. QUOTED IN: Estes, John E., Earl J. Hajic and Larry R. Tinney. (authors/editors) "Fundamentals of Image Analysis: Analysis of Visible and Thermal Infrared Data." Chapter 24. IN: Colwell, Robert N. (editor-in-chief) 1983. Manual of Remote Sensing. Second Edition. Volume I. Theory, Instruments and Techniques. American Society of Photogrammetry. Falls Church, Virginia.

[12] Normal colour film is also referred to as "true colour" film.

[13] Colour infrared film is also referred to as "false colour" or "camouflage detection" film.
[14] Becker, Rolf. 1986. "Very high resolution aerial films." Progress in Imaging Sensors. Proc. ISPRS Symposium. Stuttgart, Germany. pp. 317-326.
[15] *ibid*. pp. 322-323.

CHAPTER IV

THERMAL INFRARED SYSTEMS

All surfaces with temperatures above absolute zero (-273.2°C or 0°K) emit radiation. This is longer wavelength radiation than that recorded by infrared-sensitive films.[1] Electronic detectors must be used to sense thermal infrared radiation.

Thermal infrared systems have features which make them useful for a variety of reconnaissance missions including:

- collection of night-time imagery
- penetration of haze and smog
- detection of camouflaged or obscured objects

4.1 General concepts

Radiation emitted by surfaces may be described in relation to the radiation emitted by a blackbody. A blackbody is a theoretical "perfect emitter" which absorbs all radiation incident upon it and then emits all of that radiation.

Figure 4.1 shows the distribution of radiation from blackbodies at various temperatures. The peak emittance shifts toward shorter wavelengths with increasing temperature. The sun, at a temperature of about 6000°K, emits yellow light with a peak of about 0.5 μm or the middle of the visible spectrum. Objects at room temperature (300°K) emit radiation levels with a peak emittance at about 9.7 μm in the thermal infrared region.

The total emission of a blackbody over all wavelengths, the area under the curves in Figure 4.1, is proportional to the fourth power of its absolute temperature. Thus the intensity of radiation emitted by a blackbody may be used to determine the temperature of its surface.

The concept of a blackbody is a useful theoretical tool. In reality, however, most surfaces emit only a fraction of the radiation which would be emitted by a blackbody at the same temperature. The capability of a surface to emit radiation compared to a blackbody at the same temperature is called the emissivity, ε, of the surface, where

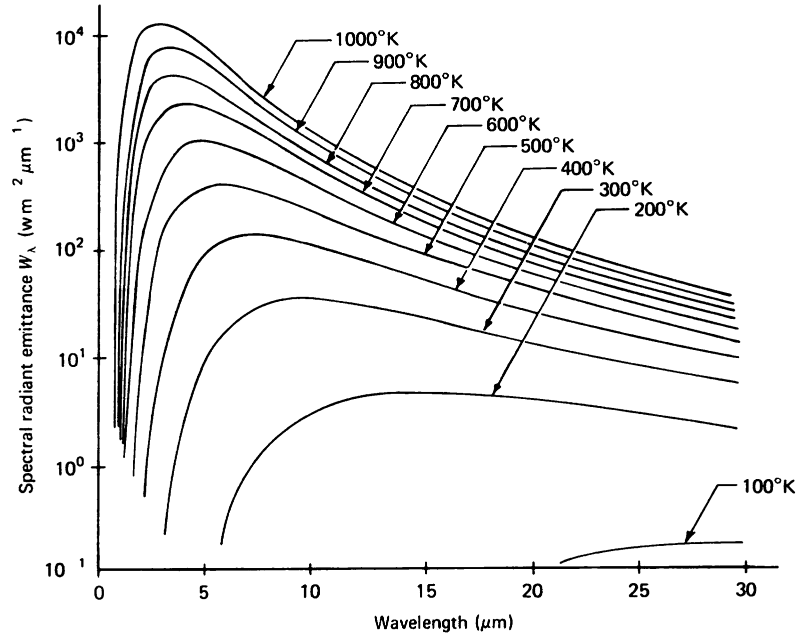


Figure 4.1 Spectral distribution of the energy radiated from blackbodies at different temperatures. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 385, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

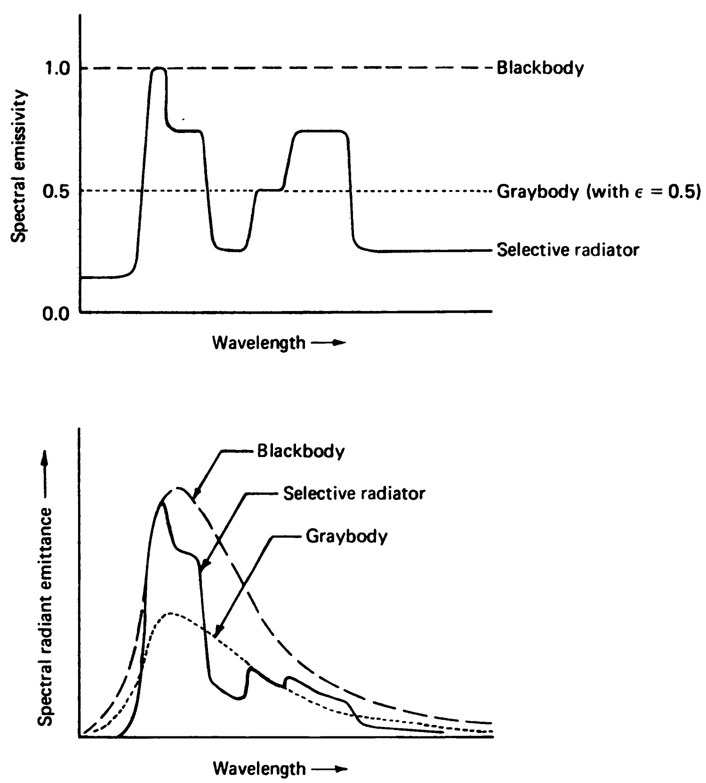


Figure 4.2 Spectral emissivities and radiant distributions of a blackbody, graybody and selective radiator. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 387, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

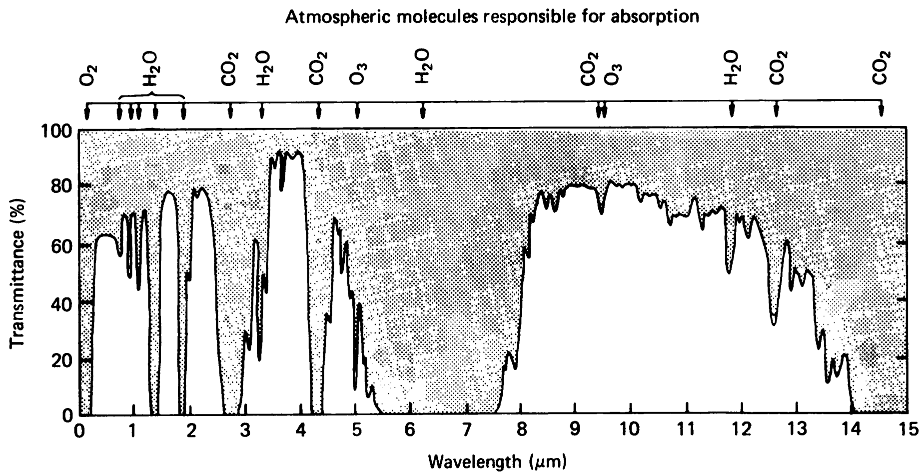


Figure 4.3 Atmospheric transmittance from 0 to 15 μm. The two major windows for thermal sensing are from 3 to 5 μm and from 8 to 14 μm. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 390, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

$$\varepsilon(\lambda) = \frac{\text{Radiant emittance from an object at a given temperature}}{\text{Radiant emittance from a blackbody at the same temperature}}$$

The emissivity of a graybody is less than 1 but equal at all wavelengths. A selective radiator has an emissivity which varies according to wavelength. Figure 4.2 contrasts the radiative characteristics of a blackbody, graybody and selective radiator.

Thermal sensing is restricted primarily to two atmospheric windows (Figure 4.3). These are spectral regions in which the atmosphere is largely transparent, allowing radiation from the ground to reach the sensor. Outside of these windows, atmospheric gases and particles block the passage of radiation by absorption or scattering.

The window from 8 μm to 14 μm is commonly used for thermal imaging since it corresponds to the peak emissions of most surfaces at ambient earth temperatures. The window from 3 μm to 5 μm is useful for separating hot surfaces from an ambient background.

4.2 Thermal infrared sensors

The heart of any thermal sensor is the detector. Detectors are available to work in either atmospheric window. A mercury cadmium telluride (HgCdTe) detector is usually used for sensing in the 8 to 14 μm range. Indium antimonide (InSb) detectors are used for the 3 to 5 μm range. The detectors must be cooled, usually with liquid nitrogen, to operating temperatures of 77°K (-196°C). Cooling the detector is analogous to keeping photographic film in the dark prior to exposure.

Thermal infrared detectors are classified according to their spatial and thermal resolutions. Spatial resolution defines the detector 's ability to resolve two separate and distinct objects of similar size from each other. Spatial resolution is directly dependent upon the size of the infrared-sensitive detector chip. The smaller the detector chip, the higher the spatial resolution of the system. Thermal resolution of an infrared sensor depends upon the sensitivity of the material used to produce the chip. Most infrared-sensitive detectors made of mercury cadmium telluride, for example, have a thermal resolution capability of 0.2°C.

Aerial infrared reconnaissance may be done using infrared line scanners (IRLS) or forward looking infrared sensors (FLIR). Each sensor is suited to particular missions. Table 4.1 outlines general criteria for selecting the appropriate sensor.

TABLE 4.1

Criteria for selection of infrared sensors for reconnaissance missions.

IRLS Selection Criteria	FLIR Selection Criteria
• hard copy imagery required	• real time imagery required
• image mensuration and analysis required	• image mensuration and analysisnot required
• wide field-of-view across track, continuously-mapped imagery desired	• narrow field-of-view providing details of selected areas desired
• operator has little or no controlover pointing of the sensor	• operator has full control overpointing of the sensor
• sensor operation may impose velocity/height restrictions on aircraft	• sensor operation will notimpose velocity/height restrictions on aircraft

Source: Noel, William T. 1976. "Utilization of IR Imagery in Tactical Reconnaissance." IN: Shea, E. (editor) Aerial Reconnaissance Systems - Pods/Aircraft. SPIE Vol. 79. pp. 99-100.

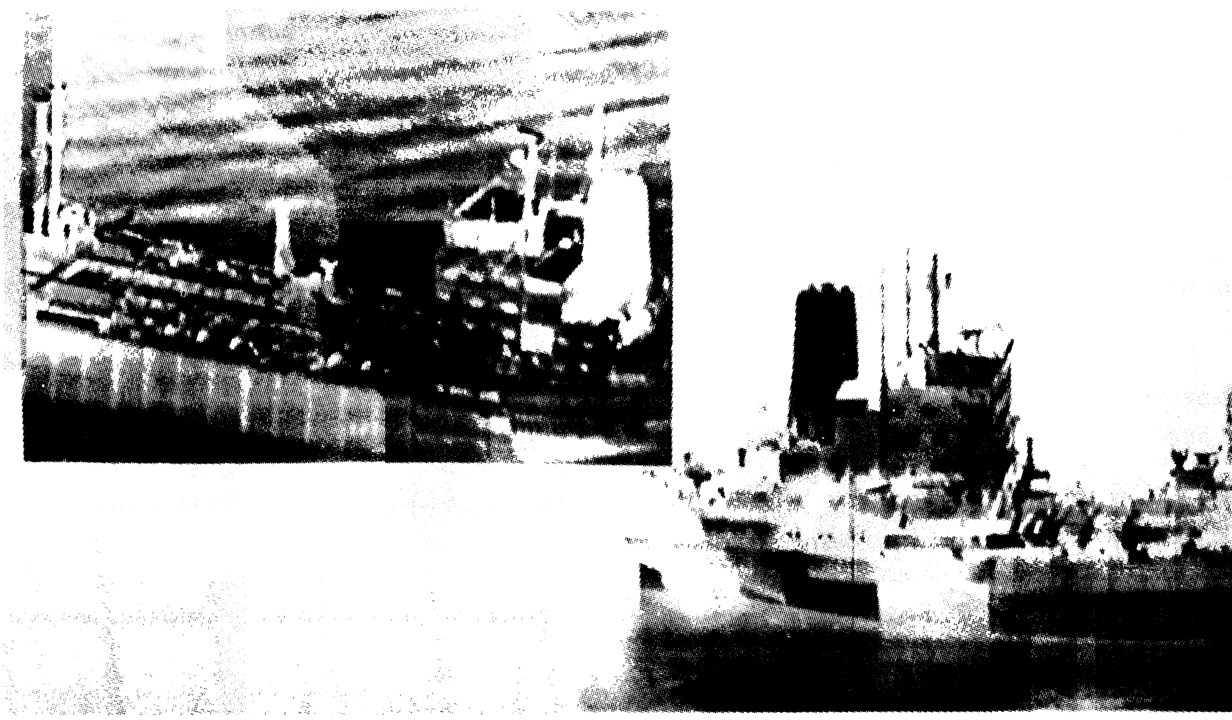


Figure 4.4 FLIR images of freighters. Notice the hot stack in the left image and the ability to "see through" the hulls because of differences in surface temperature resulting from the contents in the holds (Courtesy of David Dorschner, Aviation Resource Management).

a) *Forward looking infrared (FLIR)*

FLIR systems produce thermal images in a framed format, similar to that of a video camera (Figure 4.4). A wide variety of systems exist, from hand-held "thermal cameras" for (mainly ground-based) commercial and industrial use to specialized reconnaissance systems mounted internally or in pods (Figure 4.5). Less sophisticated FLIR's use a single detector and dual-axis scanner to build a two-dimensional image as shown in Figure 4.6. Using a single detector to scan the whole scene limits the thermal sensitivity and image quality which can be achieved. Detector arrays, which could have over 1000 elements, are used in high performance reconnaissance FLIR systems.

The use of an array with n elements improves the signal to noise ratio by a factor of $R(n)$.[2] The array may be arranged as a parallel or serial system. A parallel array is oriented vertically and scanned horizontally. Parallel arrays are compact but variations in response of the detectors can produce spatial noise in the imagery known as "banding." A serial scanning array is mounted horizontally. Each point of the image is scanned by all detectors in the array and then integrated. Serial arrays overcome the banding problem by averaging out variations between the detectors. However, the optics for serial arrays are more complicated.

The detectors produce an electrical signal in proportion to the thermal energy

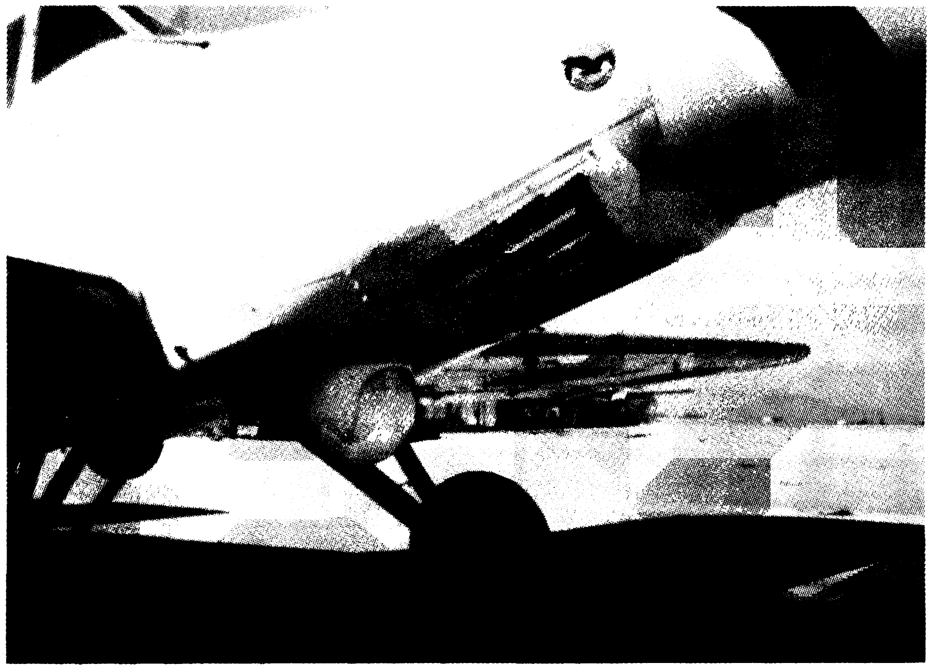


Figure 4.5 Honeywell Gimbaled Mark III FLIR Systems (one in the foreground and another in the background) installed on an Ayres S2/R Turbo Thrush aircraft. A gimballed FLIR allows an operator to image terrain anywhere ahead and all angles below, to the sides and to the rear of an aircraft. Most FLIR systems are used together with high resolution television displays to provide real time data to the pilot and system operator for navigation as well as surveillance. (Courtesy of David M. Dorschner, Aviation Resource Management)

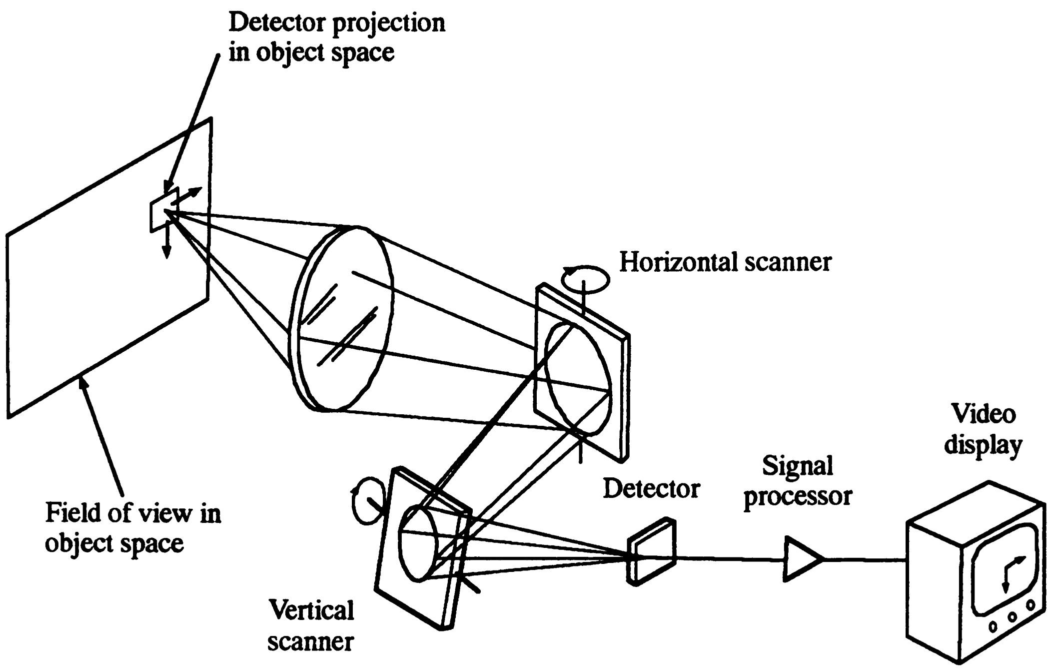


Figure 4.6 Simplified single-detector, dual-axis scanner. An image of the scene is built by focussing thermal energy onto the detector using a two-dimensional (horizontal and vertical) scanning mechanism. (Redrawn from A.L. Rodgers, I.B.R. Fowler, T.K. Garland-Collins, J.A. Gould, D.A. James, and W. Roper, Surveillance and Target Acquisition Systems, p. 80, © 1983 by Brassey's Publishers Ltd., by permission of Brassey's Defence Publishers, Pergamon Press)

received. This is amplified to power a light-emitting array. The array is arranged in the same format and has the same number of elements as the detector array. The light-emitting array is scanned by a vidicon camera which can be displayed in real time on a television screen.

b) *Infrared line scanners*

Line scanners use a rotating mirror with optics to direct 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 (Figure 4.7). The forward motion of the aircraft causes successive scan lines to cover adjacent strips on the ground, building a two-dimensional image (Figure 4.8). Figure 4.9 shows an infrared linescanner designed for reconnaissance applications.

The aircraft velocity, altitude and scan-rate of the line scanner must be coordinated to ensure contiguous coverage of a scene. If the aircraft flies too quickly for a particular height and scan-rate, the scene will be undersampled. If it flies too slowly, oversampling of the scene will occur. This will result in an increase in the spatial resolution due to line averaging and increase the signal-to-noise ratio.

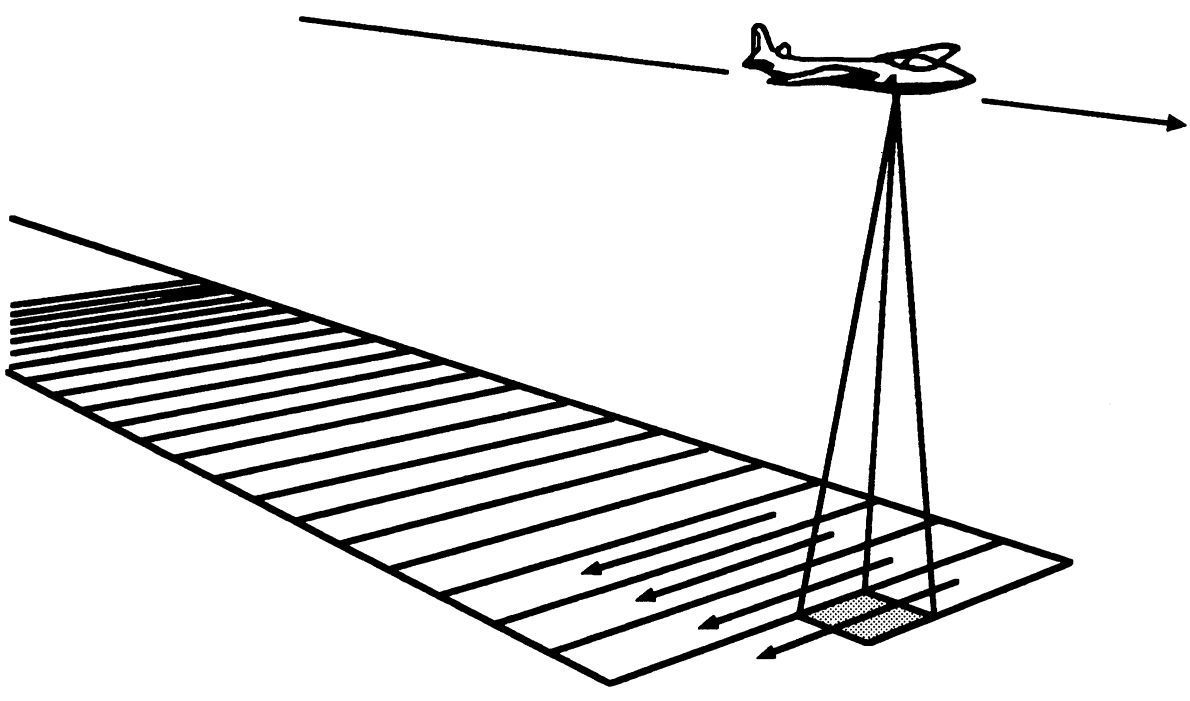


Figure 4.7 Operation of an airborne line scanner to produce contiguous imagery. (Redrawn from Madding, Robert P., "Thermographic instruments and systems." University of Wisconsin-Extension. Department of Engineering and Applied Science, p. 70, © 1979 by the University of Wisconsin Board of Regents, by permission of the University of Wisconsin System, Board of Regents, All Rights Reserved.)

Figure 4.8 Thermal infrared linescan image of airport. The direction of flight was from left to right in the image. Vertically-oriented scanlines are visible. The image was taken at night. Notice the "hot" buried steamlines and trees along the roadsides. Notice also that shiny metal surfaces, such as some of the aircraft and the flashings around the edges of some roofs appear "cold." Warm auxillary power units can be seen near some of the aircraft. One aircraft appears anomalously warm compared to the others. It may have been parked inside the nearby hangar not long before the image was acquired. (Courtesy of Intera Technologies Ltd.)

The electrical output of the detector is amplified and then recorded. The operator views the signal on a scope to ensure that the data is recorded properly. Temperature reference sources are usually incorporated into the linescanner. Reference sources act as standards to which radiation collected from the target is compared. They ensure that changes in the scanner's electrical output are due to changes in the thermal energy input or adjustments by the operator. The reference sources may also be used later to process the thermal imagery into quantitative radiant temperature levels.

Military systems are often equipped with automatic gain control (AGC) to minimize the supervision required to collect imagery. AGC automatically adjusts the gain[3] to keep the output within the dynamic range of the recording system. This is suitable for detecting small, hot targets against an ambient background. However, large hot or cold areas can produce large shifts in gain which obscure nearby detail. Comparisons between targets with a cold background and those with a warm background can be difficult.

A real-time processor may be used to produce imagery (dry silver paper or film) on-board the aircraft. This is the least expensive alternative for recording imagery but limits options for subsequent processing. Usually, an on-board hard copy product will be produced in addition to recording on another format such as magnetic tape.

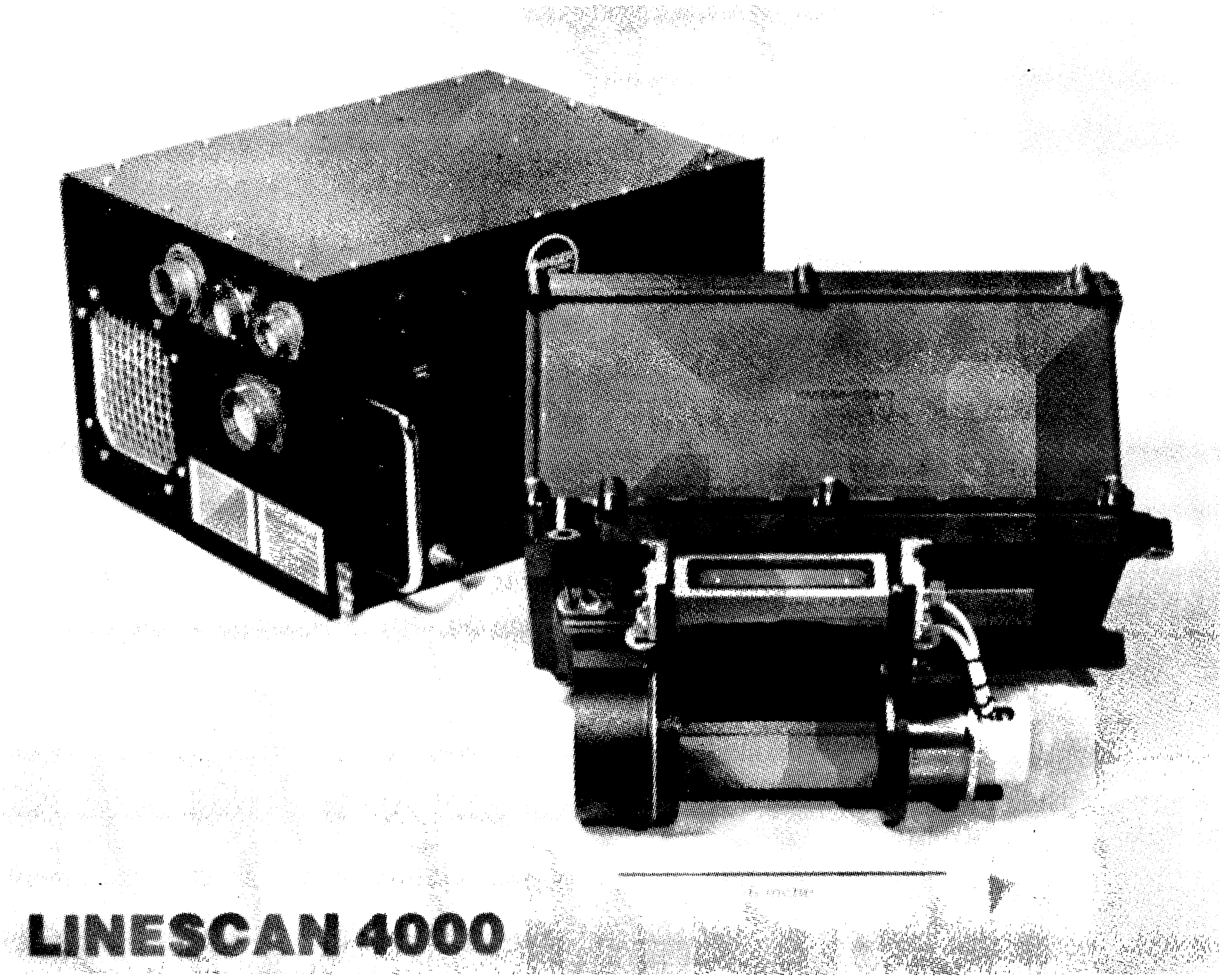


Figure 4.9 Linescan 4000 infrared linescan system. The system is compact and can be used on a wide range of platforms. It provides horizon-to-horizon coverage, electronic roll stabilisation, real time video output and can be down-linked to a ground station. It has a multi-element mercury cadmium telluride detector operating in the 8 to 14 μm waveband and a closed cycle helium detector cooling system. (Courtesy of Vinten Military Systems Ltd.)

Recording on magnetic tape increases the flexibility of the data. Provided the information has been recorded well, it can be processed in a number of ways to enhance particular features. In analogue form, the data provides a "temperature picture" showing the relative thermal variations within the target area. It displays a continuous change in greytone with target temperature. The target temperatures can also be grouped together into "level slices." Each level represents a selected range of target temperatures and is displayed as a separate greytone. It is also possible to highlight hot targets which exceed a pre-selected threshold temperature.

The thermal scanner output can be converted to a digital format and recorded on a digital tape. Digital recording provides greater dynamic range, making high-quality imagery easier to collect. The digital format of the data permits a wide variety of digital image analysis techniques to be used for interpretation of the imagery.

4.3 Acquisition of thermal imagery

The variations in tone on a thermal infrared image represent differences in the energy received by the infrared sensor. These differences are primarily caused by variations in the energy being radiated by the observed terrain, although the effects of the atmosphere and imaging geometry are also important. The best thermal imagery will result if it is acquired when the features to be discriminated have the greatest differences in radiated temperature.

Seasonal changes in terrain surfaces can profoundly influence the ability to distinguish features of interest. The average temperature of the terrain will vary from one season to another, making warm targets easier to distinguish in the colder months and more difficult to detect during warmer periods.

The natural diurnal cycle of surface temperatures results in two periods when temperature differences are maximized. During the daytime, the greatest thermal contrast usually occurs between 1400 and 1600 hours.[4] Differences in thermal properties of the surface materials, such as heat capacity, will be manifested as surface temperature variations because of daytime solar heating. These will be confused, however, by differential solar heating because of topography and shadows. At night, the largest contrast usually occurs between 0200 and 0500 hours for most natural surfaces.[5] Surface temperature differences develop through the night because of differences in radiative heat loss to the night sky and variations in the thermal properties of materials.

Ideally, there should be clear skies when thermal overflights are conducted although moderate cloud cover is permissible if it is scattered and higher than the flying altitude. The effects of clouds are twofold. Clouds behave similarly to blackbodies in the thermal infrared wavelengths. They are opaque and will obstruct ground coverage on the imagery if they are below the flying altitude. Heavy cloud cover will impede the differentiation of ground surface temperatures through the "greenhouse effect," producing imagery which may be difficult to interpret because of low thermal contrast. On the other hand, if a target of interest produces heat independently, such as from a motor, suppression of the background thermal contrast might <u>improve</u> the ability to identify the target.

The effect of wind upon thermal imagery is to reduce the image contrast resulting from surface material variations and introduce wind effects such as streaking. The wind velocity can vary considerably from one location to another. Thus the effects of wind on thermal imagery can be localized, sometimes making it difficult to recognize whether surface winds have affected specific areas of an image. Because of their high surface-to-volume ratio, trees can be warmed noticeably by a warm, moist wind.[6] They can radiate heat to a potential nearby target or mask the target's own heat.

4.4 Interpretation of thermal imagery

Object surfaces are the primary source of radiation sensed by a thermal imaging device. Tonal variations in thermal images result mostly from differences in scene emittance, either because of surface temperatures or emissivities. The images are derived from the radiant temperatures of the surfaces.

Radiant temperatures are related to the physical temperatures by the emissivity of the surface. Surfaces with low emissivities appear colder in the imagery than in reality. Surfaces with high emissivities have radiant temperatures which approximate their actual physical temperatures. Most materials found in the natural environment have high emissivities. Some surfaces, especially polished metals, have low emissivities (Table 4.2) and appear very cold in thermal images. In Figure 4.8, some of the aircraft and the flashings around the edges of some roofs appear "cold" because of their shiny metal surfaces.

Even considering the effects of varying emissivities, the apparent temperatures in thermal imagery will not equal the true surface temperatures. Attenuation, or signal reduction, by the atmosphere must be accounted for. In adverse weather conditions, such as rain, snow or fog, attenuation of infrared energy is significant, particularly from high altitudes and at long slant ranges. Thermal imagery is acquired in the "atmospheric windows" of 3-5 μm and 8-14 μm to reduce the effects of attenuation. Objects at ambient earth temperatures radiate more energy in the 8-14 μm waveband than in the 3-5 μm band, resulting in substantially higher contrast.[7]

Another source of atmospheric attenuation is the presence of airborne particles such as smoke and dust. Dust clouds from vehicles travelling on unpaved surfaces and diesel smoke will obscure individual vehicles. The infrared signatures will be attenuated and scattered by the airborne particles. However, the penetration of thermal radiation would be greater than that provided by a visible light sensor.

Hot targets which are smaller than the nominal spatial resolution of the system may nevertheless be evident in thermal imagery, and can appear exaggerated in size. The resolution of most thermal imaging systems is a function of the instantaneous field-of-view (IFOV) and rise time of the signal amplifier.[8] A hot target smaller than the IFOV will be evident if the average radiant temperature of the target together with the background is boosted sufficiently to be detected. If the thermal contrast between the target and background is large, the sensor will not be capable of recording the rapid change in radiant temperature. It will take longer to adjust to the drop, causing the effect known as "blooming" (Figure 4.10).

The interpretation of thermal images is greatly influenced by diurnal temperature

TABLE 4.2

Emissivities of common surfaces.

Surface	Remarks	Emissivity
Natural ¶		
Soils	Dark, wet	0.90 - 0.98
	Light, dry	
Desert		0.84 - 0.91
Grass	Long (1.0 m)	0.90 -
	Short (0.02 m)	0.95
Agricultural crops,tundra		0.90 0.99
Deciduous forest	Bare	0.97 -
	Leaved	0.98
Coniferous forest		0.97 - 0.99
Water		0.92 0.97
Snow	Old	0.82 -
	Fresh	0.99
Ice		0.92 - 0.97
Man-made §		
Glass	20°C	0.94
Brick	20°C	0.93
Concrete	20°C	0.92
Wood	20°C	0.90
Anodized aluminum	100°C	0.55
Stainless steel	20°C	0.16
Polished gold	100°C	0.02

¶ Source: Oke, T.R. 1978. Boundary Layer Climates. Methuen & Co. Ltd. London. p. 15.

§ Source: Lillesand, T.M. and R.W. Kiefer. 1979. Remote Sensing and Image Interpretation. John Wiley & Sons. New York. p. 389.

Values measured normal to surface of object over all wavelengths at temperatures given.

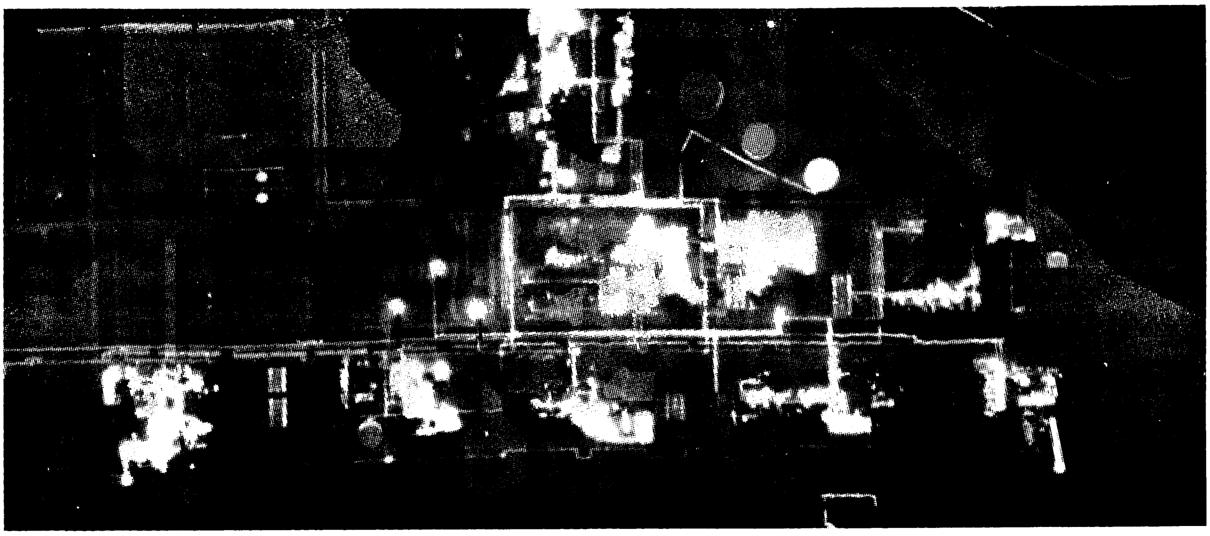


Figure 4.10 The hot targets in this thermal image of an oil refinery may not be as large as they appear. "Blooming" makes hot objects appear larger in size. It takes time for the detector to re-adjust to the relatively low ambient temperature of the background after being boosted by the high radiant temperature of a hot target. (Courtesy of Intera Technologies Ltd.)

variations. Figure 4.11 outlines changes in the radiant temperature of soil and rocks versus water over a 24-hour period. Temperatures of terrain features are usually higher than those of water during the day and lower at night. Before dawn, there is a period when the temperatures do not change appreciably. After sunrise and sunset, the temperature curves intersect. Thermal cross-overs occur when there are no radiant temperature differences between two surfaces. A cross-over between an object and the

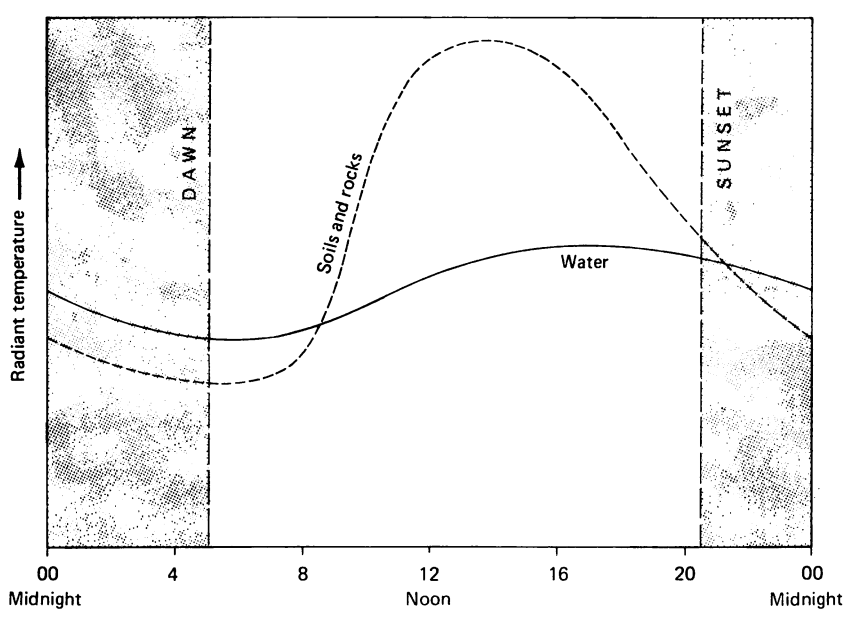


Figure 4.11 Generalized diurnal radiant temperature variations for soils and rocks versus water. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 403, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

surrounding background leads to each being imaged as the same shade of gray, thereby hiding the object.

Figure 4.12 shows daytime and nighttime images of the same area. Areas of water appear relatively cool (dark) during the day and warm (light) at night. Paved areas, such as roads and runways, appear warm during the day and may retain that warmth well into the night. Trees will usually appear cool during the day but may appear warm or cool at night. The high surface-to-volume ratio of trees makes it possible for them to be noticeably warmed by a warm, moist wind.[9]

In daytime imagery, slopes facing the sun are differentially heated according to their orientation. A complementary effect to solar heating is the creation of thermal

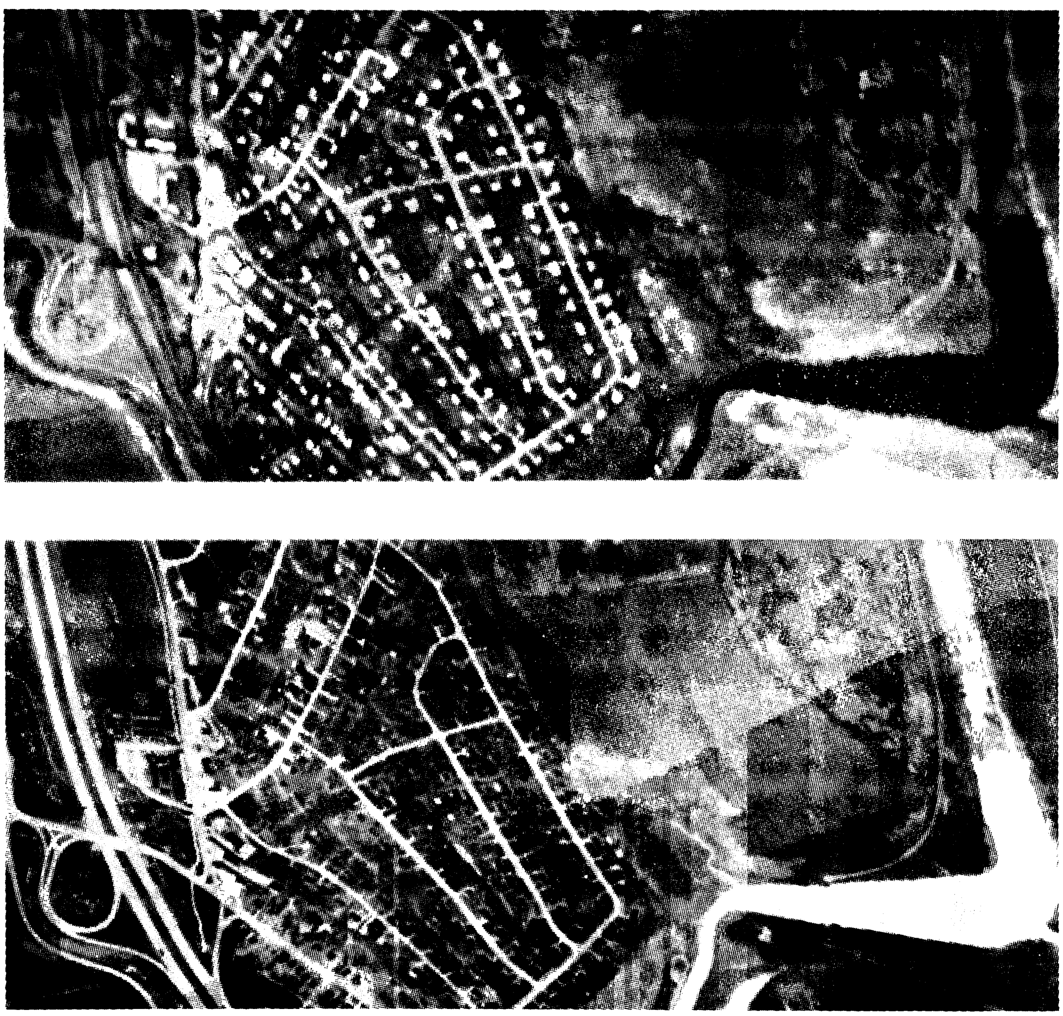


Figure 4.12 Daytime (top) and nighttime (bottom) thermal images of Clinton, New Jersey. The daytime image was acquired at 11:20 am on April 9, 1987. The nighttime image was acquired at 10:35 pm on April 10, 1987. During the day, bodies of water appear relatively cool while the rooftops of buildings appear warm. At night, water and paved roads appear warm while rooftops appear cool. Note that vehicles contrast well with the relatively warm road surfaces in the nighttime image. During the daytime, vehicles are not as visible. (Courtesy Intera Technologies Ltd.)

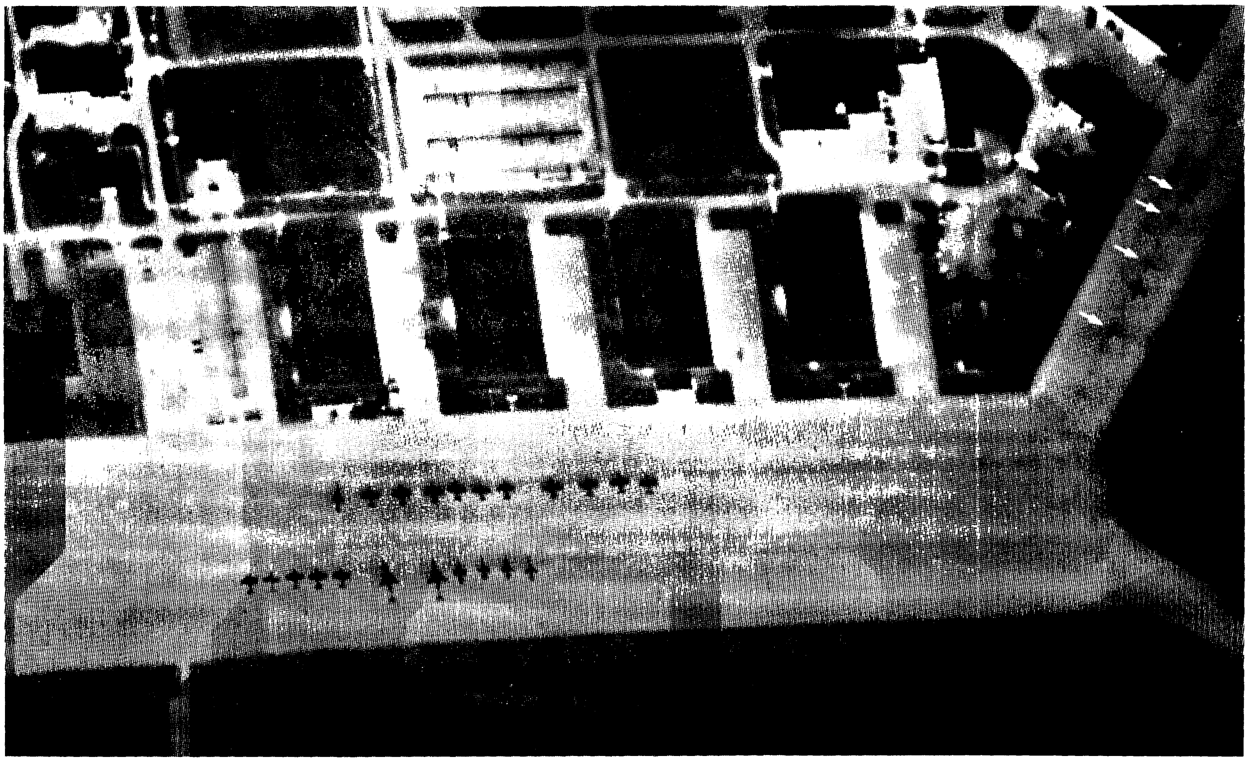


Figure 4.13 Thermal image of a military airfield. Thermal "shadows" of aircraft which were parked on the tarmac during the day are still visible (indicated by arrows) even though the aircraft are no longer there. (Courtesy of Intera Technologies Ltd.)

shadows in areas shaded from the sun. Thermal shadows can remain after the objects themselves have been removed, providing a clue to what was originally there, at least for a limited period. In Figure 4.13, cool shadows where aircraft were parked during the day are still evident after the aircraft have left. Similarly, thermal shadows or "ghosts" can be left by heat sources which are moved.

The sun's passage from east to west during the day affects the appearance of objects. Figure 4.14 shows computed temperature profiles for a parked tank. East-facing surfaces of the tank reach a peak temperature at midmorning while those facing the west reach peak temperature in the afternoon. South-facing and roof surfaces rise to a post-noon peak. The radiant contrast between the tank and a grass background is shown in Figure 4.14 (b). At 9:00 a.m., the tank will be easiest to detect from the east. In the afternoon, the roof and west side of the tank provide the greatest contrast with the background.[10]

If a vehicle has been recently used, thermal imagery will record the heat generated by the motor. When idling, the engine and the exhaust become very hot, evident as bright areas on thermal imagery. If the truck is moving, the hood will be cooled by the airstream to near air temperature. The exhaust will appear hot and the undercarriage and tires will appear warm to hot.[11]

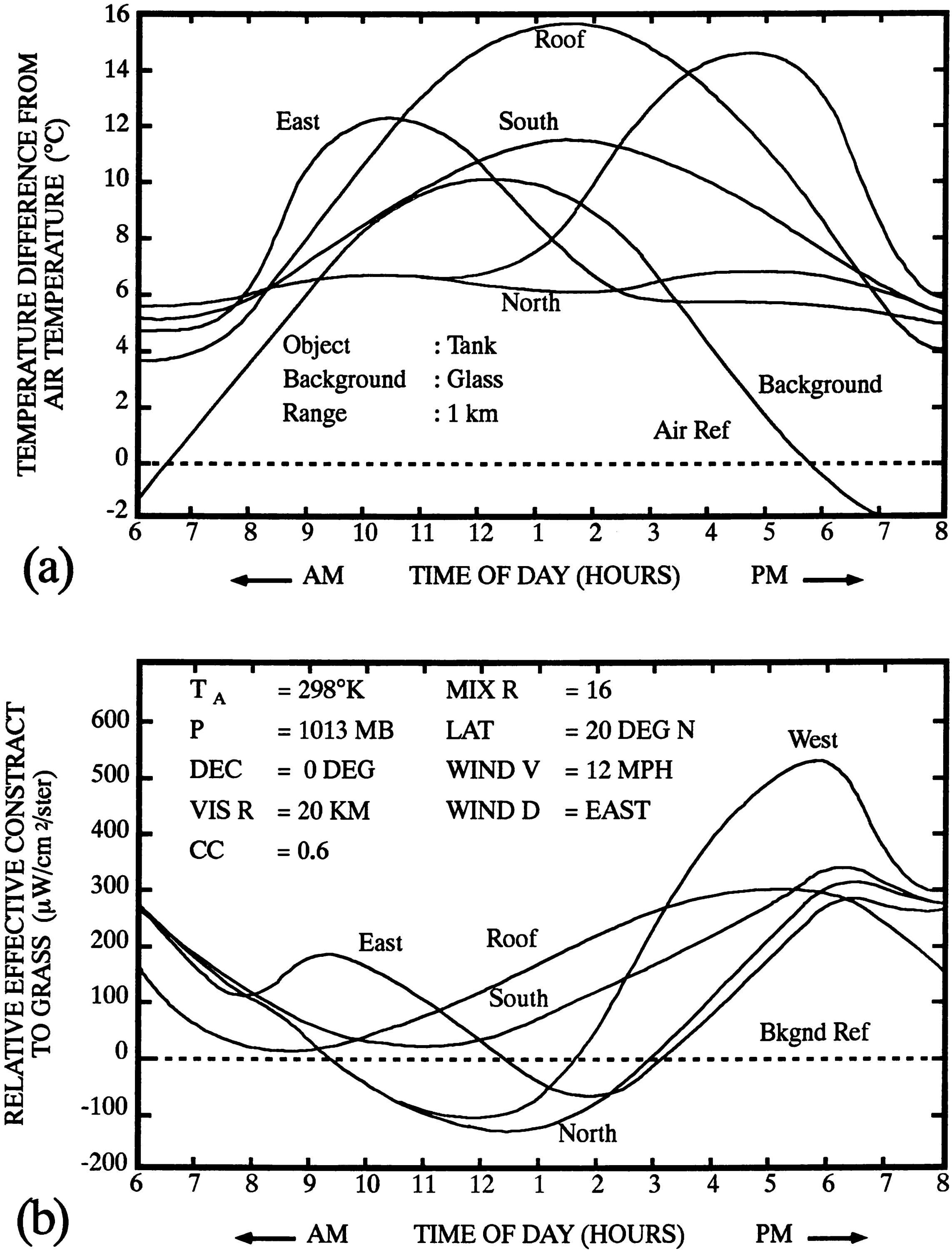


Figure 4.14 (a) Differences between the temperatures of a tank and air, and (b) effective radiant contrast between the tank and a grass background, as a function of time of day for various viewing directions. (Redrawn from Fred Rosell and George Harvey (editors), The Fundamentals of Thermal Imaging Systems. Electro-Optical Technology Program Office, Naval Research Laboratory, Washington, D.C., Report 8311, EOTPO Report No. 46, p. 15-16, by permission of Naval Research Laboratory)

For thermal images to display good contrast between features of interest on the ground, careful attention must be paid to weather conditions at the time of acquisition. Clear skies with no wind are best for most applications, but it is not always possible to fly under these conditions.

Scattered clouds below the flying height will obscure ground detail. If the overflight is during the day, cloud shadows will obscure even more image detail. A heavy overcast will greatly reduce thermal contrast because of radiative exchange between the clouds, which are warm in comparison to a clear night sky, and the terrain. If terrain detail is required, overflights should not be conducted under these conditions, even if the cloud ceiling is above the intended flying height. If the objective of the overflights is to locate heat sources, such as running vehicles or power generators, then it might be useful to fly under overcast conditions to suppress background terrain detail.

Surface winds produce smears and streaks on thermal imagery. Smears appear as parallel lines of light and dark tones which may be evident at local points or over large areas of images. Wind streaks occur downwind of obstructions, such as trees or buildings, and appear as warm plumes. The effect is to erase or confuse the normal thermal signatures of surface features. Even slight winds can affect thermal imagery, although some applications can tolerate more wind than others. Since it is not usually possible to avoid light surface winds during overflights, it is usually necessary for interpreters to simply recognize the symptoms of wind effects and endure them.

4.5 Geometric characteristics of linescan imagery

Aerial linescanners produce images with distortions which may influence interpretation of the data. These may result from the imaging geometry of the linescanner or from variations in the flight of the platform during acquisition.

If left uncorrected, linescanners produce images with severe tangential scale distortion. The mirror of a linescanner rotates at a constant speed. Figure 4.15 shows that as the distance from the nadir increases, the ground velocity of the scanner's "footprint" also increases. If the system produces output imagery using a constant sweep rate, rather than at a rate proportionate to the ground velocity, the images are compressed near the edges (Figure 4.16). The shapes of objects near the edges are distorted and linear features diagonal to the line of flight are imaged with a characteristic sigmoid curve.

Modern linescanners now mostly produce rectified images in which the effects of

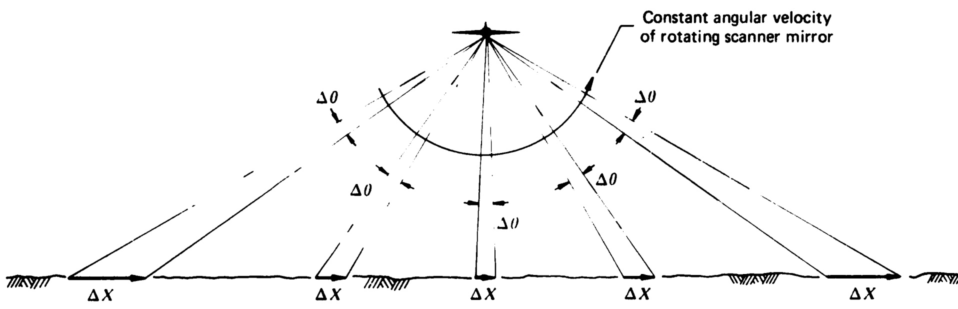


Figure 4.15 Tangential scale distortion in aerial linescanner imagery is a result of the rotation of the scanner's mirror. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 415, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

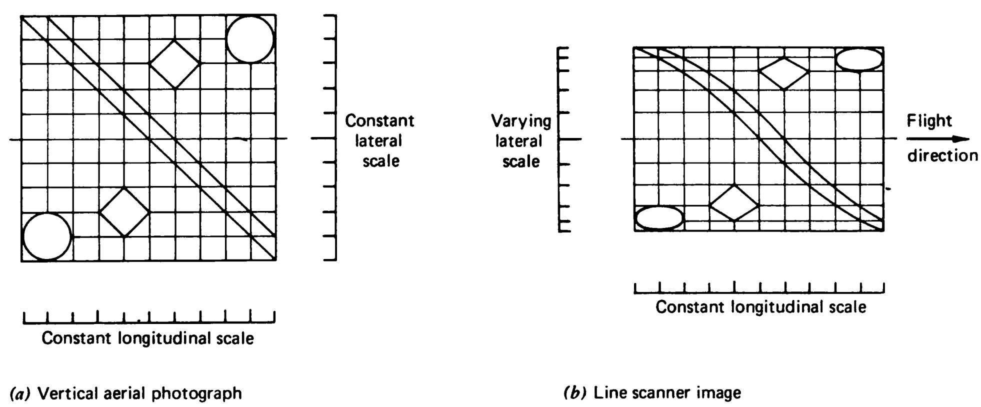


Figure 4.16 The effects of tangential scale distortion in unrectified linescanner imagery. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 416, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

tangential scale distortion are removed. Two related geometric considerations, changes in cross-scan resolution cell size and one-dimensional relief displacement, cannot be easily removed.

As the linescanner 's footprint moves outward from the nadir, it's size is increased (Figure 4.17). An object which completely fills the IFOV of the scanner when imaged at the nadir might be smaller than the IFOV when imaged further away. When objects smaller than the IFOV are imaged, the area surrounding the object will also contribute to the recorded signal. There is also an advantage to the change in resolution cell size. If the IFOV remained constant across the scan, the irradiance received by the sensor would drop off away from the nadir, darkening the edges of the imagery. But instead, the falloff is exactly compensated by the increase in IFOV.

Relief displacement in linescanner imagery is only in the scan direction, perpendicular to the line of flight. Figure 4.18 contrasts the relief displacement found in

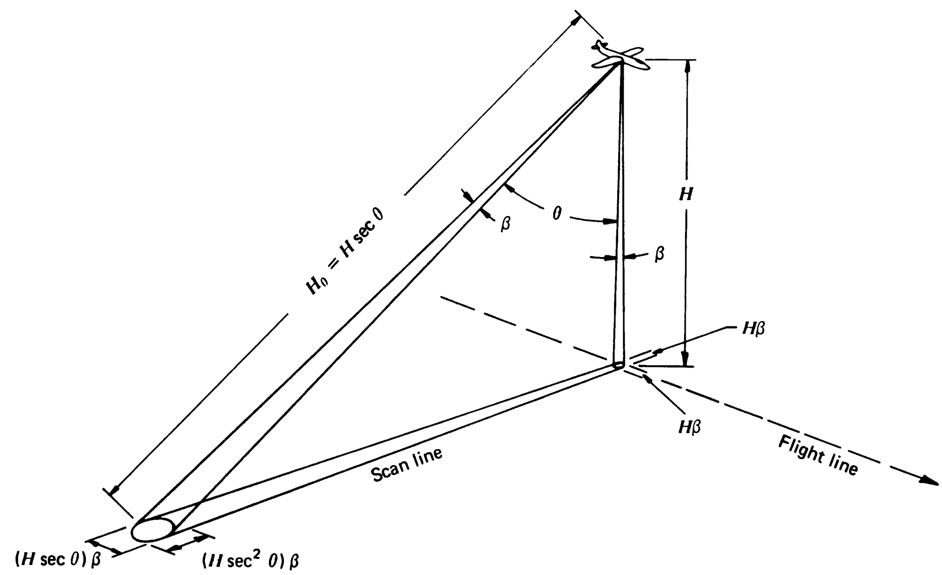


Figure 4.17 Resolution cell size variation with distance from the nadir line. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 420, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

vertical aerial photographs and that characteristic of linescanner imagery. Relief displacement has beneficial as well as detrimental effects. It provides the ability to see the sides of objects and to "look under" forest cover next to clearings. However, tall features can conceal other objects behind them when viewed obliquely.

Aerial linescanning requires strict control of the velocity and attitude of the platform. Variations in flight of the aircraft while scanning distorts the imagery. Changes in aircraft velocity will stretch out or compress the images in the direction of flight. Provided the velocity is consistent for the full flight line, it will often be possible

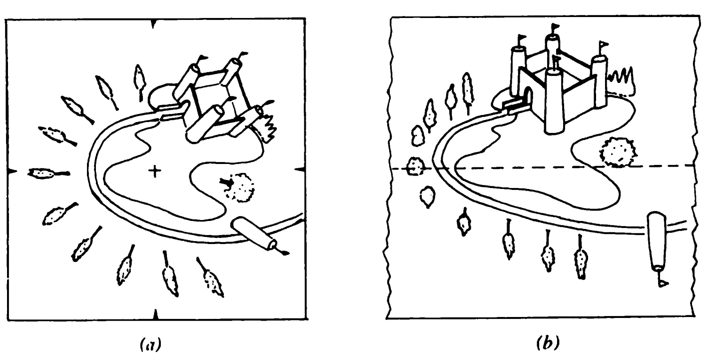


Figure 4.18 Relief displacement in a photograph and in linescanner imagery. In vertical photography, vertical features are displaced radially from the principal point (a). In linescanner imagery, vertical features are displaced at right angles from the nadir line. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 421, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

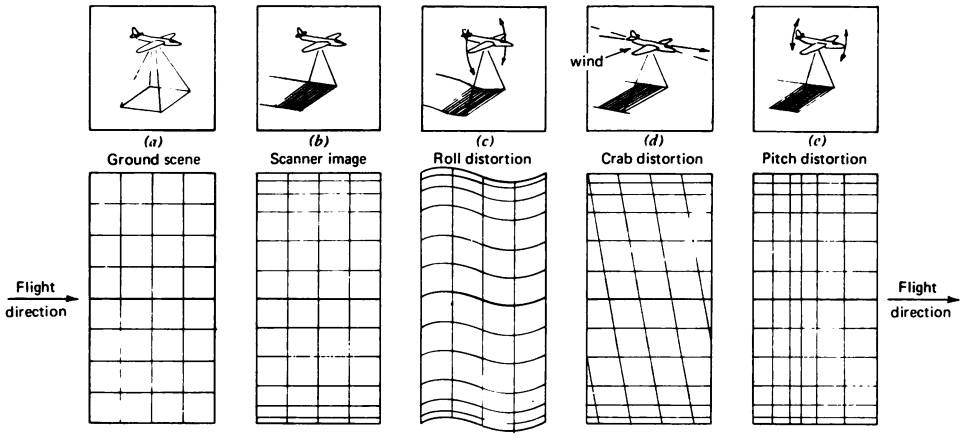


Figure 4.19 Linescanner image distortions induced by aircraft attitude variations. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 425, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

to compensate for the distortions through image processing. Intermittent changes, perhaps caused by sudden gusts of wind, cannot be easily corrected. Sudden changes in platform height from strong updrafts or downdrafts cause variations in swath width as well as changes in image scale.

Distortions which can result from flight attitude deviations are illustrated in Figure 4.19. Roll makes imagery appear "wavy." These effects, up to a certain limit, are routinely avoided using roll compensation systems. Crab produces skewed imagery. Crab occurs when the heading of an aircraft must be changed to compensate for strong crosswinds. The best way to prevent crab is avoid flying when there are strong crosswinds. However, mounting systems can also be designed to correct for crab. Variations in aircraft pitch cause local changes in image scale.

Notes to Chapter IV

[1] Infrared-sensitive films are often incorrectly identified as being "heat sensitive." These films are only sensitive out to about 0.9 μm. An object would have to be in the range of 1000°C, about the temperature of molten lava, for the emitted heat radiation to be recorded on such film. What we would consider to be a "warm" object, such as a human body, radiates with wavelengths in the range of 9 μm — a wavelength 10 times longer than the longest detectable by infrared-sensitive films.

[2] Rodgers, A.L., I.B.R. Fowler, T.K. Garland-Collins, J.A. Gould, D.A. James and W. Roper. 1983. Surveillance & Target Acquisition Systems. Brassey's Battlefield Weapons Systems & Technology, Volume VII. Brassey's Defence Publishers. Oxford, England. p. 80.

[3] Gain is analogous to the contrast adjustment of a television set or the contrast of a photograph.

[4] Link, L.E. Jr. 1977. "Procedures for planning remote sensing missions. Part II: Thermal infrared missions." Engineering and Scientific Research at WES. U.S. Army Corps of Engineers Information Exchange Bulletin. Vol. 0-77-2. p. 5.

[5] *ibid.*

[6] Madding, Robert P. 1979. "Thermographic instruments and systems." University of Wisconsin-Extension. Department of Engineering and Applied Science. p. 82.

[7] Nardone, Ralph L. 1982. "Infrared imaging in the tactical airborne environment." International Archives of Photogrammetry 24(1) p. 77.
[8] Estes et al., op. cit., p. 1101.
[9] Madding, Robert P. 1979. Thermographic instruments and systems. University of Wisconsin-Extension, Department of Engineering & Applied Science. Madison, Wisconsin. p.82.
[10] Rosell, Fred and George Harvey (editors). John B. Goodell, George L. Harvey, Walter R. Lawson, James A. Ratches, Robert E. Roberts, Fred A. Rosell, Robert L. Sendall and David L. Shumaker (authors). 1979. The Fundamentals of Thermal Imaging Systems. Naval Research Laboratory Report 8311/Electro-optical Technology Program Office Report No. 46. Washington, D.C. p.14.
[11] *ibid*. p.13.

CHAPTER V

MULTISPECTRAL SYSTEMS

Multispectral systems permit imagery to be collected in a number of spectral bands at once. These bands may include wavelengths from the ultraviolet, visible, reflected infrared and thermal infrared. By collecting and analyzing images in several spectral bands, it is possible to greatly improve the chances of distinguishing some features.

5.1 Categories of multispectral systems

There are three primary categories of multispectral imaging systems: multiband cameras, multispectral linescanners and solid-state pushbroom scanners.

a) *Multiband cameras*

Multiband cameras take several photographs simultaneously with different film/filter combinations. Figure 5.1 is a set of multiband aerial photographs taken using black and white infrared film with blue, green, red and infrared filters. The photo-

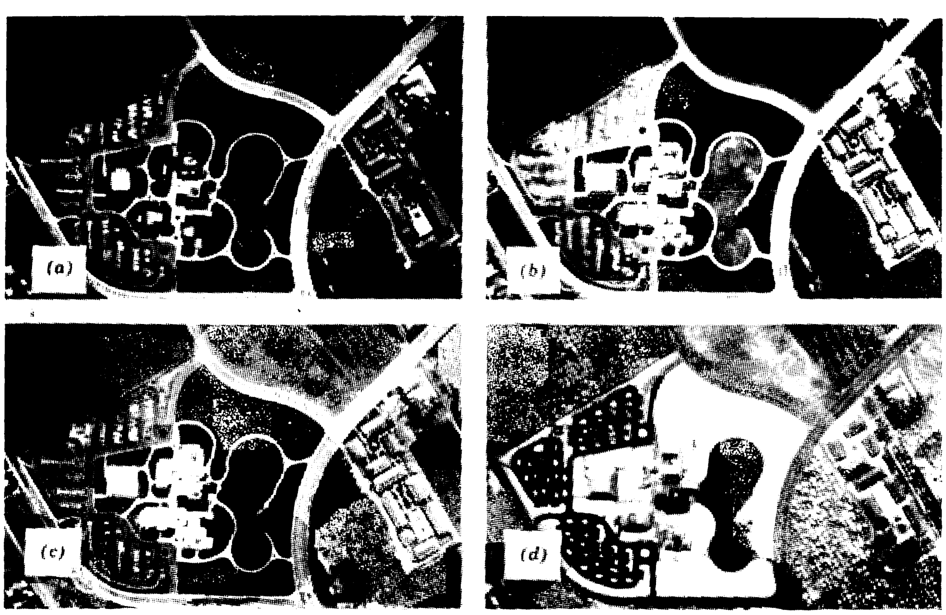


Figure 5.1 Multiband photography taken using black and white infrared film through different filters:

(a) Blue filter (Wratten™ 47B) (b) Green filter (Wratten™ 57A)
(c) Red filter (Wratten™ 25) (d) Infrared filter (Wratten™ 88A).

(From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 70, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

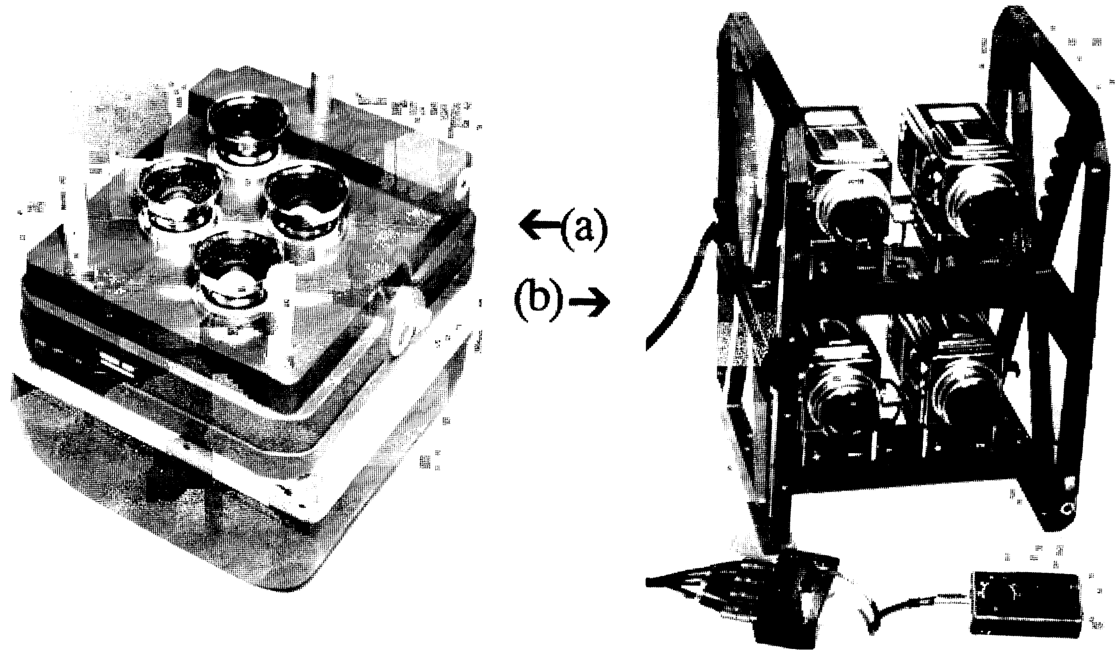


Figure 5.2 Camera systems for taking multiband photography including (a) a multilens frame camera and (b) an array of 70 mm Hasselblad cameras. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 69 & 73, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

graphs may be taken using a specialized multilens camera or by using a multiband camera array equipped with a system to release the shutters simultaneously (Figure 5.2).

Multiband camera systems have been eclipsed by electronic scanners primarily because of the limitations of film-based systems. Photographic systems are limited to the 0.3 μm to 0.9 μm spectral range. The 0.9 μm limit results from the photochemical instability of emulsions sensitive to longer wavelengths.[1] The radiometric range of photographic films is also more restricted. Spatial and radiometric comparisons between bands are more difficult because separate optical systems are used to collect the imagery. Because of the photochemical processes involved in their production, films are also difficult to radiometrically calibrate.[2]

b) *Opto-mechanical linescanners*

Multispectral linescanners operate in a similar manner to thermal linescanners, combining motion of the platform with a rotating mirror to collect a strip of imagery (Figure 5.3). Multispectral scanners, however, are sometimes capable of collecting imagery in ten or more wavebands. The energy is divided into its spectral components in several steps. Reflected energy is separated from emitted energy using a dichroic lens or grating. A prism or diffraction grating splits the reflected component into ultraviolet, visible and reflected infrared bands. The dichroic grating also disperses the emitted energy component, allowing several thermal detectors to be used to provide multiple thermal wavebands.

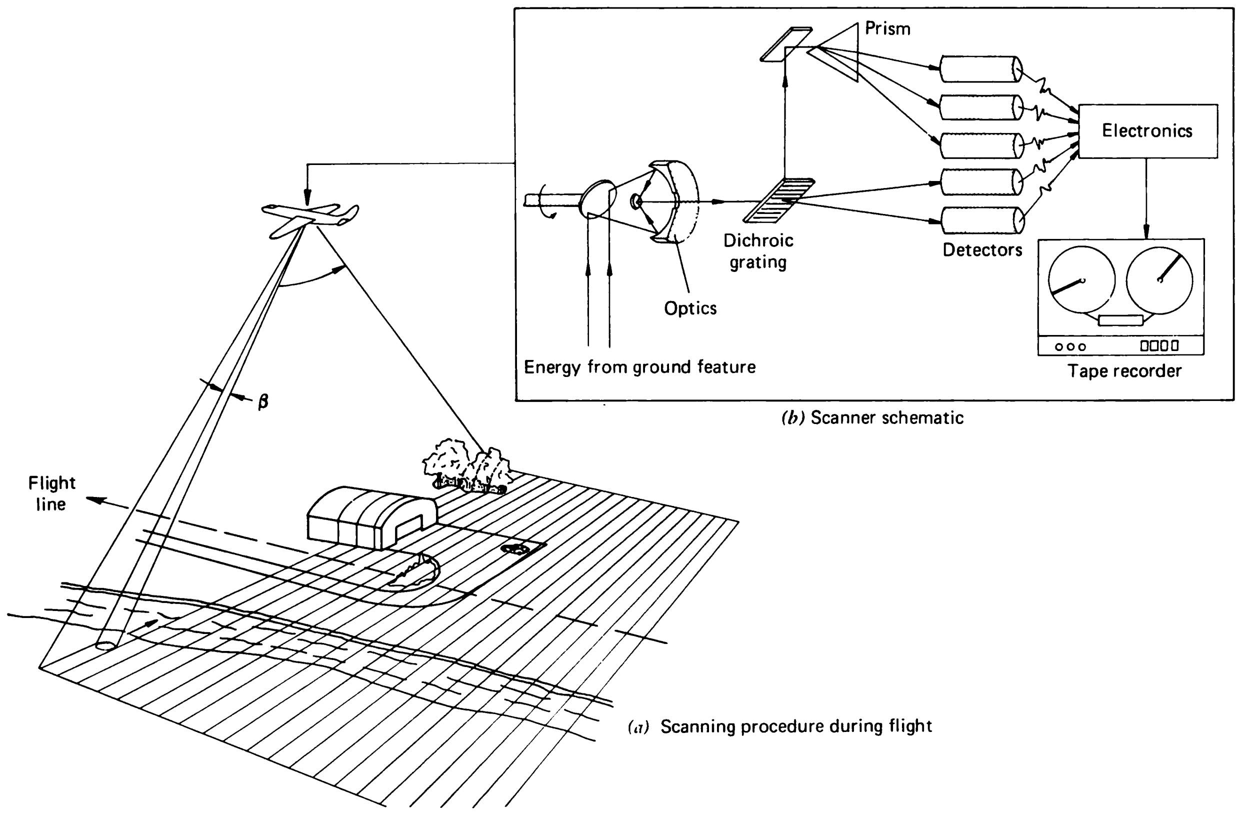


Figure 5.3 Operation of a multispectral scanner. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 444, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

Multispectral linescanners can be configured in different ways to suit particular applications.[3] Table 5.1 outlines the available spectral channels for the Daedalus AADS 1240/1260 linescanner. Two sensor ports can be equipped with two detectors in the thermal infrared range (AADS 1240) or with one infrared detector and a 10-channel spectrometer (AADS 1260). A detector sensitive to ultraviolet wavelengths can also be fitted into one of the ports.[4] This is a general purpose system designed to cover the fullest possible range for multiple applications. In contrast, the Thermal Infrared Multispectral Scanner (TIMS), developed for NASA and the Jet Propulsion Laboratory by Daedalus Enterprises Inc., has six channels, all of which are in the 8-14 μm thermal infrared window (Table 5.2).

c) *Solid-State Pushbroom scanners*

Pushbroom scanners eliminate the requirement for rotating or oscillating mirrors through the use of solid-state linear array technology. A linear array of detectors is used for across-track sensing and the motion of the aircraft provides the along-track dimension (Figure 5.4). Each detector in the array "stares" or integrates over one pixel for the period of a whole scan line, improving radiometric sensitivity. The longer dwell time allows narrow spectral bands to be used while maintaining high spatial and

TABLE 5.1

Spectral channels available with Daedalus visible and infrared multispectral linescanners.

Ultraviolet	0. 0.32	-	0.38	µm
Visible/Reflected infrared	1. 0.38	-	0.42	µm
	2. 0.42	-	0.45	µm
	3. 0.45	-	0.50	µm
	4. 0.50	-	0.55	µm
	5. 0.55	-	0.60	µm
	6. 0.60	-	0.65	µm
	7. 0.65	-	0.69	µm
	8. 0.70	-	0.79	µm
	9. 0.80	-	0.89	µm
	10. 0.92	-	1.10	µm
Thermal	11. 3.0	-	5.0	µm
	12. 8.0	-	14.0	µm

Source: Richards, John A. 1986. Remote Sensing Digital Image Analysis: An Introduction. Springer-Verlag. New York. p. 17.

Table 5.2

Thermal infrared multispectral scanner bands.

1. 8.2	-	8.6	µm
2. 8.6		9.0	µm
3. 9.0	-	9.4	µm
4. 9.5		10.2	µm
5. 10.2		11.2	µm
6. 11.2		12.2	µm

Source: Richards. Remote Sensing Digital Image Analysis: An Introduction. p. 19.

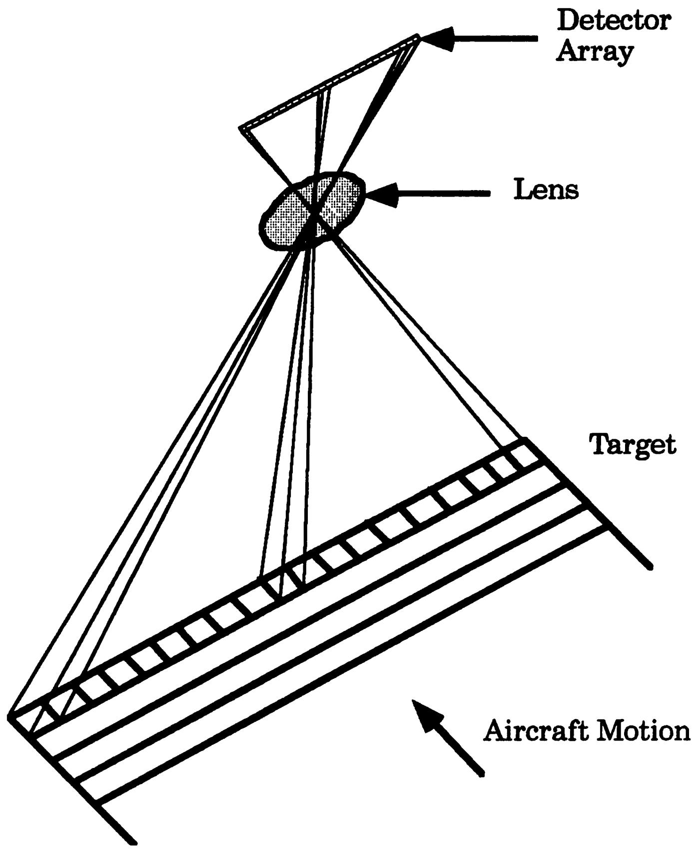


Figure 5.4 Image formation using a pushbroom scanner such as the Canada Centre for Remote Sensing MEIS II. The across-path dimension is provided by a multi-element detector array while the along-path dimension is supplied through aircraft motion. (Redrawn from S.M. Till, W.D. McColl and R.A. Neville. 1983. "Remote Sensing using the airborne MEIS II multi-detector electro-optical imaging scanner." Proc. EARSel/ ESA Symp. on Remote Sensing Applications for Env. Studies. ESA Rpt. SP-188. p. 91, by permission of S.M. Till, Canada Centre for Remote Sensing)

radiometric resolution. The geometric precision of the imagery is determined solely by the optics and arrays. It is more precise than rotating mirror systems in which the motor speed or mirror oscillation speed may fluxuate.[5]

The MEIS-II developed by the Canada Centre for Remote Sensing (Figure 5.5) is an example of a pushbroom scanner.[6] It has eight geometrically-registered channels, each with its own linear array detector and optics. Spectral bands, as narrow as 3 nm[7] wide and within the range of 0.39 to 1.1 μm, can be suited to particular missions using interchangeable spectral filters placed in front of each lens. The maximum achievable spatial resolution depends upon the minimum possible speed (and therefore the lowest possible altitude) of the aircraft in which it has been installed. As an example, a pixel size of 0.3 x 0.3 metres and swath width of 316 metres would be produced when flown from an altitude of 440 metres above ground with a ground speed of 60 m/sec and a scan rate of 200 Hz.[8] Two images acquired using the MEIS-II are shown in Figure 5.6. Approximate pixel size for each image is 0.43 metres. The green band (MEIS band 7, 549 nm) is shown in each figure.

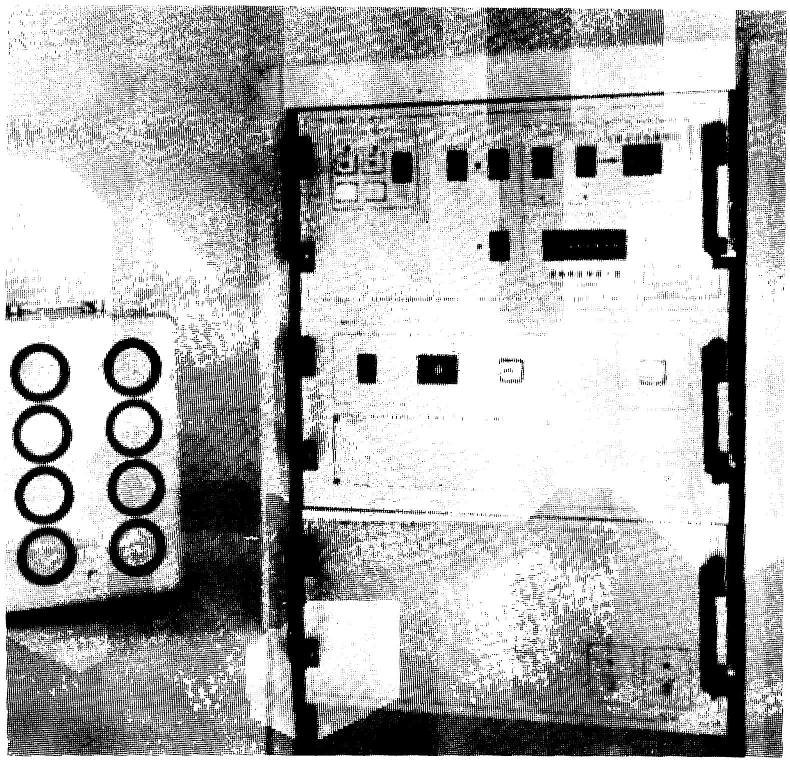


Figure 5.5 The Canada Centre for Remote Sensing MEIS II. The camera head is on the left side. The data processor and image data resampler are on the right side. (Courtesy of D. McClure, MacDonald Dettwiler and Associates)

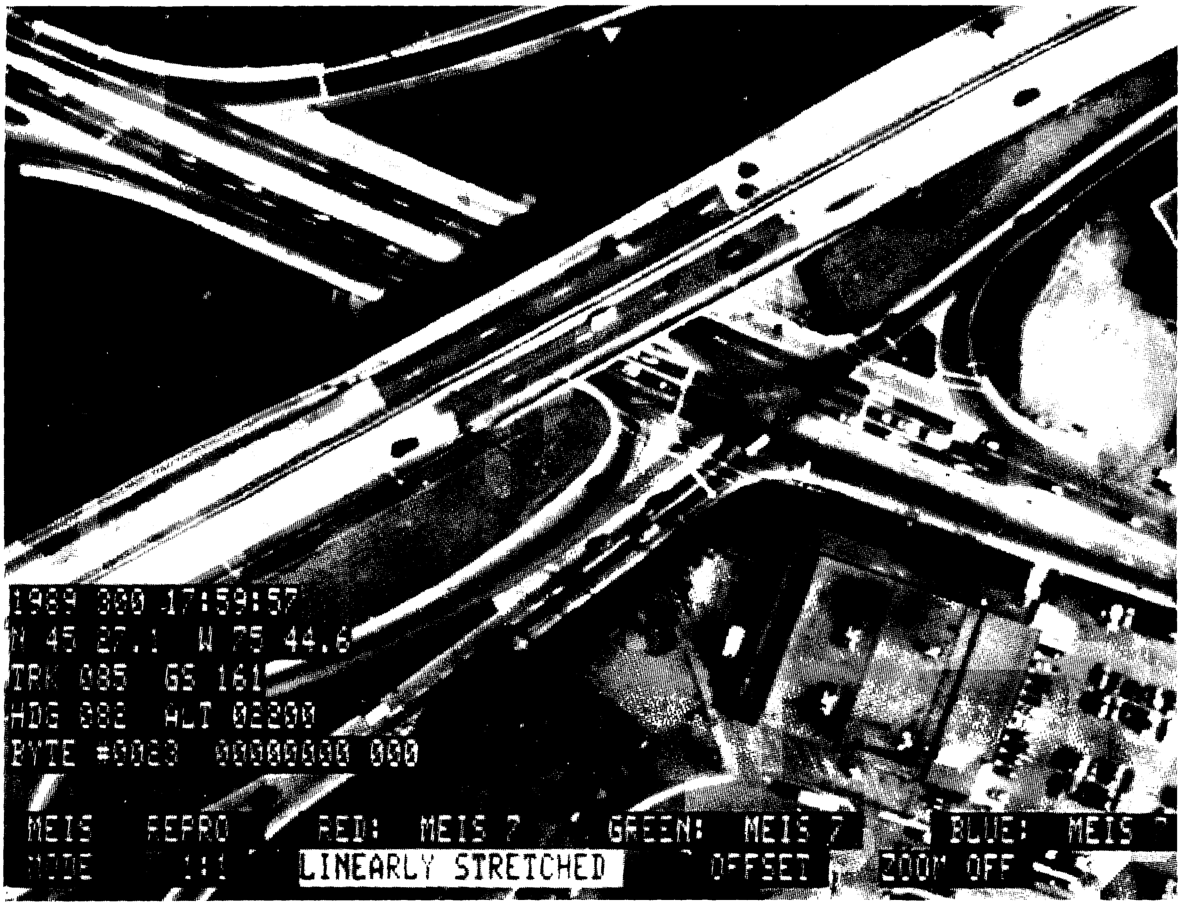
5.2 Using multispectral imagery

Multispectral imagery has been used successfully for many problems in fields such as agriculture, forestry, land use studies and others. These applications usually involve the identification of surface cover types and the quantification of the areas encompassed by the different types.

Surfaces have characteristic spectral properties. For example, the general spectral reflectance curves for water, vegetation and soil are presented in Figure 5.7.[9] Using images collected at different wavelengths, it is often possible identify surface cover types based upon their particular "spectral signatures."

Figure 5.8 shows a multispectral scan line over different surface types. The bar graphs show the relative signal responses for the various surfaces. The wavebands used in a multispectral system are selected to provide the means to distinguish between

Figure 5.6 (on facing page) Imagery acquired using the Canada Centre for Remote Sensing MEIS II. The fine spatial detail of the imagery permits general categories of vehicles and information regarding buildings to be interpreted. The image has an approximate pixel size of 0.43 metres. The images shown are in the green band (MEIS band 7, 559 nm). (Courtesy of Innotech Aviation Ltd.)


1989 300 17:59:57
N 45 27.1 W 75 44.6
TRK 085 GS 161
HDG 082 ALT 02200
BYTE #0023 00000000 000
MEIS REPRO RED: MEIS 7 GREEN: MEIS 7 BLUE: MEIS 7
MODE 1:1 LINEARLY STRETCHED OFFSET ZOOM OFF


1989 300 17:59:48
N 45 27.1 W 75 45.2
TRK 084 GS 160
HDG 081 ALT 02300
BYTE #0023 00000000 000
MEIS REPRO RED: MEIS 7 GREEN: MEIS 7 BLUE: MEIS 7
MODE 1:1 LINEARLY STRETCHED OFFSET ZOOM OFF

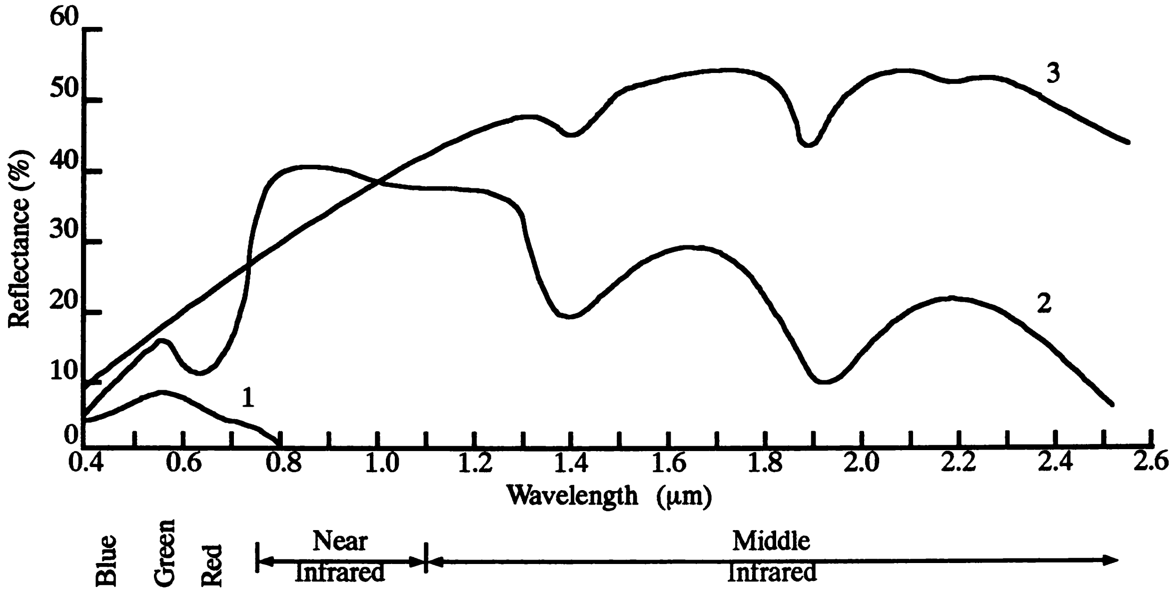


Figure 5.7 Spectral reflectance properties of common surfaces in the visible and near-to-mid infrared spectral ranges. The surfaces represented include:

1 - water
2 - vegetation
3 - soil

(Redrawn from John A. Richards, Remote Sensing Digital Image Analysis: An Introduction, p. 3, © 1986 by Springer-Verlag, by permission of John A. Richards and Springer-Verlag)

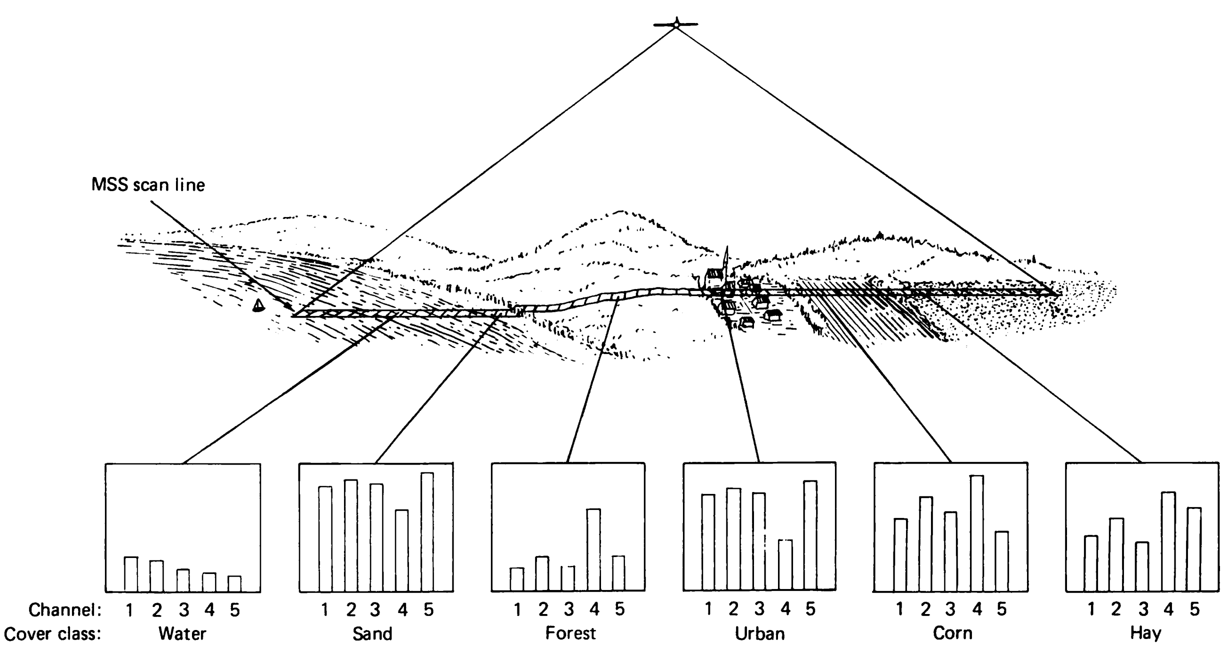


Figure 5.8 Representative multispectral values along one multispectral scan line. The spectral bands represented by the five bars include blue (1), green (2), red (3), reflected infrared (4) and thermal infrared (5). (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation p. 459, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

surfaces of interest. For example, pixels of water could be easily separated from those of forested areas by the different spectral responses of the two surface types in the reflected infrared band (Bar 4 in Figure 5.8).

If the spectral characteristics for surfaces of interest are distinctive enough, it may be possible to interpret surface cover types using a computer-based image analysis system based only upon the spectral information. However, many surfaces are spectrally similar and cannot be easily distinguished using standard computer-based techniques. Furthermore, the spectral characteristics of surfaces are not the only element determining the energy which eventually reaches the sensor. Other considerations including the slope and aspect of the imaged surface and atmospheric conditions at the time of acquisition affect the signal recorded by the sensor, making the idea of a "spectral signature" difficult to implement in most cases.

For most successful applications of multispectral imagery, spectral characteristics are of primary importance for distinguishing the features of interest. This is usually <u>not</u> the case regarding many of the objects of interest for arms control verification. A tank is more likely to be identified by its shape or association with surrounding military equipment than by its spectral characteristics.

Most of the computer-based techniques for interpreting multispectral imagery are of limited use for the tasks involved in arms control verification. Visual interpretation by trained human interpreters allows spatial and contextual information to be used together with the improved spectral data afforded by multispectral imagery. Even if the interpretation is to be performed by human interpreters, there is still much to be gained through the use of digital imagery. Imagery acquired in digital form is much more flexible, allowing more options for analysis of the data. Photographic products can be produced from the digital data with or without modification. The interpreter's task can be assisted substantially by using digital image enhancement procedures.

The simplest photographic product is a black and white print or transparency of any one of the image bands, as in Figure 5.6. Each band can be reproduced to make a set of images for analysis. A more convenient and effective product is a colour composite image in which a selected band of the multispectral image is used for each of the three primary colours.[10] If the dataset consists of more than three bands, it must be decided which bands will be used for the composite image and which will be disregarded. Otherwise the imagery may be transformed, for example by using principal components or image ratioing techniques, to allow the most significant features in the data to be displayed using only the three primary colours. A major disadvantage of the latter approach is that the resulting synthetic images may appear radically different from a normal colour composite making even familiar features difficult to recognize.

5.3 Camouflage detection

The use of camouflage to reduce the visibility of military personnel, equipment and installations is an integral part of the normal operations of modern military forces. Camouflage might also be used to conceal efforts to circumvent the terms of an arms control agreement. Verification of any agreement will likely have to include measures to overcome attempts to use camouflage to evade treaty obligations.

Colour infrared film was developed in the early 1940's to overcome visual camouflage.[11] Early paints used for camouflage did not match the high reflectance of vegetation in the near infrared beyond 0.7 μm or the "chlorophyll dip" between 0.6 and 0.7 μm (see Figure 5.7), permitting a film sensitive to the near infrared to distinguish between camouflage paint and live foliage. Camouflaged clothing, equipment and some paints are now impregnated with chlorophyll dyes to more closely match the appearance of real foliage using colour infrared film.[12]

Digital multispectral sensors offering narrow wavebands have great potential for camouflage detection. For example, modern multispectral sensors can provide imagery in which subtle variations in foliar reflection between different tree species are clearly visible. If the subtle spectral variations between forest trees is so clearly evident, then it will be difficult to mass-produce camouflage materials to match the particular vegetation at a specific location.

White-coloured materials are used for camouflage in snow-covered areas. However, these materials may appear black against a white background using photographs or electronic sensors sensitive to ultraviolet light unless the camouflage was designed with sensitivity to ultraviolet radiation in mind. However, this is not a difficult problem to overcome. For example, a lead white paint with an oil-based vehicle would provide the required high reflectivity of near ultraviolet radiation.[13] Camouflage materials which are effective against sensors operating in the ultraviolet region are readily available.[14]

Notes to Chapter V

1 Some films used for scientific studies are sensitive to about 1.2 μm. However, these films are not commonly available. Lillesand, T.M. and R.W. Kiefer. 1979. Remote sensing and image interpretation. John Wiley & Sons. New York. p. 47.

2 *Ibid*. p. 442-443.

3 Fifty-six systems, of which 23 are airborne and including both linescanners and pushbroom scanners, are reviewed by Slater, Philip N. 1985. "Survey of Multispectral Imaging Systems for Earth Observations." Remote Sensing of Environment 17:85-102.

4 Richards, John A. 1986. Remote Sensing Digital Image Analysis: An Introduction. Springer-Verlag. New York. p. 17.

[5] Zwick, H., J.N. de Villiers and W. McColl. 1978. Laboratory Evaluation of the Prototype MEIS (Multi-detector Electro-Optical Imaging Scanner. Research Report 78-5. Canada Centre for Remote Sensing, Dept. of Energy, Mines and Resources, Canada. p. 1.

[6] Till, S.M., W.D. McColl and R.A. Neville. 1983. "Development, Field Performance and Evaluation of the MEIS-II Multidetector Electro-Optical Imaging Scanner." Proc. 17th Int. Symp. on Remote Sensing of Environment, Ann Arbor, Michigan. pp. 1137-1146; Till, S.M., R.A. Neville, W.D. McColl and R.P. Gauthier. 1986. "The MEIS II Pushbroom Imager - Four Years of Operation." Proc. ISPRS Symposium, Stuttgart. pp. 247-253.

[7] one nanometre (nm) = 1×10^{-3} micrometres (μm)

[8] Till, S.M., W.D. McColl and R.A. Neville. 1983. "Remote Sensing Using the Airborne MEIS II Multi-Detector Electro-Optical Imaging Scanner." Proc. EARSeL/ESA Symp. on Remote Sensing Appl. for Environ. Studies. Brussels, Belgium. ESA SP-188. p. 90.

[9] For a review and discussion of the spectral reflectance properties of common surfaces including vegetation, soils, water, snow and clouds, see Hoffer, R.M. 1978. "Biological and Physical Considerations in Applying Computer-Aided Analysis Techniques to Remote Sensor Data." IN: Swain, P.H. and S.M. Davis (eds.) Remote Sensing: The Quantitative Approach. McGraw-Hill. New York. p. 227-289.

[10] In the case of a display device such as a colour display monitor, the image bands would be associated with each of the three additive colour primaries; blue, green and red. In the case of a colour film, each of the image bands would be associated with one of the three subtractive colour primaries; yellow, magenta and cyan.

[11] See Chapter I for further historical review.

[12] Allen, Patick H.F. 1986. "Camouflage Forward Concealment Systems." Armed Forces 5(7). p.312.

[13] Lavigne, D.M. "Counting Harp Seals with Ultraviolet Photography." IN: Holz, Robert K. 1985. The Surveillant Science: Remote Sensing of the Environment. Second Edition. John Wiley & Sons. New York. p. 68.

[14] Anon. 1986. "Concealment and Deception by Camouflage Techniques." Armada International 10(6) p. 90; Allen, Patrick H.F. op. cit. p. 312.

CHAPTER VI

RADAR SYSTEMS

Radar, an acronym for radio detection and ranging, was developed to detect objects and determine their position using radio waves.[1] It transmits short pulses of microwave energy and then records the echoes received back in their order of arrival.

Radar systems can acquire imagery in almost any atmospheric conditions: haze, smoke, cloud cover, or even light rain and snow. In some cases radar might be the only way of acquiring imagery. In one of the first large-scale mapping projects using airborne radar, the entire 10,000 square mile area of Darien Province, Panama, was imaged four times in six days. One entire coverage was completed in only four hours of flying time. Prior to the airborne radar surveys, a fifteen-year attempt to acquire photographic coverage had managed to cover only 30 percent of the area.[2]

With regard to the potential use of such systems for arms control verification, it is not necessary to cite examples of perpetually cloud-covered areas to make the case for radar imaging. Image acquisition might have to be done during a specific period, for instance, to collect overhead imagery of a major military exercise. Overflights could be required 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. With darkness being a potential cover for covert activity, it is necessary for an agency charged with the verification of an arms control agreement to have the capability to effectively monitor nocturnal activity as well as those during the day.

6.1 Microwave radiation

Radars use much longer wavelength radiation than optical systems. Microwaves are commonly measured in centimetres rather than micrometres. The long wavelength radiation provides imaging radars with their all-weather capability. Imaging radars use wavelengths greater than 1.0 centimetre to reduce the effect of weather conditions. Radars for weather forecasting use wavelengths less than 1.0 centimetre to increase the influence of clouds and rain.

The microwave region is divided into bands, designated by letters. Code letter designations were originally assigned during the early development of radars for

TABLE 6.1

Bands used for imaging radars.

Band Designation	Wavelength (λ) millimetres (mm)	Frequency (f) Megahertz (10^6 cycles/sec)
K_a	7.5 - 11	40,000 - 26,500
K	11 - 16.7	26,500 - 18,000
K_u	16.7 - 24	18,000 - 12,500
X	24 - 37.5	12,500 - 8,000
C	37.5 - 75	8,000 - 4,000
S	75 - 150	4,000 - 2,000
L	150 - 300	2,000 - 1,000
P	300 - 1000	1,000 - 300

security. Radar bands are still referred to by letter designations, although the wavelength ranges represented by the letters may vary somewhat. Table 6.1 lists the common bands used for imaging radars.

6.2 SLAR operation

Side-looking airborne radars (SLAR) produce continuous strips of imagery of terrain adjacent to the flight path of the aircraft. A radar antenna is mounted on the aircraft, pointing to the side. The antenna acts as a transmitter as well as receiver of microwave energy. 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 as shown in Figure 6.1.

SLAR systems may be divided into two major types: real aperture and synthetic aperture radars.[3]

a) *Real aperture radar (RAR)*

A real aperture, or "brute force," radar (RAR) transmits and receives the returns of a single pulse to form each line of the image. The returns are converted into a video

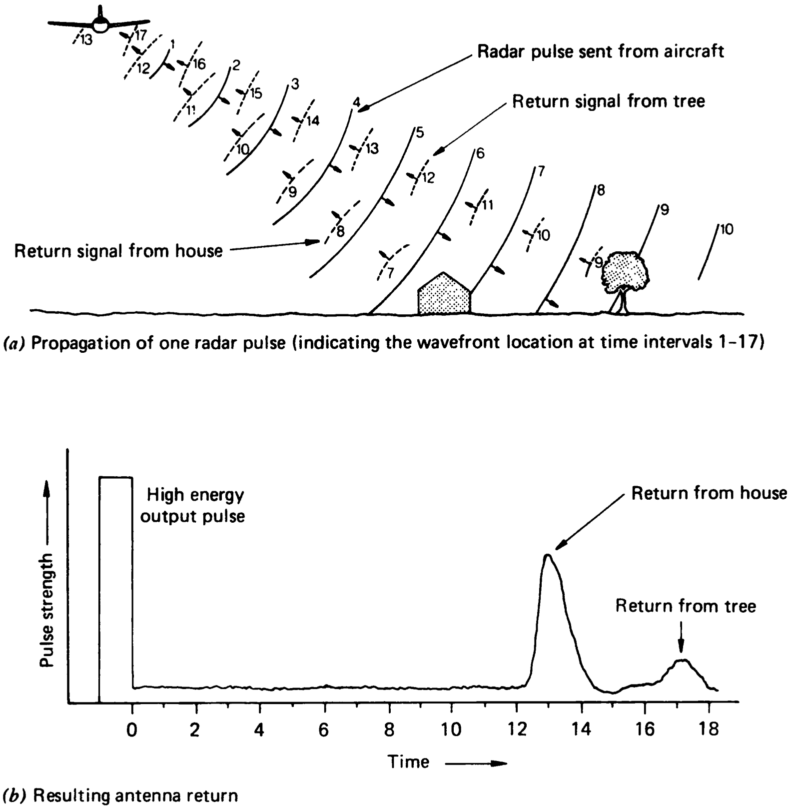


Figure 6.1 SLAR signal transmission and return. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 493, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

signal (Figure 6.2) which may then be used to modulate the intensity of a cathode ray tube (CRT) to write the image line onto photographic film. The motion of the aircraft repositions the antenna before the next pulse is transmitted. By moving the film past the CRT using a speed proportional to that of the aircraft, a continuous strip of imagery is recorded. Some systems permit the signal to be recorded on either an analogue or digital tape recorder rather than directly onto film.

The imagery may be presented in a slant range or ground range format. Slant range is the radial distance from the antenna to the target. Ground range is the horizontal distance from the ground track of the aircraft to the target.

Slant range is obtained directly from the elapsed time between the transmission of a pulse and when the returns arrive back. Using a constant sweep rate on the film recorder gives a slant range presentation of the imagery. SLAR imagery in this format is compressed in the near range (Figure 6.3).

The ground range is computed from the slant range and altitude above ground of the aircraft. This can be used to derive a sweep waveform which is faster in the near range and approaches the slant range rate as the range increases. The ground range format presents horizontal distances more closely matching those shown on a map than

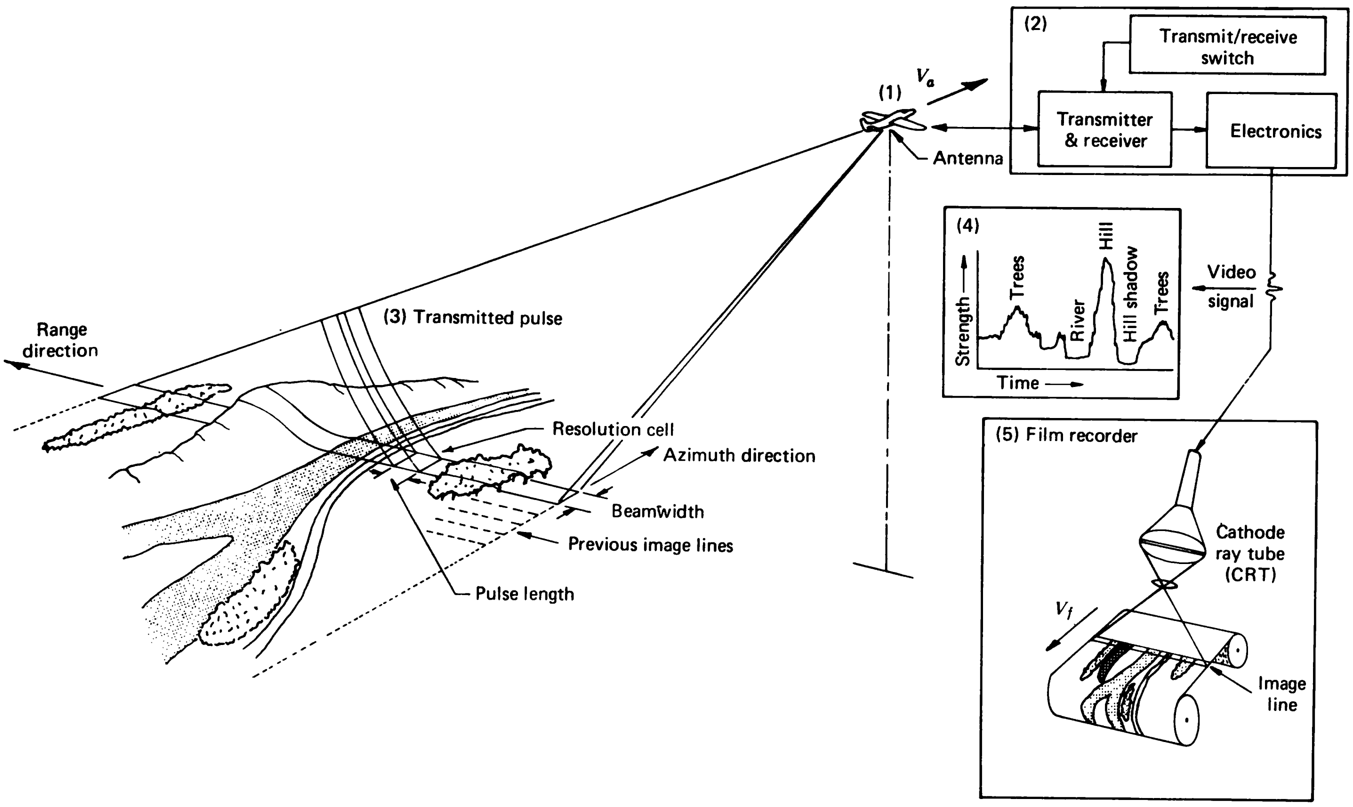


Figure 6.2 Operation of a real aperture SLAR system. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 495, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

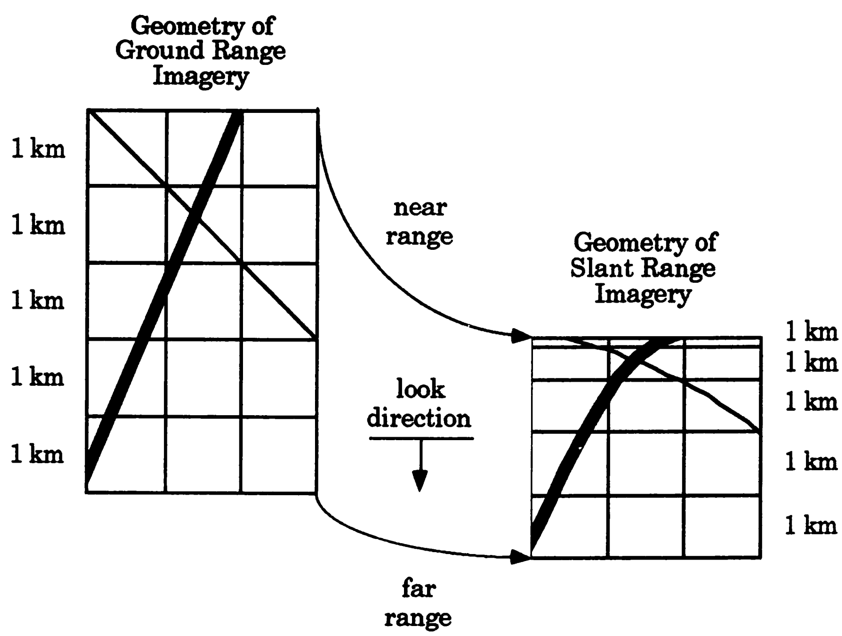


Figure 6.3 Geometry of slant range and ground range presentations. (Redrawn from A.J. Lewis and H.C. MacDonald, "Interpretive and Mosaicking Problems of SLAR Imagery," Remote Sensing of Environment 1 (1970), p. 232, © 1970 by American Elsevier Publishing Company, Inc., by permission of Elsevier Science Publishing, Inc.)

the slant range format but cannot exactly match the true positions of terrain features because of variations in ground elevation.

The ground resolution of a SLAR is defined as the minimum distance between ground reflectors which will give separate returns. For real aperture systems, resolution is dependent upon the physical length of the antenna and pulse duration of the emitted microwave radiation. There are two components. Azimuth, or along-track, resolution is in the same direction as the aircraft's flight path. Range, or across-track, resolution refers to resolution perpendicular to the flight path.

Range resolution is determined by the duration of the pulses of microwave energy. Shorter pulses produce finer across-track resolution. Slant range resolution is equal to half the transmitted pulse length and remains constant regardless of the distance from the sensor. The corresponding ground distance, however, is affected. The ground resolution in the range direction (R_r) is reduced with increasing distance from the antenna according to

$$R_r = \frac{c\tau}{2 \cos \alpha}$$

where τ is the pulse duration and α is the depression angle, the angle between the line joining the radar antenna and the object being sensed and a horizontal ground plane.

The azimuth resolution (R_a) is given by the relationship

$$R_a = \frac{\lambda GR}{D}$$

where

λ	= wavelength of the radar system
GR	= range (distance from the aircraft)
D	= aperture of the antenna

For real aperture radars, the azimuth resolution deteriorates with increasing distance from the aircraft (Figure 6.4). Increasing the size of the antenna or using shorter wavelength energy can improve the resolution to some extent. However, there are limits to how much these parameters can be changed. The use of shorter wavelengths increases atmospheric attenuation and if the antenna is made too large, the aircraft will not be able to carry it.

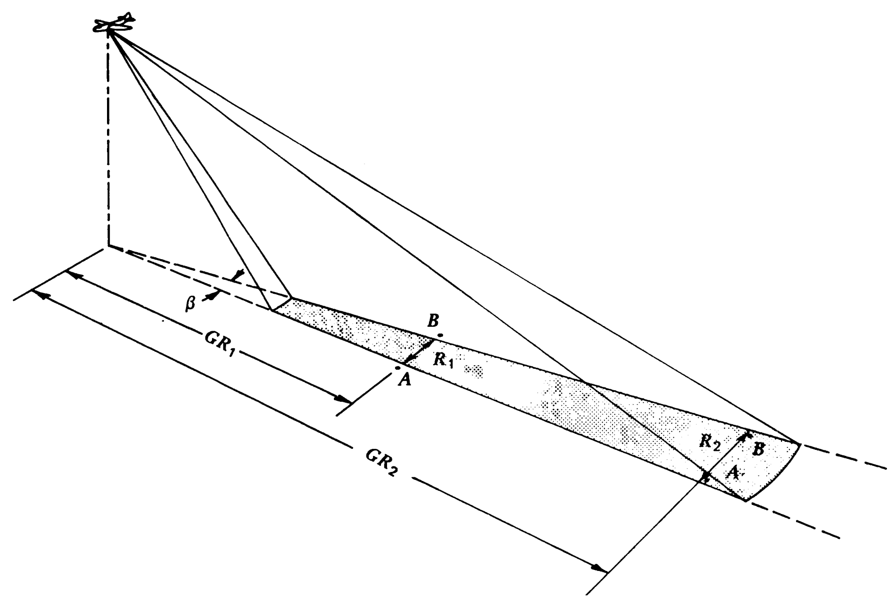


Figure 6.4 Reduction of azimuth resolution (R_a) with increasing ground range (GR) for a real aperture radar with beamwidth ß. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 498, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

b) *Synthetic aperture radar (SAR)*

Synthetic aperture radars (SAR) were developed to overcome some of the operational limitations associated with real aperture systems. Synthetic aperture systems use the forward motion of the aircraft to create the effect of an antenna hundreds of metres long. A very narrow effective antenna beamwidth is made possible without requiring a physically long antenna or a short operating wavelength (Figure 6.5).

In a SAR system, objects are illuminated repeatedly and the corresponding returns are also received many times by the antenna as the aircraft flies past. The frequency as well as the amplitude of returns are recorded. Returns from various parts of the beam have upshifted or downshifted frequencies in accordance with the Doppler Effect (Figure 6.6). A phase history of returns is recorded which is later used to generate the image.

Using the Doppler shifts, it is possible to create a very narrow effective beamwidth. Because the signals are received over a long period of time during which the relatively short physical antenna travels a long distance, a long effective antenna is synthesized. The azimuth resolution of a SAR is theoretically not reduced with increasing range since the effective antenna length also increases at longer ranges. This means that SAR systems can provide imagery with high resolution even at high altitudes and long ranges.

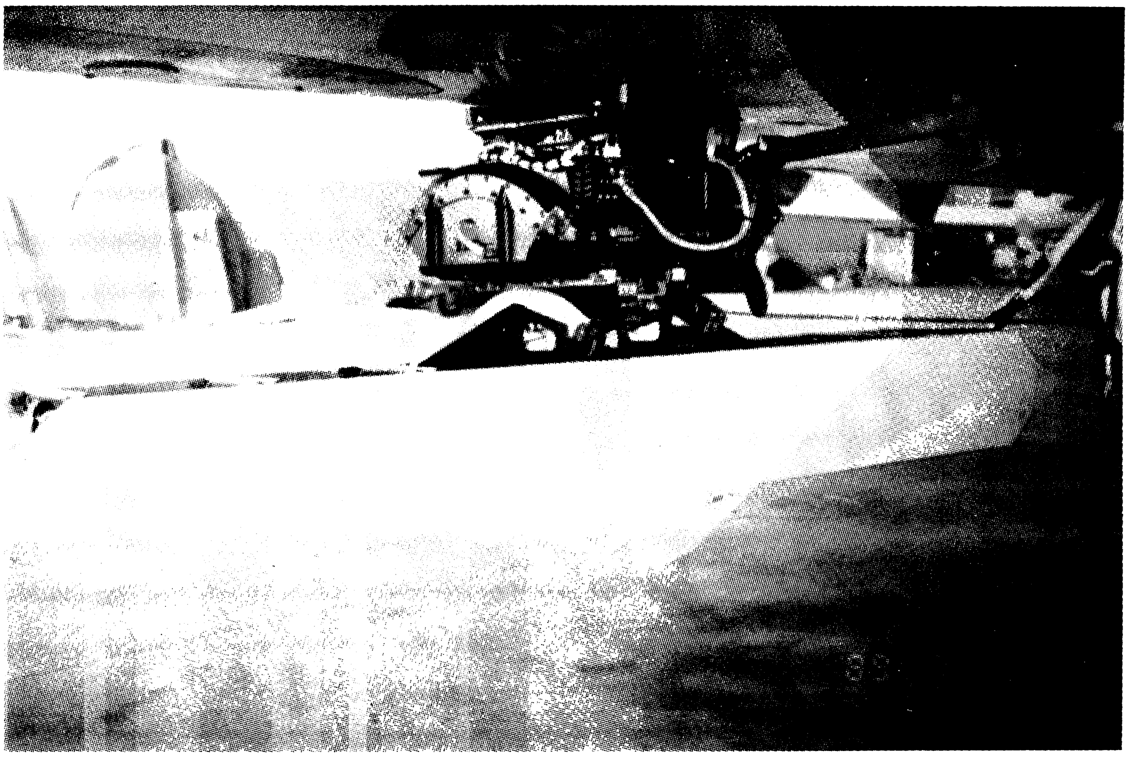


Figure 6.5 Side view of a dual-sided radar antenna. The physical length of this antenna is only one metre. Using SAR technology, it is possible to create the effect of having an antenna hundreds of metres long. (Courtesy of K.L. Link, Intera Technologies Ltd.)

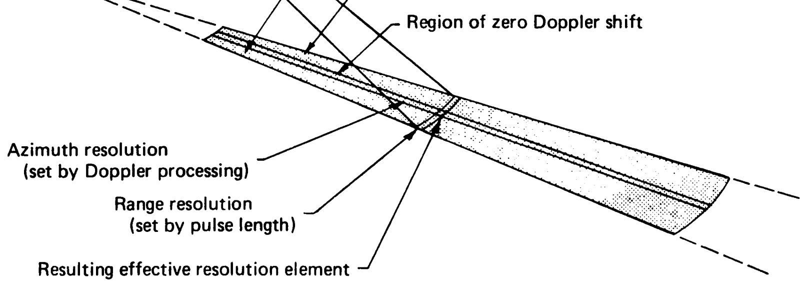


Figure 6.6 Determination of resolution in synthetic aperture radar systems. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 500, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

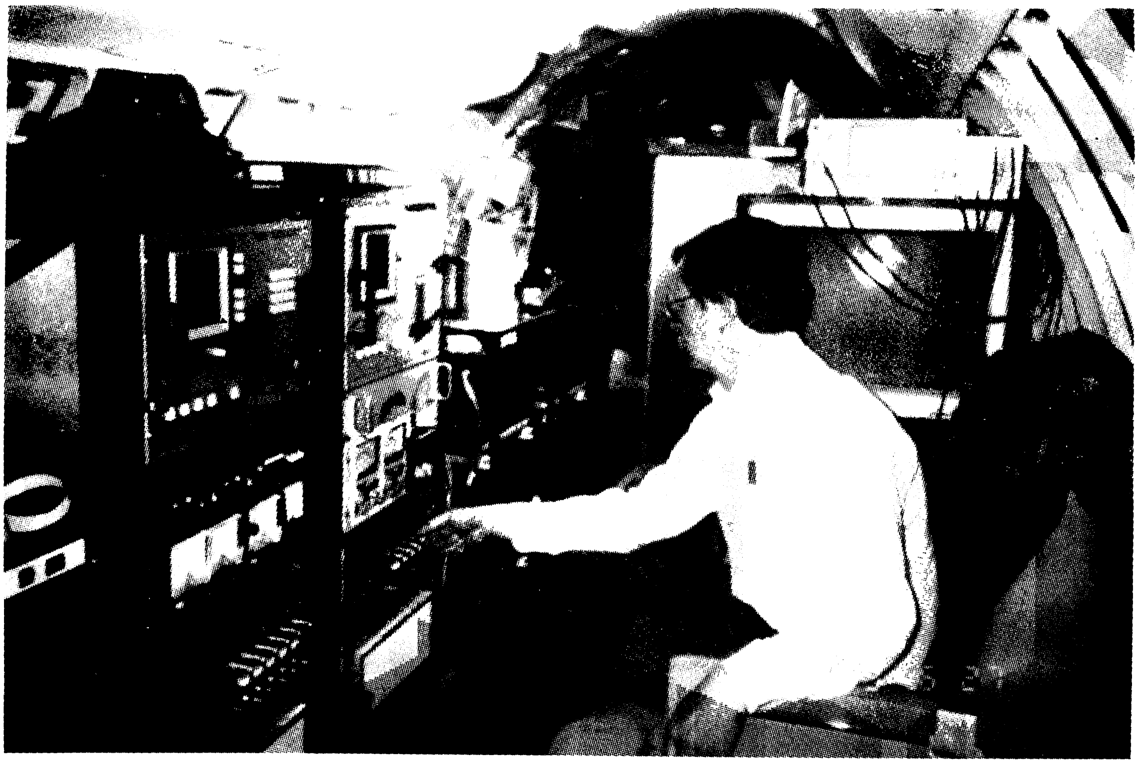


Figure 6.7 Operator at the controls of a SAR with real time, on-board digital processing. (Courtesy of K.L. Link, Intera Technologies Ltd.)

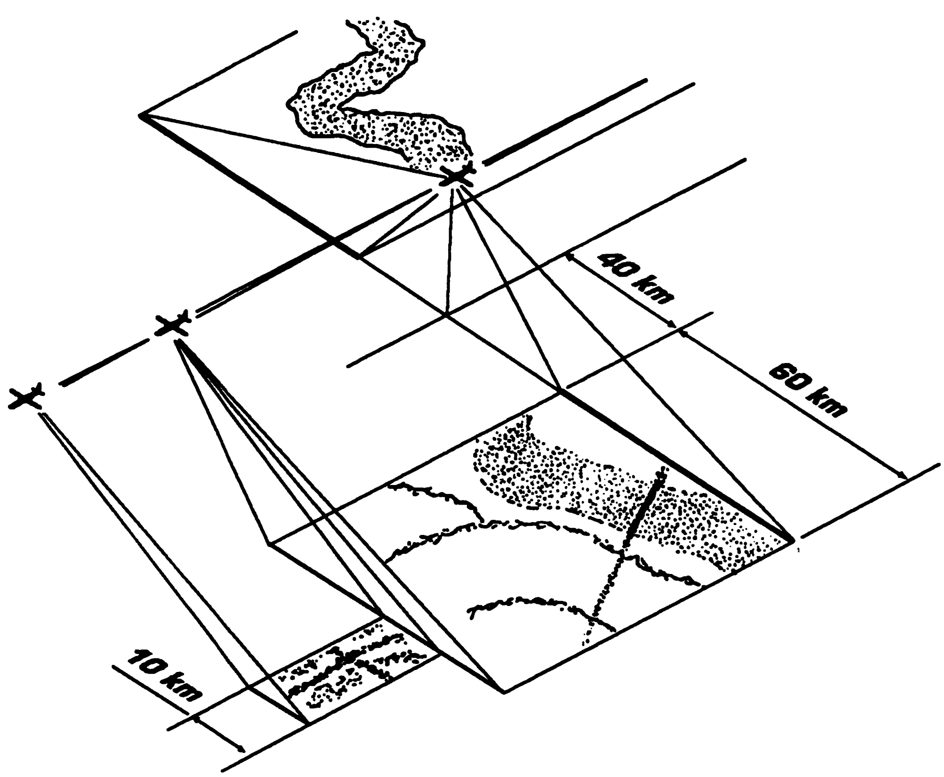


Figure 6.8 Modern stripmap SARs can operate in several modes: a wide-area mode for general surveillance and a high resolution mode for finer detail of smaller areas of interest. They can also be configured to provide a dual-sided capability to maximize the territory which can be imaged in one overpass. (Courtesy of MacDonald Dettwiler and Associates)

Early SAR systems recorded the data on a holographic signal film which was later processed using an optical processor which passed laser light through a signal film to expose the film to be used for interpretation. Current systems record and process the data digitally. Real time imagery may be produced on dry silver paper or the data can be downlinked to a ground receiving station. Figure 6.7 shows some of the electronic equipment which must be installed in an aircraft to operate a modern SAR.

Modern strip-map 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 (Figure 6.8). In addition to the traditional 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 increases the Doppler bandwidth of the signal in return for the reduced areal coverage. The greater bandwidth can be used to provide finer azimuth resolution or more speckle smoothing that could be achieved using a fixed antenna beam of equivalent size.[4] SAR systems can also be "squinted" to image an area obliquely ahead or behind the aircraft.[5]

c) *Moving Target Indication (MTI)*

Some SLAR systems can process imagery in a "moving target indication" (MTI) mode as well as the more conventional "fixed target" mode. Moving targets are distinguished by comparing successive radar signal returns. Each signal is amplified and delayed for a fraction of a second[6] so that it can pass through a phase comparator with the following signal (Figure 6.9). Imagery produced using MTI shows only the moving targets and must be used in combination with fixed target mode imagery to provide the background terrain information.

The minimum target size for motion detection is variable because size is inversely proportional to speed. For example, detected targets could include large trucks moving at 5 km/hr or bicyclists moving at 30 km/hr.[7] There is a minimum separation distance below which two targets will be indistinguishable from a single target on the imagery.[8] The size of this distance will depend upon the direction of travel of the targets, similar to how spatial resolution varies in the range and azimuth directions for imagery in the fixed target mode. The direction of radar illumination relative to major terrain features can also affect moving target detection. In rough terrain, targets along valley bottoms are more easily sensed when the direction of travel is perpendicular to the valley axis.[9]

Because of the limitations imposed by the minimum separation distance between moving targets, it may not be possible to use this technique to obtain an accurate count of the number of vehicles moving together in a line. However, the method would be appropriate to simply detect the presence of moving vehicles or to assess the relative traffic volume from one time to another using a multitemporal analysis.

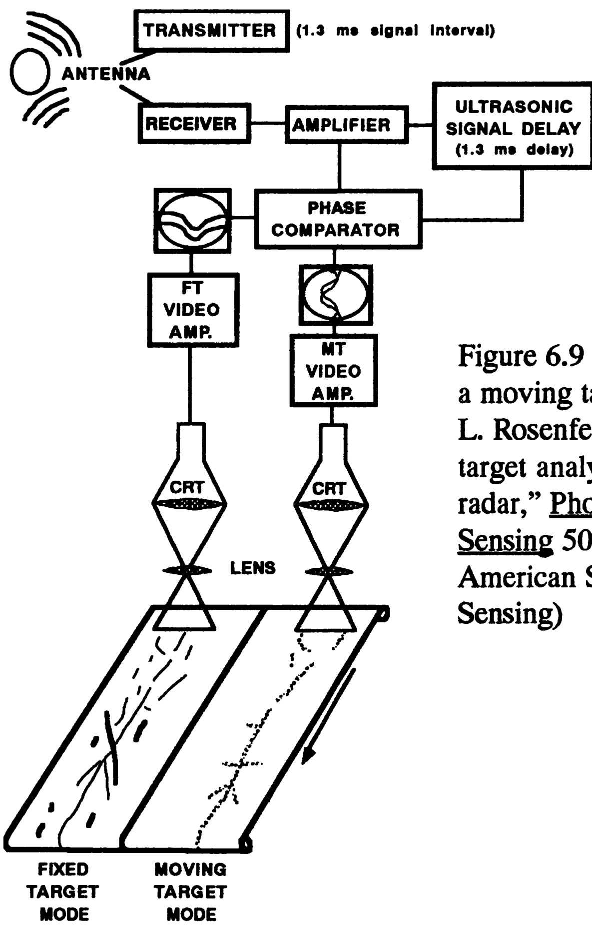


Figure 6.9 Architecture of a SLAR incorporating a moving target indicator. (Redrawn from Charles L. Rosenfeld and A. Jon Kimerling, "Moving target analysis utilizing side-looking airborne radar," Photogrammetric Engineering and Remote Sensing 50 (11), p. 1520, by permission of the American Society of Photogrammetry and Remote Sensing)

6.3 Radar image acquisition

An analysis of the weather characteristics of a target site will often be the primary consideration for the choice of a radar sensor for a reconnaissance mission. This is clearly a major consideration for areas where persistent cloud cover would make regular acquisition of imagery using other sensors almost impossible. Radars also have other features, such as day/night operation and moving target indication, which might also be suited to arms control verification requirements regardless of whether all-weather capability is important.

While the operational contraints 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 acquired when any form of visual navigation will be impossible because of cloud cover. Any aircraft intended as a SLAR platform must be equipped with the best navigation systems to operate successfully. If ground range correction is required, the height above ground level of the platform must be accurately recorded. The aircraft will need to be equipped with a precision altimeter providing a continuous flight record. Accurate topographic data for the area will also be required to provide information regarding the underlying terrain height.

Radar is an active system, generating microwave energy and directing it in a beam towards the ground. This energy can affect any ground radar receivers which may be oriented toward the aircraft. There have been occurrences of defence-related radar receivers suffering system shut downs for several minutes resulting from the microwave energy surge of a SLAR.[10] SLAR overflights of sites or exercises using radar receivers would need to be coordinated so that the normal functioning of ground equipment was not disrupted.

6.4 System and terrain effects

The tonal variations of radar imagery represent differences in strength of the signal returned from the illuminated terrain. The parameters determining the radar return include the signal characteristics of wavelength, polarization and incidence angle, and the terrain-related features of surface roughness and dielectric constant.

Surface roughness may have the largest influence upon the return signal. Whether a surface appears rough in a radar image depends upon a number of factors, such as the radar's wavelength and the incidence angle, as well as the physical roughness of the surface. Surfaces with micro-relief much less than a wavelength give rise to mirror-like, specular reflection and appear smooth. Rough surfaces lead to more diffuse reflection and have micro-relief on the order of a wavelength or more (Figure 6.10). The long wavelengths used by imaging radars cause more surfaces to act as specular reflectors than for imagery collected at optical wavelengths. Roads, roofs, storage tanks and the sides of buildings become specular reflectors when using a 3 centimetre wavelength. Forested areas and agricultural fields are typical diffuse reflectors.

The complex dielectric constant of a surface is a measure of its ability to absorb and propagate electromagnetic energy. It determines whether a radar return from a surface with a particular geometry will be weak or strong compared to surfaces with a similar geometry. The dielectric constant for a surface is greatly influenced by the moisture content. Most non-metallic surfaces have small dielectric constants when they are dry but become much better reflectors if they are wet. Metallic surfaces are typically very good radar reflectors.

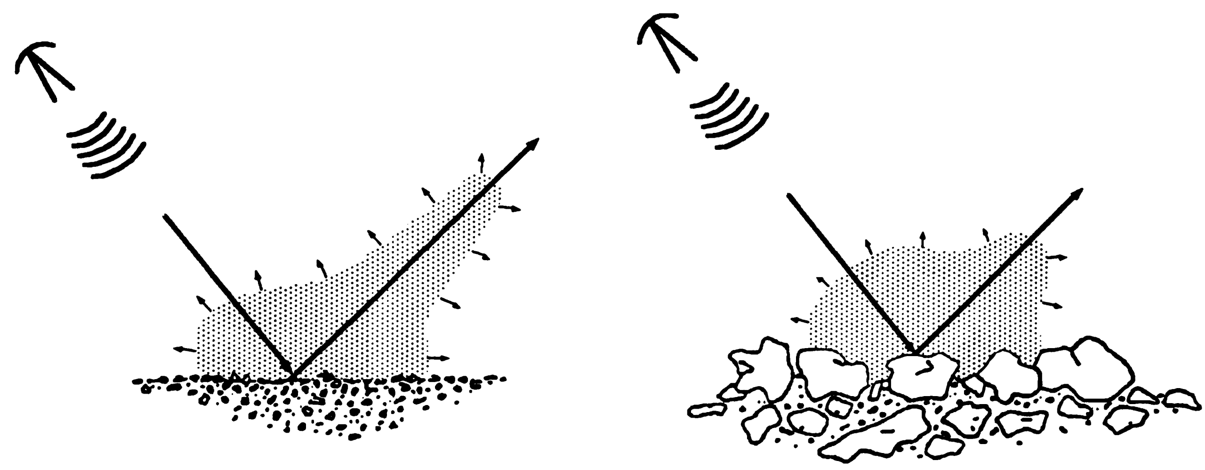


Figure 6.10 Radar backscatter for smooth and rough surfaces. Backscatter from a smooth surface will be characterized by a larger specular component. Backscatter from rough surfaces has a greater diffuse component with little specular reflection. (Redrawn from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 1145, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

The selection of wavelength for a radar affects the apparent roughness of the surface. Surfaces will appear rougher at short wavelengths and produce more diffuse returns, and smoother with more specular reflection at longer wavelengths. The same surface can appear smooth to a radar using longer wavelengths and rough to a shorter wavelength system. The wavelength of a radar also influences its capability to penetrate foliage. Longer wavelengths provide more effective penetration. Radar returns may come from objects or surfaces beneath the foliage. Using shorter wavelengths, the returns will be primarily from the vegetation canopy.[11]

Polarization refers to how a radar signal is transmitted and received. Radar signals can be transmitted or received in either a horizontal or vertical plane. Signals sent and received in the same plane are known as "like-polarized." Those sent and received in different planes are known as "cross-polarized." Radar returns are not influenced greatly by polarization if the terrain is rough. For smooth terrain, however, the influence of polarization becomes more apparent. Forest/non-forest boundaries and agricultural patterns are more distinguishable using like-polarized imagery.[12]

The angle of incidence is the angle formed by an impinging radar beam and a perpendicular to the imaged surface at the point of incidence.[13] In flat terrain, there is a continuous change of incidence angle across the imaged swath. The energy returned to the sensor is reduced as the angle of incidence is increased. If the beam were directed straight below, the amount of energy returned would be maximized. At near-grazing angles, most of the energy will be reflected away from the sensor. A surface may appear smoother at large incidence angles than at small incidence angles. The same surface, therefore, may appear different on overlapping coverage from adjacent flight lines.

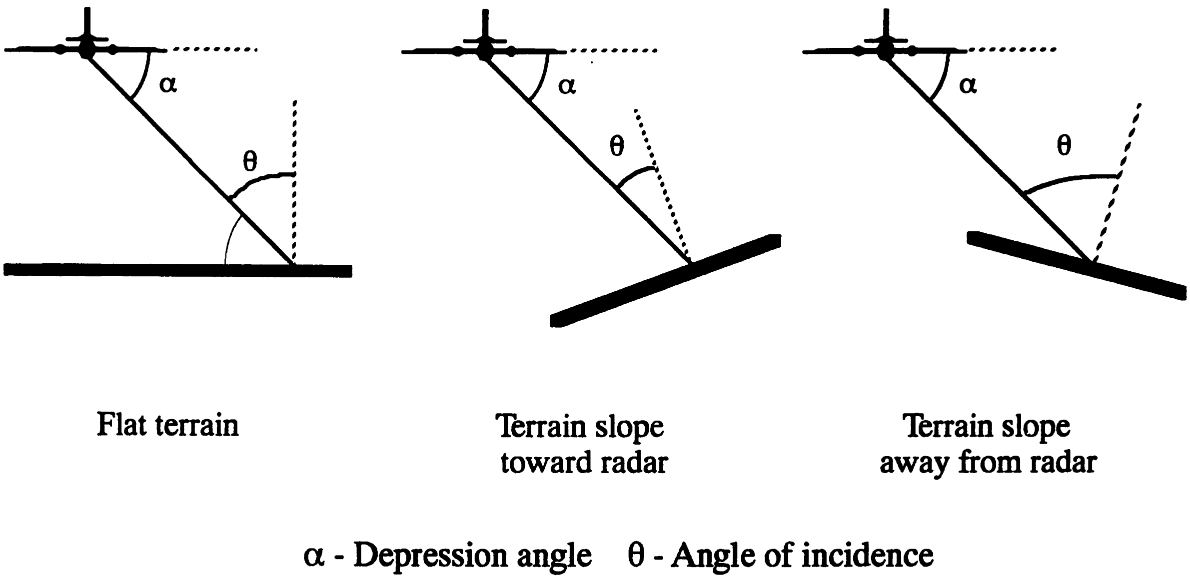


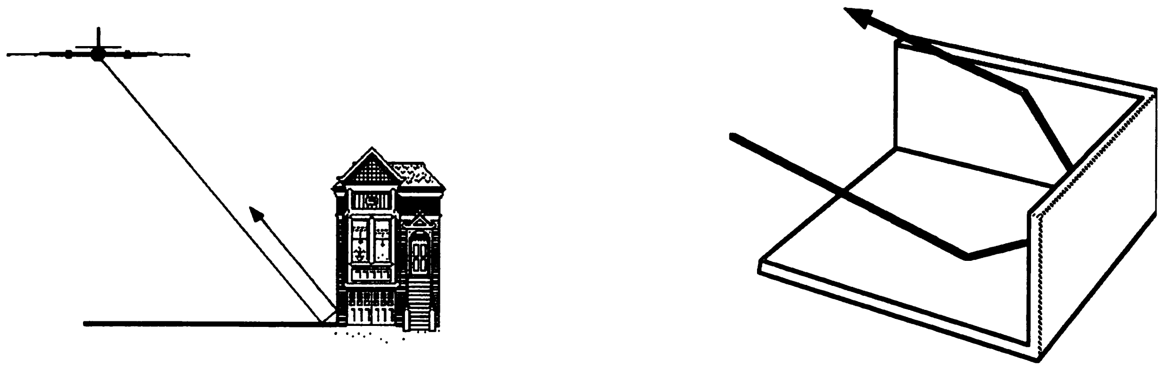
Figure 6.11 Effect of terrain slope on angle of incidence with depression angle kept constant. (Adapted from Anthony J. Lewis and Harold C. MacDonald, "Imaging radars: operation, characteristics and limitations," p. 24, by permission of Anthony Lewis)

Variations in terrain slope will also cause variations in the incidence angle (Figure 6.11). Similar surfaces can appear quite different on radar imagery depending upon their relative slopes. Terrain sloping towards the radar reduces the incidence angle and increases the energy reflected back to the sensor. Terrain sloping away from the radar increases the incidence angle, reducing reflection back to the sensor.

Strong specular reflections occur, regardless of the angle of incidence, if corner reflectors are illuminated by the radar (Figure 6.12). A dihedral corner reflector is created when two surfaces lie perpendicular to each other and in the same plane as the sensor. A trihedral corner reflector occurs when three surfaces are perpendicular to each other.

Many objects associated with human activity act as corner reflectors. Telephone poles are usually imaged clearly because regardless of the direction from which they are illuminated, a strip along the full length of the pole will form a corner reflector with the ground. Military vehicles may include many corner reflectors such as armoured vehicle tracks, air intakes and antenna mountings.[14] Many corner reflectors, including aircraft, ground vehicles and ships, buildings and perimeter fences, are evident as bright returns in Figures 6.15 and 6.16 in Section 6.6.

The orientation of objects in the target scene relative to the aircraft's direction of flight strongly influences their appearance on the resulting imagery. For example, a group of aircraft on a tarmac may appear quite different when imaged from varying perspectives. The sides of buildings form dihedral corner reflectors with the adjacent ground. Radar imagery of urban centres with a rectangular street pattern will be



Dihedral corner reflector　　　　Trihedral corner reflector

Figure 6.12 Structure of dihedral and trihedral corner reflectors. (Adapted from L.C. Graham, "Exploitation of Synthetic Aperture Radar Imagery," Aerial Reconnaissance Systems: Pods and Aircraft, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 9, p. 110-111, © 1976 by the Society of Photo-Optical Instrumentation Engineers (SPIE), by permission of SPIE)

saturated by strong returns from the sides of buildings if the aircraft's flight orientation during the image acquisition is parallel to that of the street grid. For this reason, flight lines for overflights of urban areas should be oriented so that they are not parallel to the street pattern.

6.5 Geometric characteristics

Radar images are characterized by geometric distortions arising from the image formation process: foreshortening, layover and shadowing. The distortions are most apparent in areas of uneven terrain. Figure 6.13 illustrates the geometric factors involved in each case.

Foreshortening refers to variations in the length of terrain slopes as depicted in radar imagery. The appearance of a slope is determined by the length of time that it is illuminated. Slopes facing the radar appear shorter on the image than those facing away since they are illuminated for a shorter period. The amount of foreshortening is a function of the incidence angle as well as the actual slope of the terrain. Similar slopes will have different lengths if they are at different positions across the illuminated swath of the radar (Figure 6.13). The same terrain feature will have different slope lengths in overlapping radar images acquired from different flight paths.

Foreshortening influences the ability to interpret imagery in areas of severe relief. The effects of foreshortening can increase the total energy returning to the receiver to

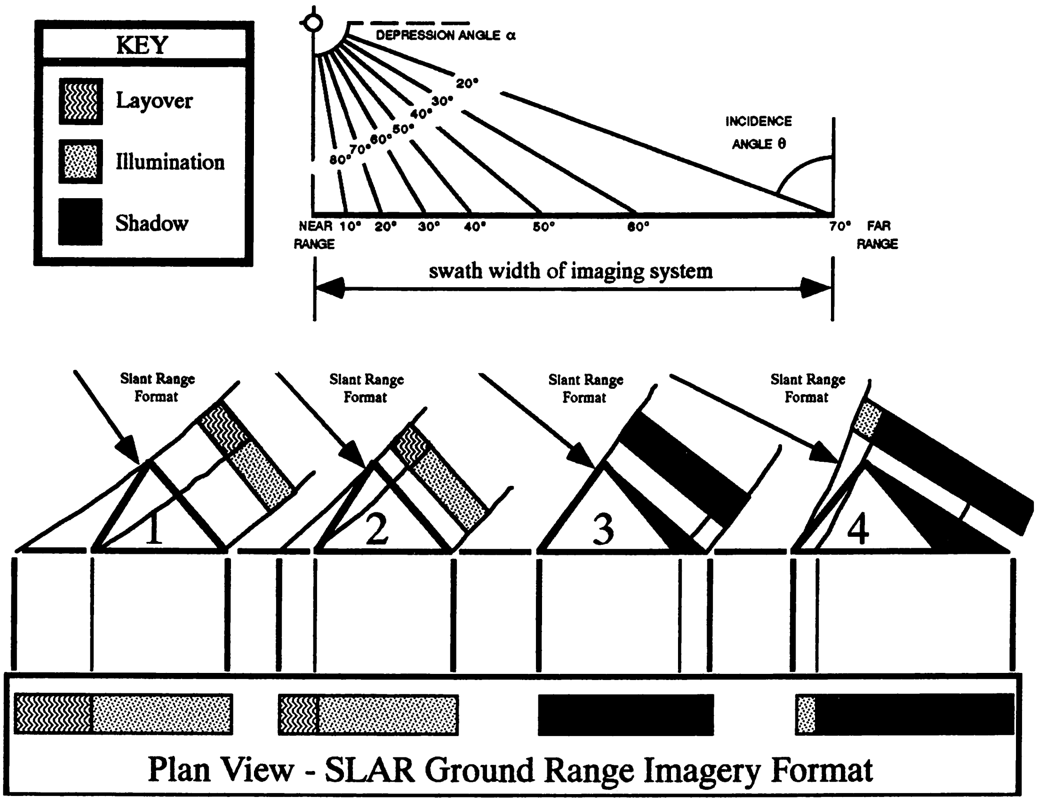


Figure 6.13 Dependence of layover, illumination and shadow on depression angle. If the base of a feature is imaged before the top, the slope appears compressed or foreshortened (4). Layover is an extreme case of foreshortening in which the wave front reaches the top of the feature before the bottom and, therefore, the top is recorded in a nearer range location than the bottom (1 and 2). In the near range (1 and 2) the backslope of an object may be illuminated. In the far range (3 and 4), the same backslope may give no return at all and illumination of adjacent areas may be blocked as well (4). (Redrawn from Modern Geology with permission from Gordon and Breach Science Publishers, Inc.)

the point that it becomes saturated. Near slopes are compressed, making it difficult to discriminate spatial detail. Back slopes are characterized by a fall-off of return energy, with a loss of information as grazing incidence is approached.[15]

Layover is an extreme case of foreshortening which primarily occurs in the near range of radar images in mountainous terrain. It is similar to the relief displacement found in aerial photographs, but in the opposite direction. The tops of features appear to "lean" toward the sensor rather than away from it. This occurs because radar pulses reach the top of the feature before the base and, therefore, return pulses are received from the top before the base. Layover occurs only on slopes facing the radar, rendering the layed-over foreslopes virtually uninterpretable on the imagery.[16]

Shadows in aerial photographs are determined by the positions of the camera and sun relative to objects within the camera's field of view. Radar shadows always occur on the far side from the source of the transmitted radar signal, whenever the terrain

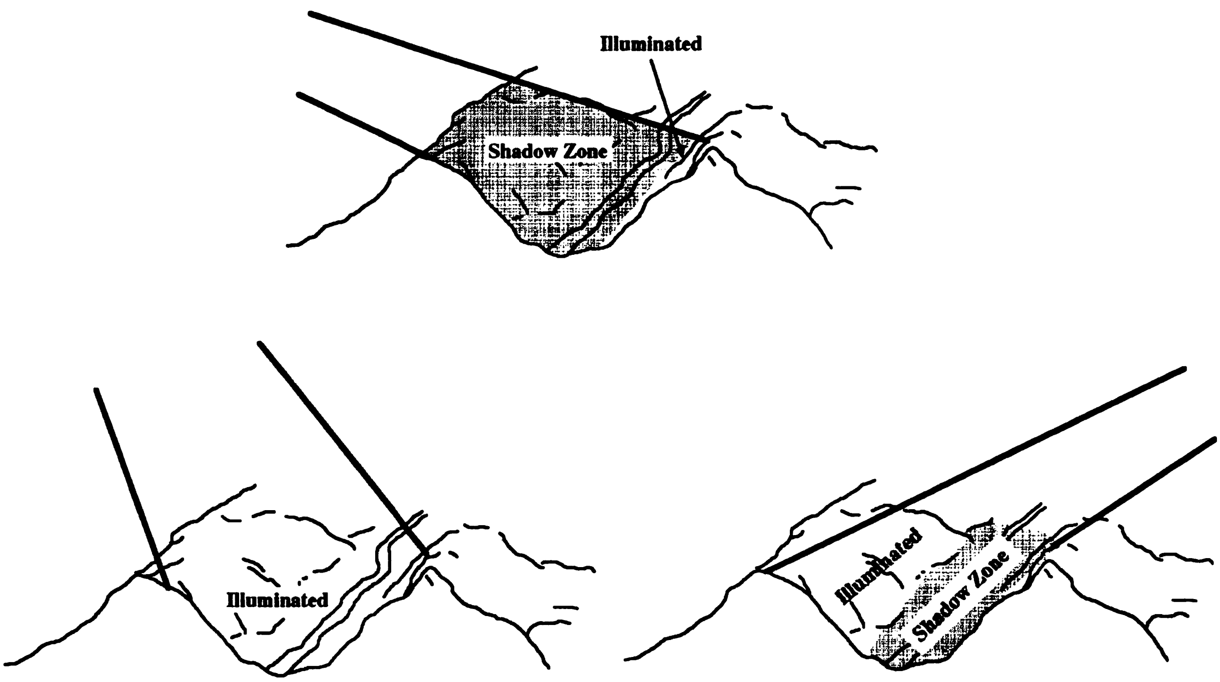


Figure 6.14 Reducing losses of information by radar shadow using overlapping coverage with (a) a steeper depression angle or (b) a different look direction. (Redrawn from L.F. Dellwig et al., "A Demonstration and Evaluation of the Utilization of Side Looking Airborne Radar for Military Terrain Analysis," p. B-8, by permission of U.S. Army Engineer Topographic Laboratories)

backslope exceeds the depression angle. Shadowing of features of equal relief will be greatest in the far range as the depression angle decreases. The far slopes of similar features may be fully illuminated in the near range but in complete shadow in the far range. Diffuse illumination in the shadowed areas of aerial photographs sometimes allows some details to be discerned. Radar shadows are entirely "black" with no contained detail whatsoever. Unlike aerial photographs, however, the illuminant can be controlled. Through careful flight planning, it is possible to ensure that detail lost because of shadow in one overpass can be obtained in another overpass. The second overpass can provide the radar with an unobstructed view through a change in the depression angle or in the look direction (Figure 6.14).

6.6 Interpreting radar imagery

To the uninitiated, radar imagery may appear very similar to black and white aerial photographs. However, the physical reasons for tones, textures and other features in radar images may be radically different than for images taken by cameras operating in the visual portion of the spectrum. The final format of radar images may be visual, but the data are not. Interpreters of radar imagery must learn to "think radar."[17]

Figure 6.15 A radar image of an airfield. The image was acquired using a synthetic aperture radar with 3 metre x 3 metre resolution. The image is characterized by speckly overall appearance with bright "hard targets," such as the aircraft on the tarmac (a). Perimeter fences are detectable as bright lines (b), particularly if they run parallel to the line of flight. The asphalt runway and river (on the right) are areas of low returns, and therefore appear dark. (Courtesy of Intera Technologies Ltd.)

Figure 6.15 is a radar image of a military airfield. Figure 6.16 shows some tethered destroyers in the water and typical cultural features on the land. Figure 6.15 was acquired using an X-band (3 centimetre) SAR with 3 metre resolution in the range and azimuth directions and from an operating altitude of 10,000 metres. Figure 6.16 was acquired using a 6 x 6 metre resolution X-band SAR.

One of the first aspects of the image which an uninitiated interpreter will notice is the speckle. Even homogeneous areas, such as agricultural fields, appear speckled in radar imagery. The radar antenna transmits minor pulses together with the major pulses. Some of the minor pulses enhance the backscatter of the major pulse while others suppress it, leading to speckle in the imagery. Speckle can be reduced by smoothing or combining several independent "looks." However, these techniques also reduce spatial resolution so speckle is simply tolerated by many users of radar imagery.[18]

Figure 6.16 The tethered destroyers evident as bright returns near the bottom of this radar image are plainly visible but not necessarily easy to identify. Many common cultural features, such as roads, an airport, and housing subdivisions, are evident. The flight line was oriented parallel to the lengths of the ships to maximize the return from them. (Courtesy of Intera Technologies Ltd.)

A radar may be able to detect objects even though they are physically smaller than the radar's resolution. Small, but highly reflective, hard targets in an open area often become the dominant reflector for a resolution cell. The composite reflectance of the hard target and its surroundings are recorded as a single bright target.

Detection might often be no problem but identification will only be possible by its relationship with other features in the scene. Hard targets, such as the aircraft seen as bright "blobs" on the runway in Figure 6.15 or destroyers in Figure 6.16, are good examples. Although the bright returns are plainly visible, the shapes are not discernible and the identification must be based primarily upon indirect cues such as their location and how they are arranged. Shape information is lost because of resolution limitations of the radars and microwave reflection properties of the targets.[19]

Although state-of-the-art digital SAR systems are capable of resolutions as low as 1 metre,[20] the imagery is still not good enough, in practical terms, for detailed identification of vehicles.[21] It is possible for military airborne surveillance radars to detect and track moving and static targets in heavy ground clutter and distinguish between wheeled and tracked vehicles.[22]

Advanced concepts aimed at improving the spatial detail achievable using airborne radars include spotlight mode operation and inverse SAR. A SAR featuring spotlight mode allows the radar beam to dwell upon a target as the aircraft passes to improve the achievable resolution.[23] Inverse SAR uses the pitching, rolling and yawing motions of a ship at sea to generate a two-dimensional profile image of the vessel, facilitating their identification.[24]

Notes to Chapter VI

1 See also Section 1.1.

2 Dellwig, Louis F., Bradford C. Hanson, Norman E. Hardy, Julian C. Holtzman and Paul L. Hulen. 1976. "A demonstration and evaluation of the utilization of side looking airborne radar for military terrain analysis." University of Kansas Center for Research, Inc. Lawrence Remote Sensing Lab. Rept. RSL-TR-288-1; ETL-0023. p. 3.

3 "SLAR" is often used to refer only to real aperture radars and "SAR" to synthetic aperture radars although both types are actually side-looking radars.

4 Ausherman, Dale A. 1985. "SAR digital image-formation processing." Digital Image Processing. Proceedings of SPIE - The International Society for Optical Engineering. Vol. 528. p. 118. January 22-23, 1985. Los Angeles, California.

5 Sweetman, Bill. 1987. "Airborne reconnaissance radars — US synthetic aperture radar developments." International Defense Review 20(9): 1183-1191.

6 Rosenfeld and Kimerling (1977) quote a delay of 1.3 milliseconds for the U.S. AN/APS-94C SLAR, used in the OV-1B (Mohawk) reconnaissance aircraft. (p. 1520.)

7 Rosenfeld, Charles L. and A. Jon Kimerling. 1977. "Moving Target Analysis Utilizing Side-Looking Airborne Radar." Photogrammetric Engineering and Remote Sensing 43(12):1519-1522.

8 Rosenfeld and Kimerling (1977) quote a minimum distance of 80 metres for the AN/APS-94C (p. 1521.)

9 Rosenfeld and Kimerling (1977). op.cit. p. 1521.

10 Trevett, J.W. 1986. Imaging Radar for Resources Surveys. Chapman and Hall Ltd. New York, NY. p. 97.

11 Lewis, Anthony J. and Harold C. MacDonald. 1981. "Imaging radars: operation, characteristics and limitations." Proceedings from the First Columbian Symposium on Remote Sensing. University of North Dakota Institute for Remote Sensing. Grand Forks, North Dakota. p. 25.

12 Maffi, C.E. 1982. "Side-looking airborne radar (SLAR)" IN: Geological Interpretation of Aerial Photographs and Satellite Images. Workshop Course 210/82, Section B. Adelaide, Australia. p. 14.

13 A related angle, the depression angle (α), is the angle between a line from the transmitter to a point on the terrain and a horizontal plane passing through the transmitter.

14 Anon. 1986. "Measuring radar reflectivity using scale models." International Defense Review. 19(3):378.

15 Simonett, David S. and Robert E. Davis. (authors) "Image Analysis - Active Microwave." Chapter 25. IN: Colwell, Robert N. 1983. Manual of Remote Sensing. op. cit. p. 1127.

16 *ibid*. p. 1128.

17 Dellwig, Louis F., Bradford C. Hanson, Norman E. Hardy, Julian C. Holtzman and Paul L. Hulen. 1976. "A demonstration and evaluation of the utilization of side looking airborne radar for military terrain analysis." University of Kansas Center for Research, Inc. Lawrence Remote Sensing Lab. Rept. RSL-TR-288-1; ETL-0023. p. G-12.

18 Curran, P.J. 1985. "Aerial sensor imagery." Chapter 4. IN: Principles of Remote Sensing. Longman Group Ltd. Harlow, England. p. 126.

19 Henderson, Floyd M. and James W. Merchant. 1983. "Microwave Remote Sensing." Chapter 9. IN: Benjamin F. Richason, Jr. (ed.) Introduction to Remote Sensing of the Environment. 2nd Edition. Kendall/Hunt Publishing

Company. Dubuque, Iowa. p. 210.
[20] Wanstall, Brian and Ramon Lopez. 1987. "Second echelon surveillance: Stand-off radars to even battlefield odds." Interavia 11/1987. p.1154; Anon. 1987. "UK strives for improved SAR information extraction." International Defense Review 20(9):1186.
[21] *Ibid*., p. 1187.
[22] Wanstall and Lopez, 1987. op. cit. p.1152; Turbé, Gérard. 1987. "The Orchidée battlefield surveillance system" International Defense Review 20(9):1187.
[23] Sweetman, Bill. 1987. "US synthetic aperture radar developments." International Defense Review 20(9):1183.
[24] Klass, Philip J. 1987. "Inverse synthetic aperture technology aids radar identification of ships." Aviation Week & Space Technology 127(10):88-89.

CHAPTER VII

IMAGE 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 aerial imagery. It also necessarily involves a selection process whereby the interpretive effort is concentrated on those features in the imagery which are most relevant to the task at hand. Therefore, the interpretation of remotely sensed images requires an understanding of two distinct bodies of knowledge:

- knowledge of the technology and methods used to collect, process and analyse remotely sensed imagery, and
- knowledge of the subject area of interest; in this case, the equipment and activities of armed forces relating to a particular arms control agreement.

The technical aspects of image interpretation presented here must be distinguished from another kind of "interpretation" which is central to arms control verification. This is the "interpretation" required to assess whether the evidence collected from various sources indicates that the provisions of a particular treaty have been observed or not. Technical analysis, using many data sources, is only one of the inputs to this policy level "interpretation." While the results of monitoring usually play a major role in the formulation of compliance decisions, there are also legal, military and political dimensions which are also considered.[1] The policy level "interpretation" related to arms control compliance is beyond the scope of this document and will not be discussed in depth.

7.1 Interpretive elements

Interpretation of remotely sensed imagery, whether by a human interpreter or using a computer-based image analysis system, is founded upon the basic elements of tone or colour, size, shape, texture, pattern, height, shadow, site and association.[2]

The most fundamental property of an image is the <u>tone</u> or <u>colour</u>. Almost invariably, differences in tone or colour between objects or between an object and its background are required for interpretation.[3] The other elements (Figure 7.1) are products, with varying degrees of complexity, of these two basic elements.

<u>Size</u> and <u>shape</u> represent geometric arrangements of the tone or colour of pixels of

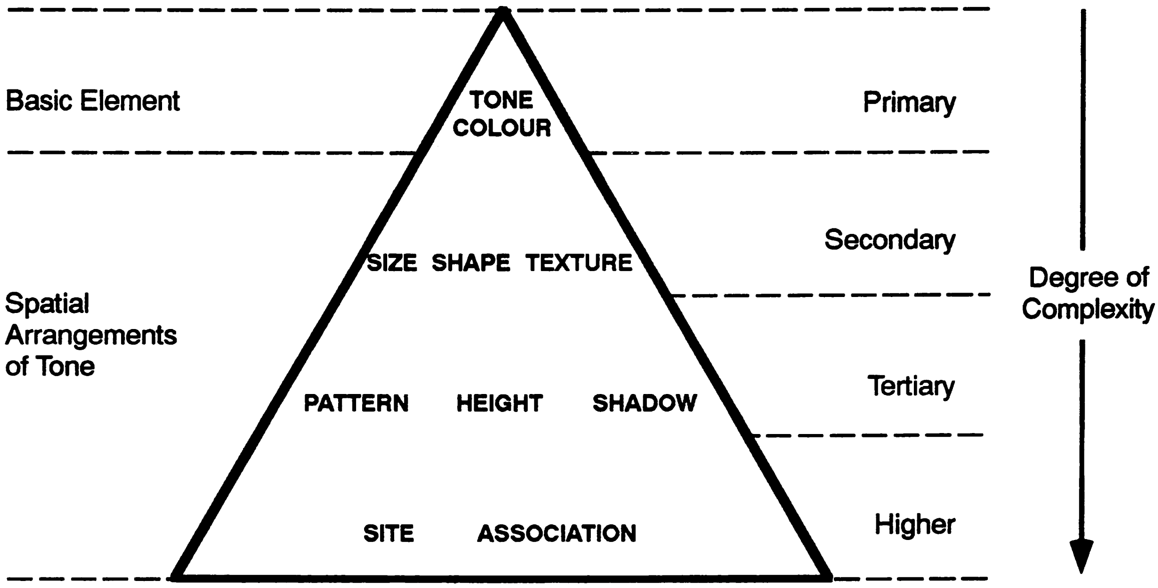


Figure 7.1 Hierarchical relationship of the basic interpretation elements. Tone or colour is the primary element. Spatial arrangements of tone or colour produce elements of various levels of complexity. (Redrawn from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 994, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

objects in an image. The absolute size is not always required to identify features in an image. For example, if a truck is identifiable in the image whose dimensions are known, the size of a nearby object can be determined by comparison. The shape of some objects is sufficiently distinctive that they can be identified on the basis of this criterion alone. Man-made features are often characterized by straight lines and regular geometric shapes. Natural objects, such as vegetation, usually have irregular shapes. One objective of camouflage is usually to break up the outline of an object's shape, making straight edges less apparent to reduce the chances of detection.

Texture, the impression of "roughness" or "smoothness," is the result of tonal repetitions within an object or within object groups which are too small to be discerned separately. The size of objects required to produce texture depends upon the image scale. Trees are visible as individual objects in large-scale photographs while the leaves contribute to the texture. At smaller scales, the trees as a whole contribute to the textures of forest stands. Texture is particularly important for the interpretation of radar imagery.

Pattern is characteristic of many man-made and some natural phenomena. As with shape, man-made patterns are usually more regular than natural patterns. Aerial photographs can reveal small, but possibly important, patterns which would be missed entirely by an observer on the ground. The interpretation of pattern requires an analyst to integrate, to some degree, a number of lower order elements such as size or shape. It is a very scale-dependent feature. What appears as a pattern at one scale will often appear as a texture at a smaller scale.

The perception of height and three-dimensional shape provided by stereo pairs of imagery might be next only to tone and colour in terms of importance to the interpretation of an image. Stereoscopic viewing of images will be discussed in greater depth in Section 7.2.

Shadows can help or hinder the interpreter. Silhouettes provide side-profiles which may reveal important details regarding objects which cannot be interpreted directly from the image of the object itself. For example, although a new bridge might be easily identifiable in an image, a shadow profile might enable an interpreter to identify the exact type of the bridge. Shadows are particularly helpful if the objects are very small or lack tonal contrast with their surroundings.[4]

Shadows can also hide important detail. Under natural lighting conditions, some detail might still be available in the shadows because of illumination from the sky. Aerial photography can be acquired under evenly overcast conditions to produce "shadowless photographs" to provide low-contrast imagery with minimal loss of detail. Shadows resulting from artificial illumination, as in the case of radar shadow, usually result in a complete loss of detail.

Site and association represent higher order image elements. Understanding site requirements for an object can be useful to narrow down possible interpretations or reduce the number of locations which must be investigated. Airports are the place to look for military aircraft. Association is one of the most helpful clues to the identity of man-made features. Military installations often have associated security measures such as perimeter fencing which provide indications that the contained buildings are not being used for civilian purposes. Association requires that the interpreter make a number of intermediate labelling decisions before an overall identification is reached.

7.2 Manual analysis

Manual interpretation techniques, using human interpreters with the required 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.

a) *Analysis procedures*

Even familiar objects may be difficult to recognize the first time they are viewed from an aerial perspective. The ability to interpret overhead imagery is an acquired skill. Much of the training of photo interpreters is directed at developing their "vertical perspective" to enable them to quickly and easily recognize objects seen from above. Once an analyst's skills have been developed, the overhead perspective can provide crucial indications of the structure, composition and functions of objects in the image. To an expert interpreter, a vertical photo of an industrial site may be as useful as actually being there.

To identify unknown objects, or to understand their meaning and importance once they have been identified, an interpreter must use convergence of evidence.[5] Few things are perfectly certain in photo interpretation. There may be many clues to help identify an unknown object or to indicate the presence of hidden objects. The clues could be subtle and indirect, such as vehicle tracks leading into what appears to be an impenetrable swamp. None of the signs may be conclusive on their own, but when considered together, it may provide a good indication of what is happening there. Several interpretations may suggest themselves, but examination of all the evidence will usually reduce the possibilities.

Manual interpretation of imagery can be a time-consuming and laborious task. Interpreters should work methodically, from general considerations to specific detail and from the known to the unknown.[6] Although it may be tempting to exhaustively analyse every available image to ensure that "no stone has been left unturned," it is usually not necessary or wise. A selective approach, focussing primarily upon those areas and images which are most likely to contain relevant information and disregarding those which are unlikely to be significant, makes more effective use of an interpreter's time and skills. This approach, the logical search,[7] involves a quick initial scan followed by intensive study of smaller areas. The time required for careful study relative to that spent rapidly scanning will depend upon the nature of the work. In some cases, most of the area will require no more than a cursory glance whereas, in other cases, it may be important to look over the entire area carefully.

Part of an interpreter's task in analysing images related to multilateral arms control verification will involve counting individual objects, such as tanks or barracks. The ability to distinguish and count the objects of interest is obviously important. Some objects are harder to count than others, depending upon several factors, including[8]

- size and shape of the objects
- scale and resolution of the imagery
- spatial arrangement of the objects
- contrast between the objects and backgrounds
- type of film or sensor
- use of stereo imagery

b) *Stereoscopic viewing*

Stereoscopic analysis is one of the most important tools for the analysis of remotely sensed imagery. Although most sensor systems can be used to acquire stereoscopic images, vertical aerial photographs are most commonly used. An interpreter can visually create a stereoscopic, or three-dimensional, model of the imaged terrain using overlapping images. By using a stereoscopic model, it becomes possible for the interpreter to measure the height of objects in the imagery.

An interpreter sees the stereomodel in three dimensions through the perception of parallax. Individuals have varying depth perception capabilities, called "stereoscopic acuity." An average person can perceive angles of parallax of two seconds or more.[9] An interpreter does not require perfect vision to see stereoscopically but should have approximately equal vision in both eyes.[10]

Vertical relief will appear exaggerated in height by about three or four times using vertical photographs with the usual 60 percent forward overlap.[11] The vertical exaggeration of a pair of photographs is determined by the geometric conditions under which the photos were taken and viewed. The ratio of the ground distance between the two exposure points for the photos, referred to as the air base, and the flying height is used as a measure of vertical exaggeration. A larger base-height ratio provides more vertical exaggeration. Because of vertical exaggeration, a photo interpreter is able to measure the heights of objects which could not be seen by an observer in the plane during the overflight.

c) *Interpretation aids*

Collateral materials consist of additional information collected to assist in the interpretation process. These might include relevant literature, maps, statistical data, laboratory measurements and many others. Collateral data serves a dual role in the interpretation process: first, it assists in the analysis of the imagery and second, it is used to provide verification of the image interpretation.

Interpretation keys help the interpreter evaluate the image information in an organized and consistent manner. They provide guidance for the identification of relevant features which may be encountered by the interpreter. The keys will often include imagery or graphical illustrations to describe the distinctive characteristics to be looked for.

A key may be organized for identification by selection or by elimination. A selective key describes or illustrates classes of objects or phenomena. An interpreter chooses the example which most closely resembles the unknown item in the photograph being studied. Figure 7.2 is an example of a selective key which uses illustrations to assist in the identification of major types of naval vessels. An elimination key works

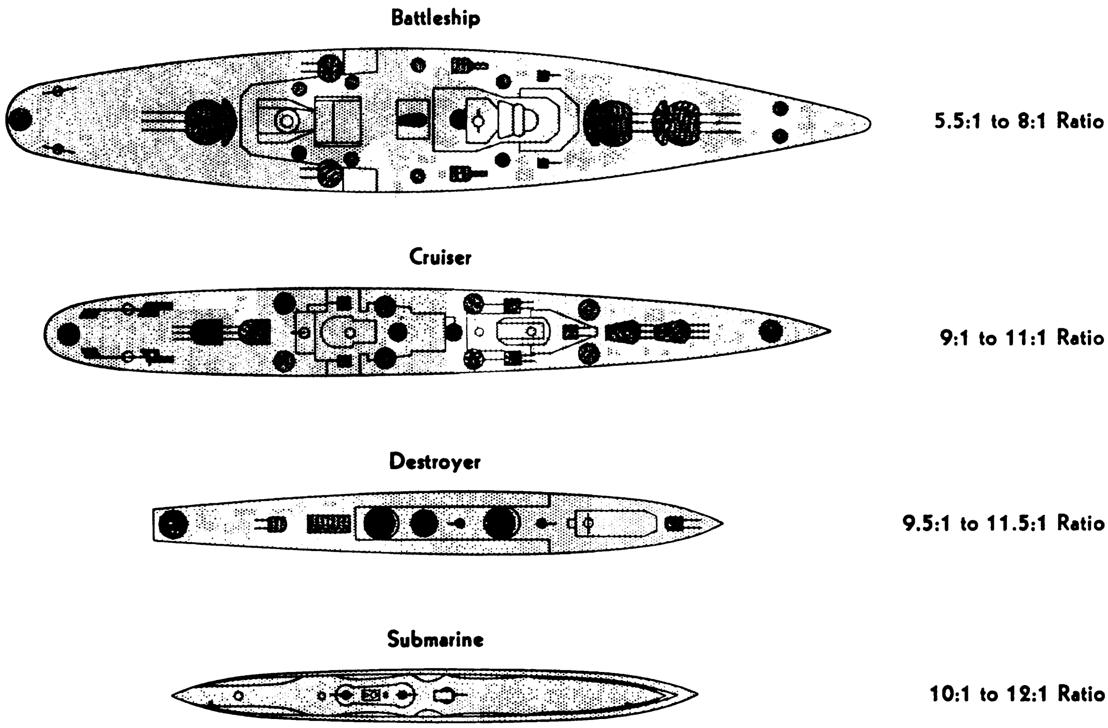


Figure 7.2 Example of a selective interpretation key to distinguish four general types of naval vessels. The numbers indicate length-to-beam ratios for each type, a useful means of identification. The illustrations provide other identification clues including relative size and hull shape, number and positions of gun turrets, masts and stacks, type of superstructure and the presence of aircraft-launching catapults. (Reprinted from Eugene T. Avery, Interpretation of Aerial Photographs, Second Edition, p. 303, © 1968 by Burgess Publishing Company. Courtesy of U.S. Navy.)

in a step-by-step manner, guiding the interpreter through a series of progressively more specific choices, eventually leading to the elimination of all possibilities except one. Table 7.1 shows a portion of a dichotomous elimination key for the identification of U.S. naval vessels. Most interpreters prefer elimination keys.[12] They can lead to more positive answers than selective keys, but can also lead to mistaken interpretations if the interpreter is forced to make an uncertain choice between unfamiliar features.

A key should be suited to the purpose of the interpretation and to the abilities of the interpreters who will be using the key. It may be necessary to identify specific features of military equipment which are covered under the terms of an agreement or it may be sufficient to label broad categories of equipment or facilities. Keys might apply primarily to a specific region or to particular categories of equipment. A key which assumes extensive knowledge regarding a particular subject might be of little use to an interpreter in training.

TABLE 7.1

Sample portion of a dichotomous elimination key for identifying naval vessels.

A. Flight deck	See B
A. No flight deck	See D
B. Flight deck has no taper aft (square end); 1 large gun tube forward of flight deck; both forward and aft aircraft elevators square	CVE Commencement Bay
B. Flight deck has slight taper aft; no large gun tube forward of flight deck; either forward or aft aircraft elevator rectangular	See C
C. 1 large gun tube aft of flight deck (only half visible on vertical photos); aft aircraft elevator square	CVE Casablanca
C. 2 large gun tubes aft of flight deck; aft aircraft elevator rectangular	CVE Bogue
D. Wide beam in relation to length; pyramidal superstructure	BB South Dakota
D. Narrow beam in relation to length	See E
E. 3 main turrets - 2 forward, 1 aft	See F
E. 5, 4, 2, or no main turrets	See I

Source: U.S. Department of the Navy, reprinted in Eugene T. Avery, 1968. Interpretation of Aerial Photographs. Burgess Publishing Company. Minneapolis, Minn., p. 303.

d) *Interpretation equipment*

Interpretation can be done from paper prints or film transparencies. Paper prints are more convenient to use, more easily annotated and can be easily transported. Transparencies provide better spatial resolution and colour fidelity. Transparencies must be viewed on a light table which supplies light of a suitable brightness and "colour temperature."

Equipment for manual image analysis are used for three main purposes: image viewing, measuring and transfer of detail. Instruments are available to work with stereo imagery or with single (monoscopic) images.

The stereoscope, which facilitates three-dimensional viewing of stereo images, is the most fundamental interpretation instrument. Stereo viewing without the assistance

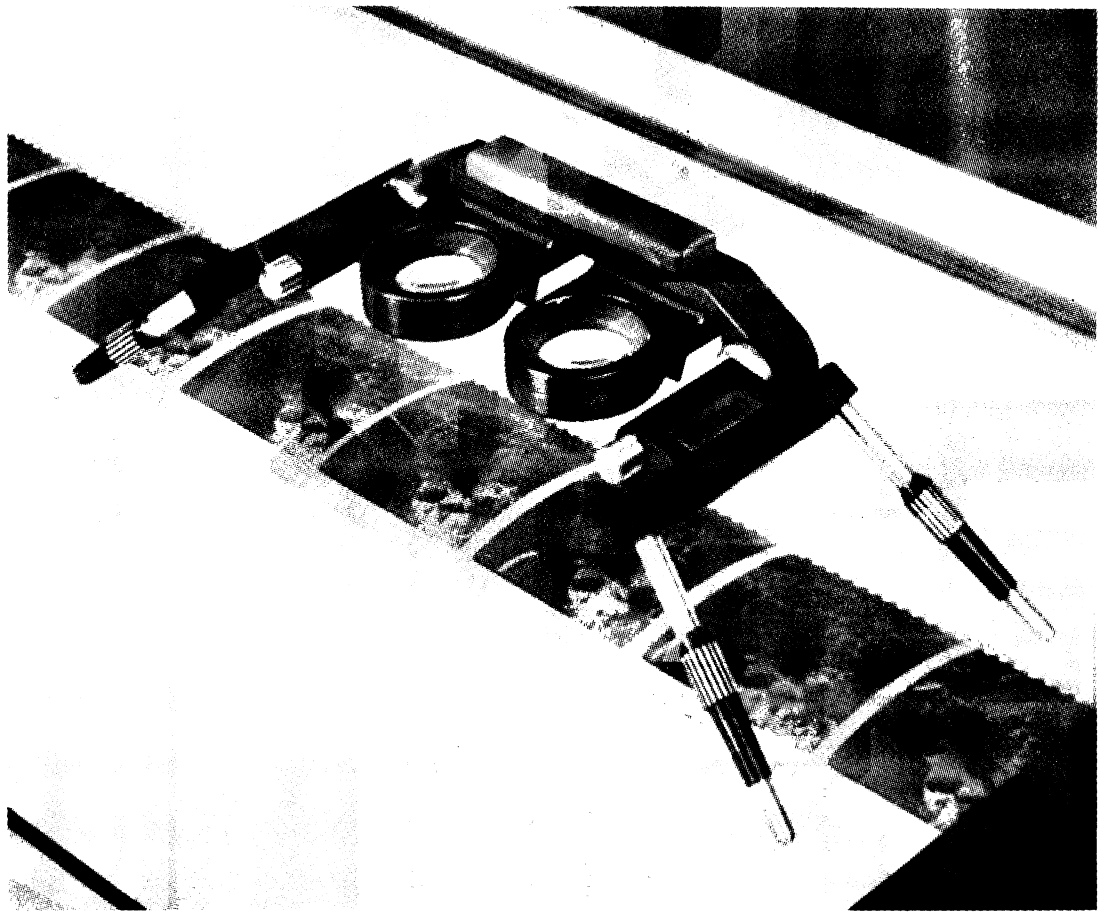


Figure 7.3 Lens stereoscope with 2x and 4x magnification lenses. (Courtesy of Vinten Military Systems Ltd.)

of a stereoscope is possible, but produces eyestrain if done for an extended period of time.

The simplest and cheapest instrument is the lens stereoscope, also called a "pocket stereoscope." Lens stereoscopes have two lenses mounted in a metal or plastic frame with folding legs (Figure 7.3). 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 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

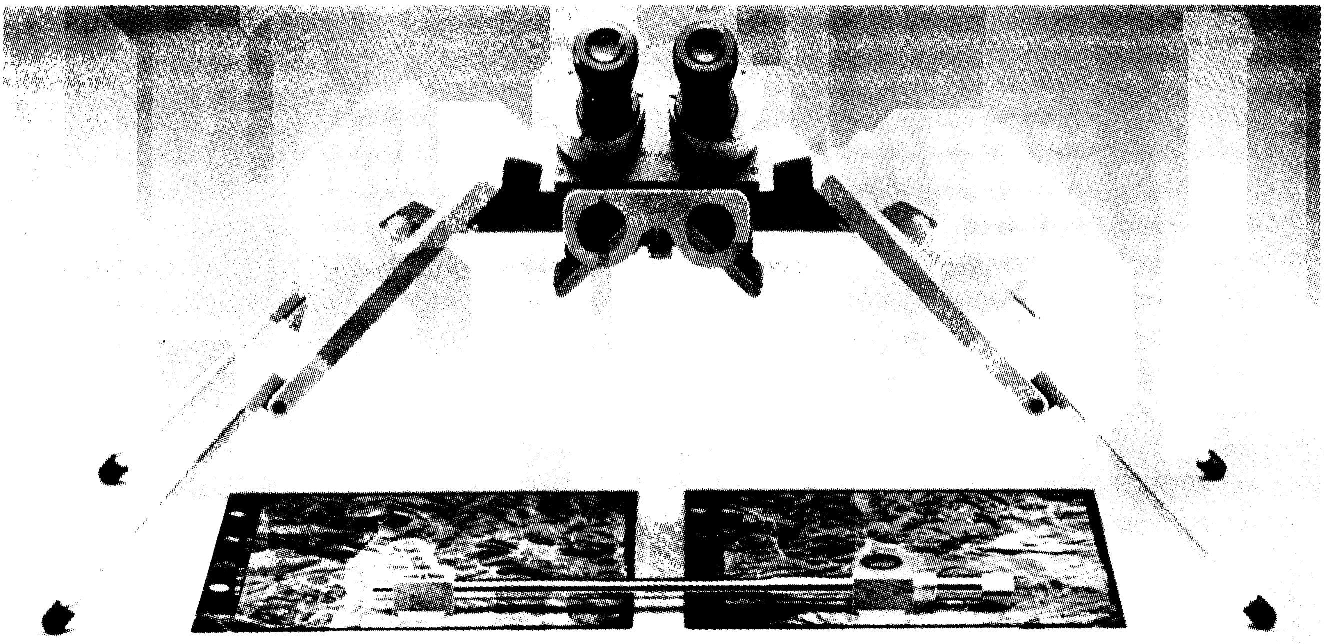
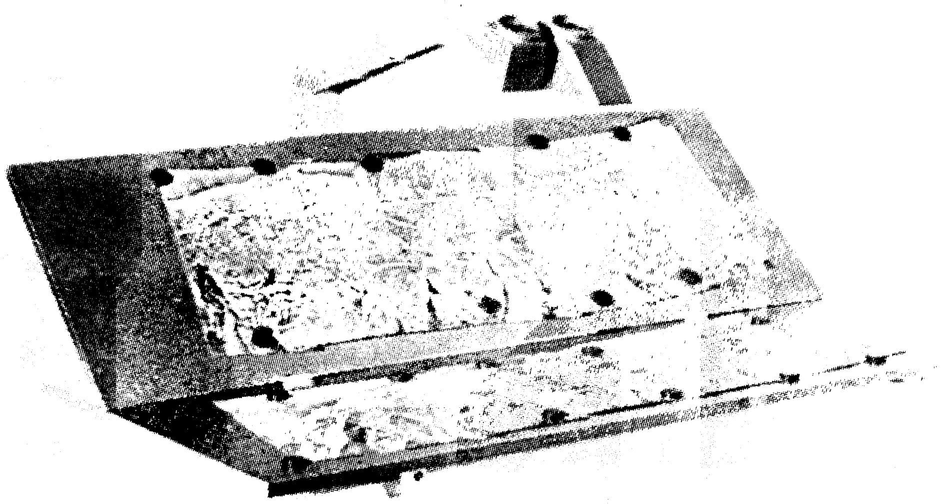


Figure 7.4 Sokkisha MS27 mirror stereoscope with a pair of aerial photographs prepared for stereo viewing and with a parallax bar. (Courtesy of Mark Lystiuk, Currie Engineering, and Sokkisha Co., Ltd.)

measuring instruments to be used under the stereoscope (Figure 7.4). 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. Mirror stereoscopes are less portable and must be handled with more care than pocket stereoscopes. In particular, the mirror surfaces must be treated with great care.

Other stereoscopes make it easier to scan over large areas or to enlarge areas of interest. The strip stereoscope (Figure 7.5) allows a strip of photographs to be viewed at once. The scanning mirror stereoscope allows the field of view to moved around the entire overlap area of a stereopair at several magnifications without moving either the photos or stereoscope (Figure 7.6). The zoom stereoscope provides continuously variable magnification, allowing an interpreter to easily "zoom in" on features of interest (Figure 7.7).

Working monoscopically with imagery can be as simple as looking at a single photograph with a magnifying glass. There are sophisticated systems, however, which are designed for rapidly displaying and analysing film-based imagery. The system shown in Figure 7.8 uses a closed circuit television system to display images. It can be used to magnify part of an image or to instantly present a negative image as a positive.



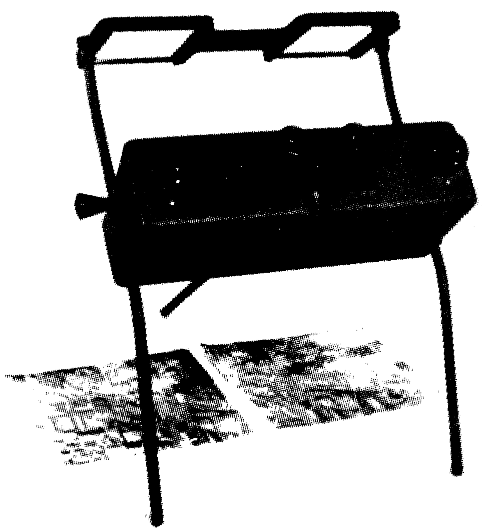


Figure 7.6 Old Delft Scanning Stereoscope. A scanning mirror stereoscope permits the field of view to be moved across the entire stereo overlap area of a pair of photos without moving either the photographs or the stereoscope. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 105, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

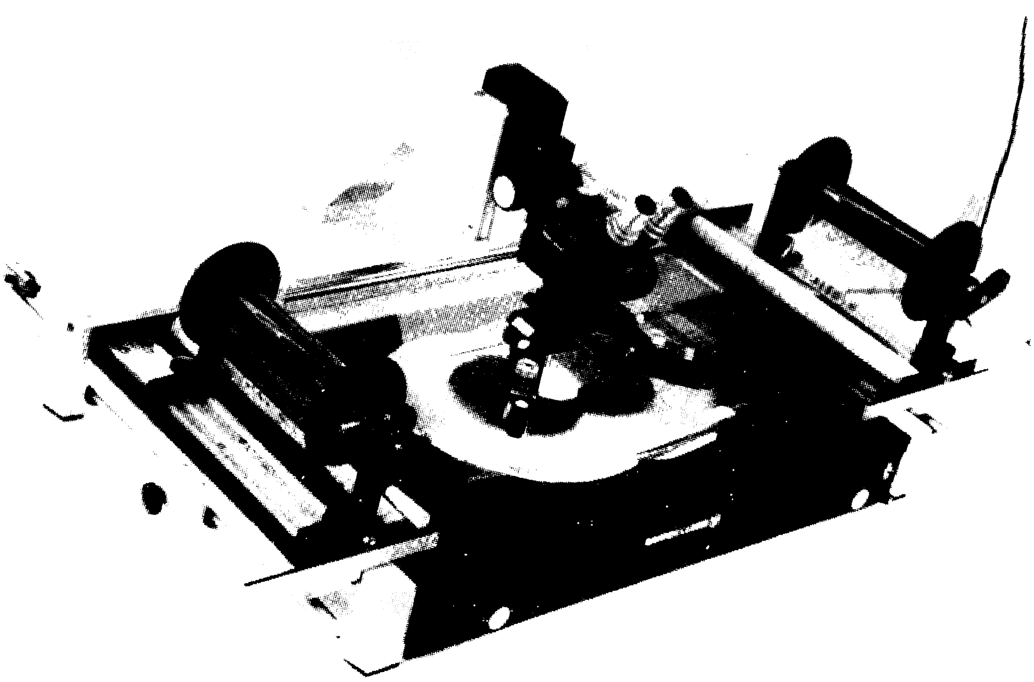


Figure 7.5 (on facing page, top) Wild ST10 Strip Stereoscope. The strip stereoscope permits a strip of photographs to be viewed together. (Reprinted from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 1014, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

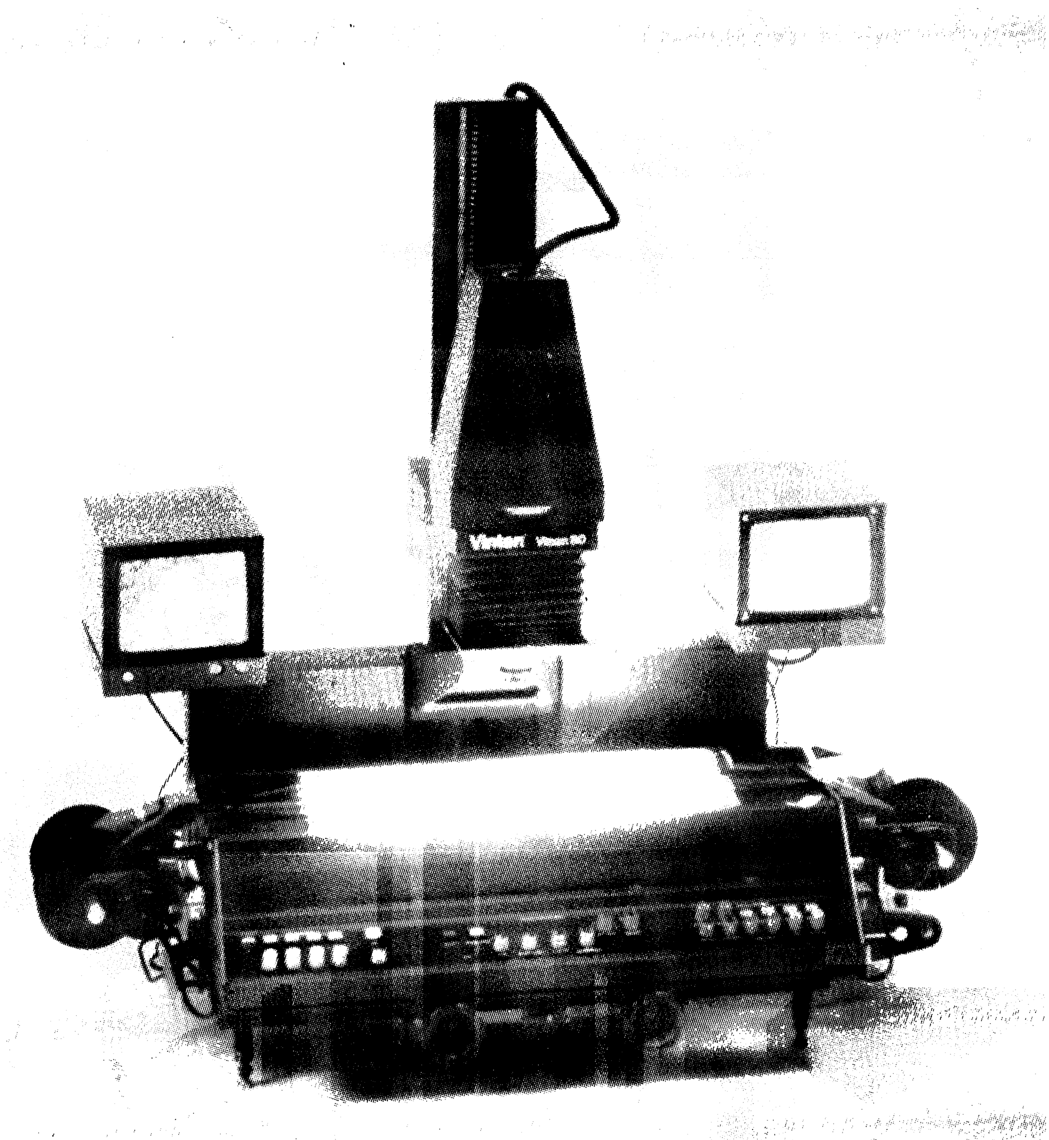


Figure 7.8 The Vinten Vicon 80 Imagery Interpretation and Reporting System. Based upon a closed circuit television system, the Vicon 80 provides a flexible system for rapid presentation, enhancement and visual interpretation of film-based imagery. (Courtesy of Vinten Military Systems Ltd.)

Figure 7.7 (on facing page, bottom) Zoom stereoscope mounted on a high intensity light table for viewing transparency roll film. (Reprinted from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 1016, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

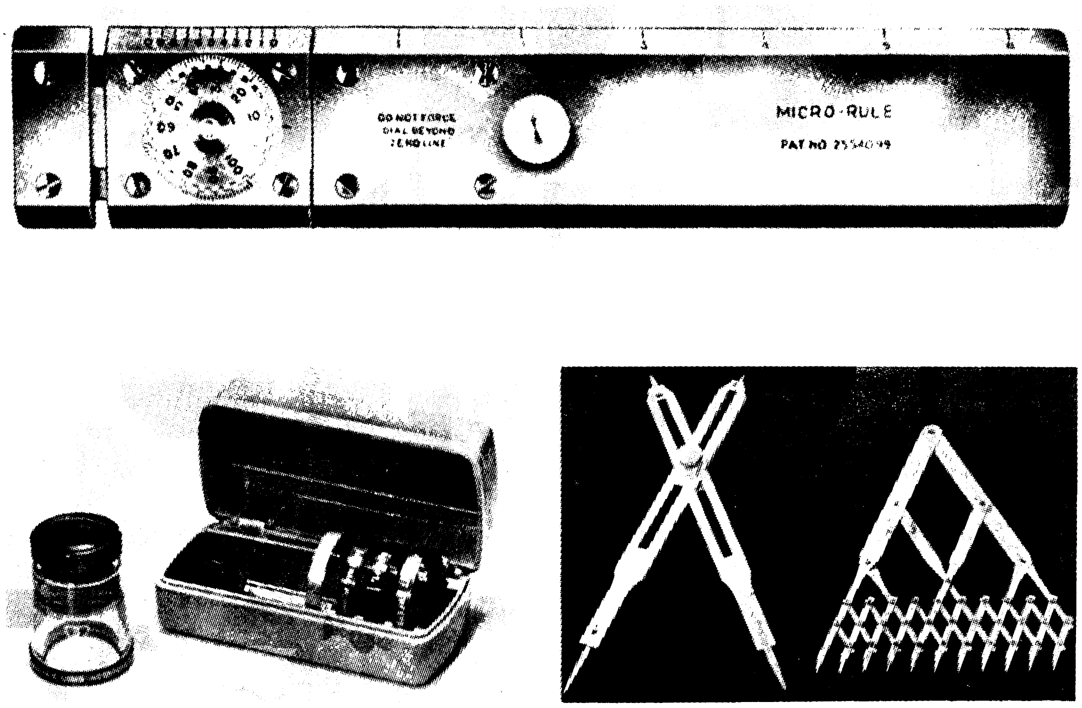


Figure 7.9 Instruments for making linear distance measurements on imagery: (a) micro rule, (b) magnifying scales and (c) proportional dividers. (Reprinted from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 1019, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

Measuring instruments may be divided into four categories:

- linear measuring instruments
- area measuring instruments
- height measuring instruments
- density measuring instruments

A number of devices may be used to make linear measurements. If a high degree of accuracy is not required, an ordinary metric scale may be sufficient. For more exacting work, a metal micro-rule (Figure 7.9a) or a magnifying scale (Figure 7.9b) could be used. Proportional dividers (Figure 7.9c) are used for comparing or plotting distances at different scales. It is also possible to get attachments for digital planimeters to measure linear distances.

One of the simplest techniques for area measurement on photographs is to use a dot grid (Figure 7.10a). A transparent grid of uniformly spaced dots is superimposed over the photo and the dots falling within the area of interest are counted. An alternative method is to use a polar planimeter (Figure 7.10b). The user traces around the perimeter of the area in a clockwise direction. The area physically measured on the photograph is read from a vernier scale and then converted to the desired units using the photo scale. The boundary is usually traced several times to ensure precise

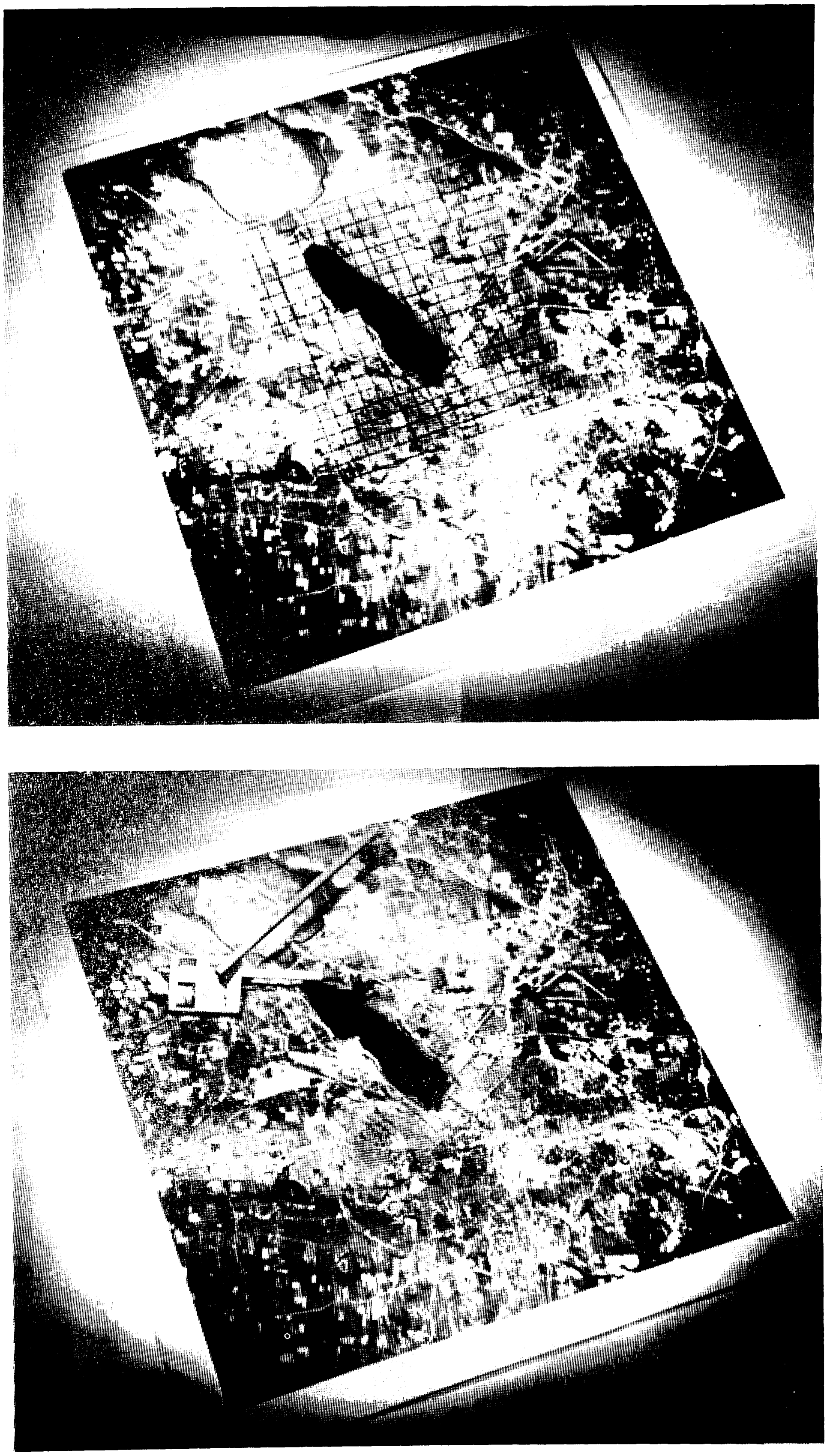


Figure 7.10 Instruments for area measurements on imagery: (a) dot grid and a (b) polar planimeter. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 107-8, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

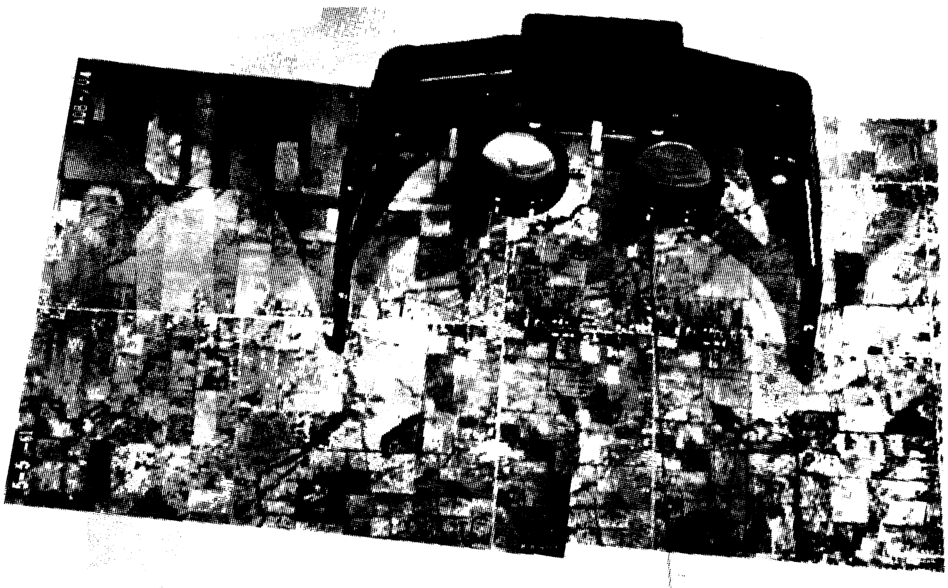


Figure 7.11 Parallax wedge oriented under lens stereoscope. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 311, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

measurement. Measurements using the dot grid method have been estimated to take only one-third to one-sixth of the time required for planimetering.[13] However, both of these techniques are slow and tedious. Electronic digitizers are faster and less painful for the user. As with polar planimeters, the user must trace around the area of interest. The digitizer will automatically compute the area according to any user-specified units.

If truly accurate distance or area measurements are required, it would be better, if possible, to use maps rather than imagery. The accuracy of distance and area measurements directly from imagery is not only a function of the quality of the measuring device, but also of the extent to which the image is distorted due to relief displacement, tilt and other factors.

Stereoscopic measurement of height can be done using a parallax wedge (Figure 7.11) or parallax bar (Figure 7.4). The parallax wedge consists of two slightly converging graduated lines printed on a clear template which is stereoscopically fused to make height measurements. It is mostly used with pocket stereoscopes. The parallax wedge is a very simple, inexpensive and rapid method for height measurement. The parallax bar has two lenses attached to a metal bar. A micrometer built into the bar changes the separation of two half marks, one on each of the lenses. When viewed stereoscopically, the marks can be fused to create the impression of a "floating dot." This dot can be raised or lowered to match the tops and bases of objects in the scene, providing the means to compute the height of the objects. Many interpreters prefer the

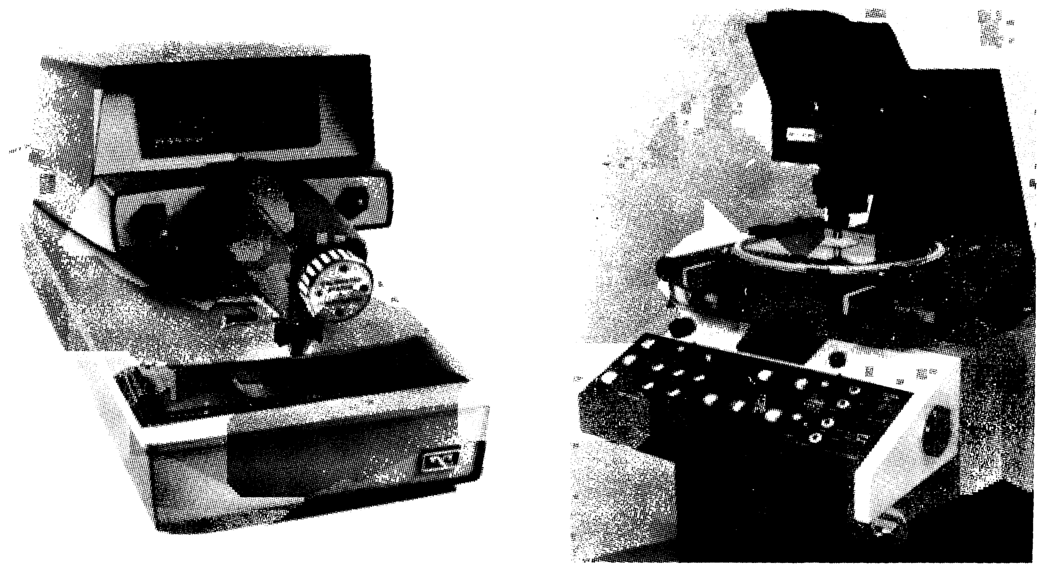


Figure 7.12 Instruments for density measurements on imagery: (a) spot densitometer and (b) flatbed scanning densitometer. (From Thomas M. Lillesand and Ralph W. Kiefer, Remote Sensing and Image Interpretation, p. 347 and 351, © 1979 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc., All Rights Reserved.)

parallax bar because the floating dot is moveable and easier to place on the ground and on the tops of objects.

Photographic density is measured using a densitometer. Reflectance densitometers are used to obtain spot density readings from photographic prints. Transmission densitometers are used for spot density measurements from transparencies or negatives. Spot densitometers, such as the one shown in Figure 7.12a, are used to measure film densities for quality control work in processing laboratories. They can be used to take density measurements at specific locations in an image to supplement visual interpretation. However, these instruments are of limited value if measurements are required for small areas on the film since the apertures are fairly large. Scanning densitometers are used when density measurements are required throughout an entire image (Figure 7.12b). The product of a scanning densitometer is a digital image which may then be analysed using a digital image analysis system.

Once information has been interpreted from images, it is often 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. Sketchmasters, such as the one shown in Figure 7.13a, have been in use for many years. They are inexpensive but tedious to use, requiring many changes to the photo and base map positions. Zoom transfer scopes provide all the capabilities of camera lucida instruments as well as continuous zoom magnification of the image and a system to stretch

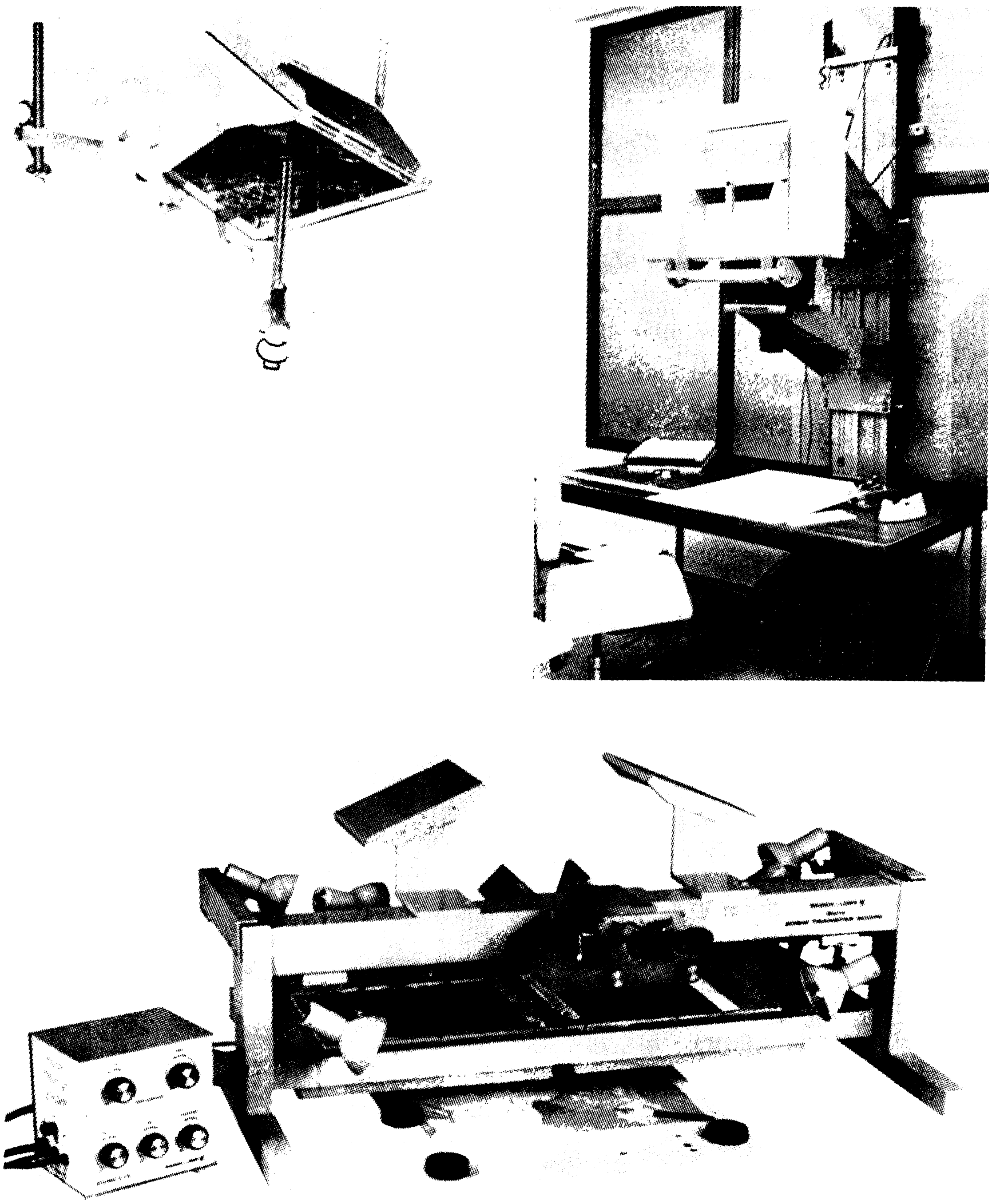


Figure 7.13 Instruments for transfer of detail: (a) Vertical Sketchmaster, (b) Stereo Zoom Transfer Scope and (c) Map-O-Graph optical projector. (Reprinted from Robert N. Colwell (editor-in-chief) Manual of Remote Sensing, Second Edition, Volume I, p. 1022-1024, © 1983 by the American Society of Photogrammetry and Remote Sensing (ASPRS), by permission of the ASPRS)

the image, partially compensating for geometric image distortions. Stereo Zoom Transfer Scopes allow the operator to simultaneously view a pair of stereo images and a map (Figure 7.13b). Optical projection instruments optically project the image onto a map (Figure 7.13c). These are standard equipment in cartographic labs. They are useful for transferring detail from near-vertical imagery. They provide a large work area and comfortable working position for the analyst.

7.3 Digital analysis

Digital image analysis systems vary in terms of capability and software, but share the same basic hardware. Figure 7.14 illustrates the hardware associated with a typical image analysis system. The computing is performed by a host computer. The host computer can range from a personal computer to a supercomputer. A computer terminal and keypad, similar to those used for any other computer, is used to interface with the host. Images are displayed on a screen which, typically, can display full colour

Figure 7.14 Dipix ARIES III Workstation with 1024 x 1024 image display, MicroVAX host computer, graphics tablet and operator's terminal. (Courtesy of Dipix Technologies Inc.)

images with graphics overlays. Display screens are often 512 x 512 pixels or 1024 x 1024 pixels in size. The user interfaces with the image display using a graphics pad, track ball or joystick. Most systems allow the user to zoom in on specific points in the image or roam around the image interactively. Selection of training sites for classifiers, picking ground control points for image registrations, and adding annotation labels are also done interactively using the image display. Periferal devices, such as lineprinters and film recorders, can be added on to most systems.

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.[14] The following section provides a brief outline of the range of computer-based techniques for working with remotely sensed imagery.

a) *Image restoration*

Image restoration is concerned with the correction of distortions, noise and other degradations introduced during the image acquisition process. Restoration uses *apriori* knowledge of the mechanisms which cause image degradation. The objective is to produce, using a degraded image as the input, an image which radiometrically and geometrically approximates how the original scene should have appeared. Image restorations are usually applied as required, whether the interpretation will be done visually, using human interpreters, or by computer-based techniques.

Radiometric corrections include the removal of sensor-induced noise effects, atmospheric interference and illumination effects because of variations in terrain slope and aspect. Geometric corrections permit images to be "registered" to a map coordinate system or to another image. Registration to map coordinates facilitates the use of geographic information databases during the analysis. A geographic information system, for example, might include the permitted locations and compositions of military forces under the jurisdiction of a particular treaty. Registration of multiple images to each other permits changes from one image to another to be located easily.

b) *Image enhancement*

The objective of image enhancement is to improve images for visual interpretation by humans. Information in the image is selectively emphasized or suppressed to suit the particular application or tastes of the interpreter. Image enhancement is usually not done prior to computer-based interpretation. Some enhancements produce misleading results if a computer is used to interpret the imagery. Enhancements do not generally incorporate *a priori* knowledge other than an understanding of the typical preferences of interpreters.

Contrast enhancement involves changing the range of image intensities present in an image. A new brightness value is computed for each pixel in an image based upon its old value and using one of a variety of algorithms. The objective of contrast enhancement is to produce an image which uses the full dynamic range of the display device, thereby improving the appearance of the imagery for visual analysis.

Filtering is used to compute a new image intensity for a pixel based upon the intensity values of the surrounding neighbourhood of pixels. The size of the "neighbourhood" and the algorithm used by the filter to compute the new image intensity are varied to achieve the desired effects. Large filters usually emphasize low spatial frequency components, thereby visually "smoothing" the image. Smaller filters accentuate high spatial frequency components, enhancing edges and small detail in the image.

Image transforms may be used to reduce the size of a data-set while retaining most of the information for interpretation. The principal components transform uses the correlation between channels in a multispectral image to compute a new set of "component images" in which most of the information will be found in the first few components. Transforms can also produce alternative forms of the image data, emphasizing features which were not previously evident. Image ratios may be used to suppress topographic variations while accentuating subtle spectral changes. Images can be subtracted from one another to identify spectral differences or temporal changes between images of the same area.

c) *Computer-based interpretation*

The capability of computers to solve complex mathematical problems and manipulate large quantities of data is widely recognized. This might suggest that computers should be used to interpret the potentially large quantities of imagery which could result from an operational airborne verification system. In most respects, however, computer-based image analysis procedures lag far behind what can be accomplished visually using human interpreters.

The basic elements used for the analysis of images were outlined in Figure 7.1. These elements are used, to some extent, in computer-based analysis as well as for manual interpretation (Table 7.2). While human interpreters will routinely use all of these elements, many commercially-available computer-based systems for analysing remotely-sensed imagery rely entirely upon the tone or "colour" (for multispectral images) of individual pixels. Systems which make use of higher-level information often work within a restricted domain, limiting their use in an operational environment.

There are three general categories of computer-based image interpretation techniques: statistical classification, target detection and image understanding methods.

TABLE 7.2

Image interpretation elements with examples of computer interpretation techniques.

IMAGE INTERPRETATION ELEMENTS	DOMAIN	EXAMPLES OF COMPUTER INTERPRETATION TECHNIQUES
tone	spectral	density slicing
colour	spectral	multispectral classification
texture	spectral/spatial	texture classification
pattern	spectral/spatial	spatial transforms and classification
size	spatial	segmentation algorithms and size feature classification
shape	spatial	syntactic classification
site	spatial	a priori's modified
association	spatial	contextual classification syntactic classification

Source: Estes, John E., Earl J. Hajic and Larry R. Tinney. (authors/editors) "Fundamentals of Image Analysis: Analysis of Visible and Thermal Infrared Data." Chapter 24. IN: Colwell, Robert N. (editor-in-chief) 1983. Manual of Remote Sensing. Second Edition. Volume I. Theory, Instruments and Techniques. American Society of Photogrammetry. Falls Church, Virginia. p. 1037.

Statistical classification uses the distribution of sampled image pixels in a "feature space" defined by the range of possible intensity levels in each spectral band of the image. Pixels are assigned to categories using a decision rule, such as the maximum likelihood method (Figure 7.15). Statistical classification methods have been widely used for applications such as crop identification and monitoring using imagery from the U.S. LANDSAT and French SPOT satellites.

Statistical classifiers rely upon spectral differences to discriminate between the classes but disregard most, if not all, of the spatial information in the image.[15] Since

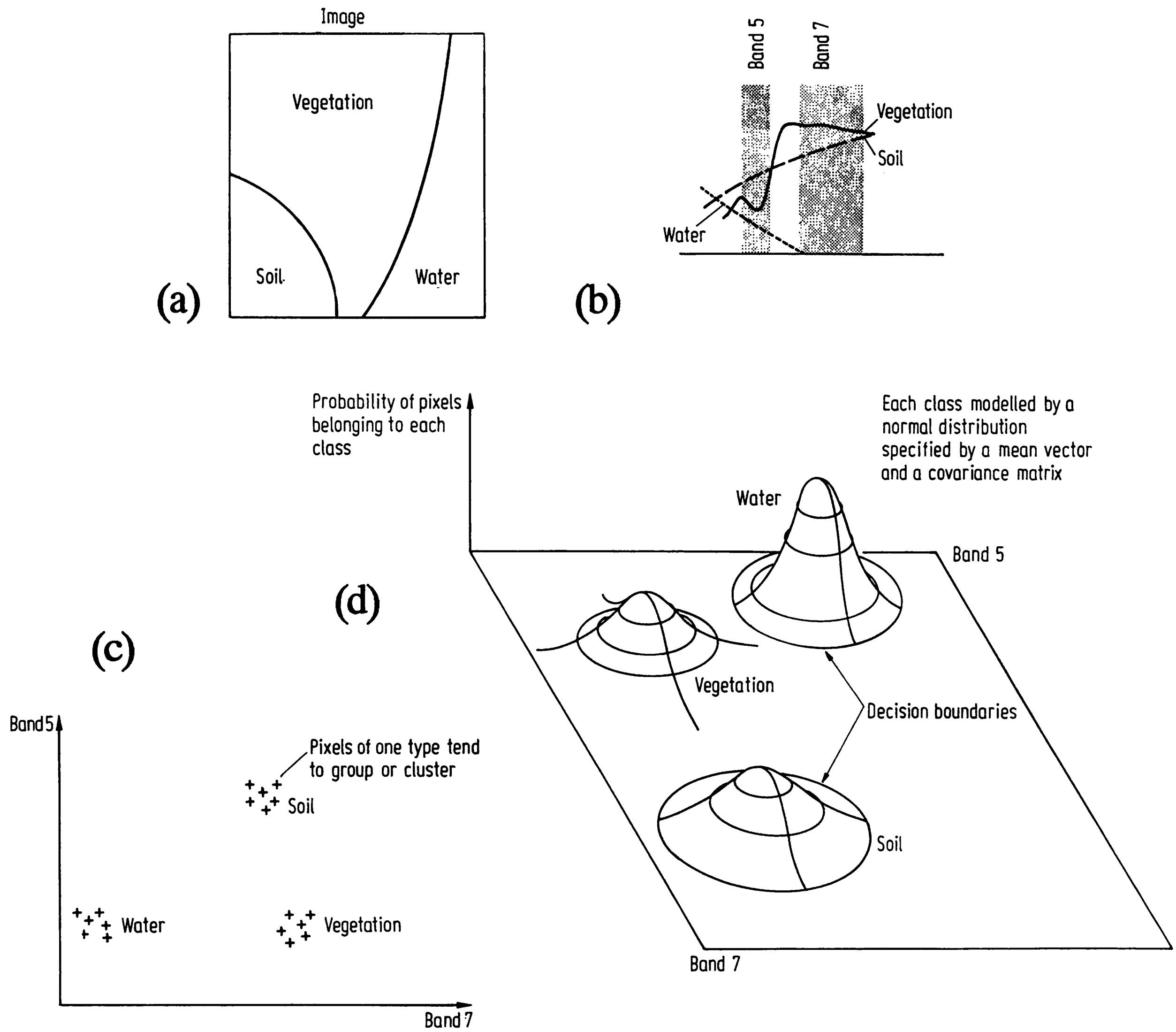


Figure 7.15 Statistical classification of multispectral imagery. An image is taken with three surface types (a), each with characteristic spectral characteristics (b). In (c), distribution of the pixels in a two dimensional, multispectral space is shown. The pixels of one surface cover type tend to group together because of common spectral characteristics. In (d), the two dimensional multispectral space is shown with the spectral classes represented by Gaussian probability distributions. Distributions such as these form the basis by which maximum likelihood classifiers segment images. (Reprinted from John A. Richards, Remote Sensing Digital Image Analysis: An Introduction, p. 77 and 80, © 1986 by Springer-Verlag, by permission of John A. Richards and Springer-Verlag)

spatial information plays such a major role in the analysis of high resolution imagery, these classifiers cannot interpret such imagery effectively. Essentially, statistical classifiers determine the categories to which *pixels* in the image belong, but they do not provide information regarding *objects* in the scene. A battle tank might have spectral properties similar to those of many other objects. Even with unique spectral properties, it would be impossible to "count the number of tanks" since statistical classifiers could not recognize the tanks as objects.

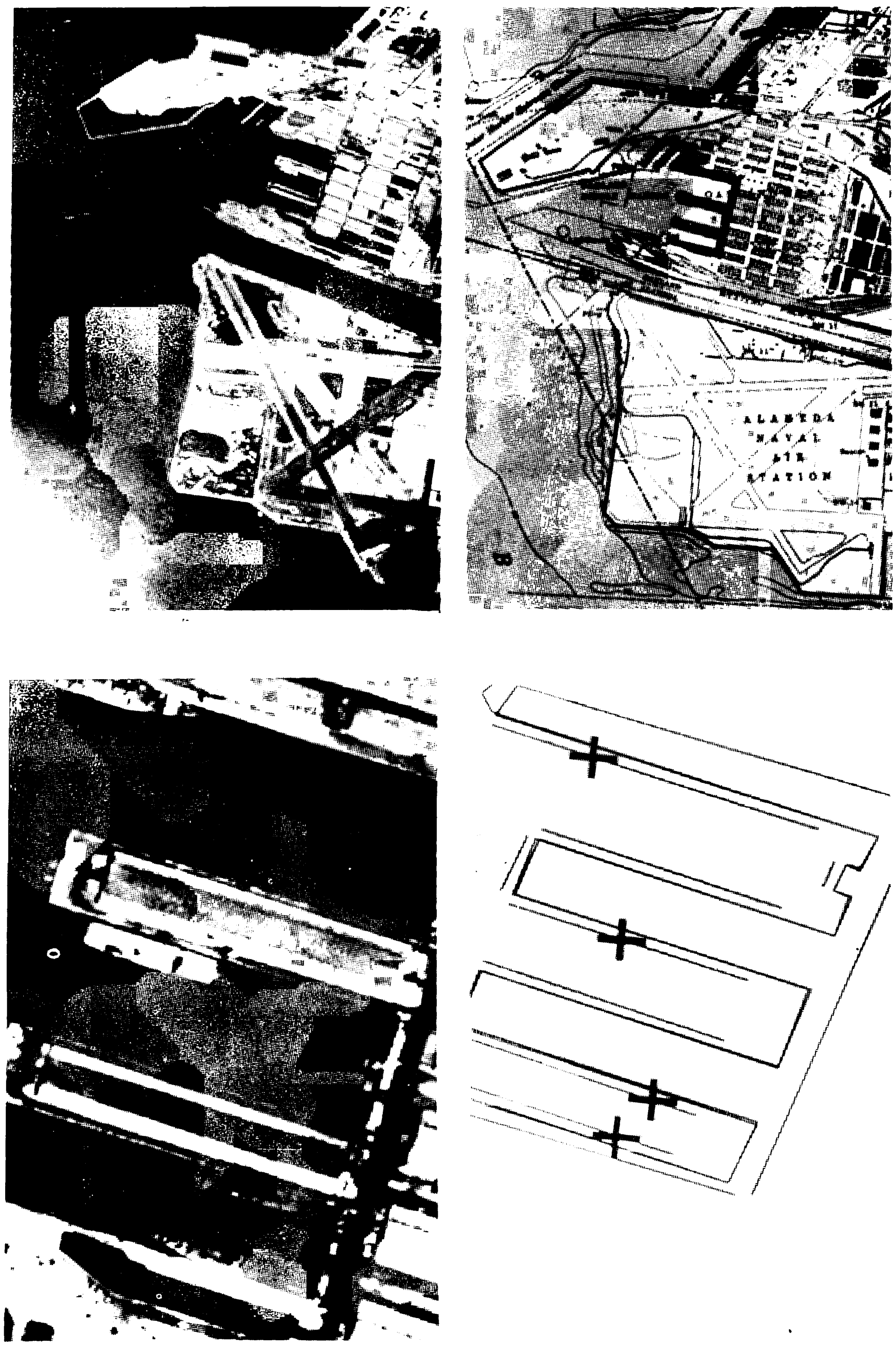


Figure 7.16 Use of computer-based image understanding to locate ships in an aerial photograph:

(a) the photograph,

(b) a corresponding map,

(c) the dock area of the photograph, and

(d) map/image showing the interpreted ship locations.

A map is used to locate the wharf in a registered aerial photograph. Ships are distinguished according to their location on the water alongside a wharf. (Reprinted from Dana H. Ballard and Christopher M. Brown, <u>Computer Vision</u>, p. 2-3, © 1982 by Prentice Hall, Inc., by permission of Prentice Hall, Inc.)

Target detection methods locate specific objects in an image using knowledge of their distinguishing characteristics such as colour, size and shape. Models of the objects are used to separate "objects" from "background" in the images. Programs have been developed to identify roads using line detectors. Others have been used to find vehicles using their shape and structure.[16]

These programs do not include knowledge of the environment in which the objects appear. However, objects can be defined by the surroundings as much as by their own characteristics. A camouflaged tank might not be directly visible. However, it *may* be possible to see evidence of tracks or subtle signs that *something* has been camouflaged.

Image understanding, through the introduction of artificial intelligence techniques, attempts to overcome some of the limitations of statistical classifiers and target detection methods. It attempts to build a description of the scene using knowledge-based symbolic processing. Information used by the other techniques, the spectral properties of surfaces and the structure of targets, are combined with knowledge of contextual and semantic constraints among objects and their environment. In Figure 7.16, the location of a naval yard and the fact that ships are tied up alongside wharves was used to locate four ships. Specific information regarding defining characteristics of various kinds of ships would be required for more precise identification.

Image understanding is a difficult and challenging area of current research. Human beings seem to have no difficulty doing many of the recognition tasks which are required to interpret remotely sensed imagery. However, humans are equipped with sophisticated "wetware" to perform the task. Unfortunately, the human visual system cannot be inspected to find out how it works, forcing researchers to "re-invent the wheel." For example, one of the major challenges of image understanding systems is finding ways to represent and efficiently manipulate the knowledge required to identify and analyse images of complex scenes, a task which requires no conscious effort for a human interpreter. Although artificial intelligence and image understanding techniques show great promise for specific applications, they are unlikely to match the capabilities of a trained human interpreter in the foreseeable future.

Notes to Chapter VII

1 Rowell, William F. 1986. Arms Control Verification. A Guide to Policy Issues for the 1980's. Ballinger Publishing Company. Cambridge, Massachusetts. pp. 32-35.

2 Estes, John E., Earl J. Hajic and Larry R. Tinney. (authors/editors) "Fundamentals of Image Analysis: Analysis of Visible and Thermal Infrared Data." Chapter 24. IN: Colwell, Robert N. (editor-in-chief) 1983. Manual of Remote Sensing. Second Edition. Volume I. Theory, Instruments and Techniques. American Society of Photogrammetry. Falls Church, Virginia. p. 993.

3 This includes the potential case of a multi-sensor operation where imagery from one sensor may indicate no differences in tone or colour but that of another sensor does. In this case, attention is drawn to the lack of differences in the one set of imagery by changes evident in the second set.

[4] Rabben, Ellis L., E. Lawrence Chalmers Jr., Eugene Manley and Jack Pickup. "Fundamentals of Photo Interpretation." Chapter 3. p. 102. IN: American Society of Photogrammetry. 1960. Manual of Photographic Interpretation. Banta Publishing Co., Menasha, Wisconsin.
[5] Rabben et al., op. cit., p. 109.
[6] Stone, K.H. 1956. "Air photo interpretation procedures. " Photogrammetric Engineering. Vol. 22 p. 223. IN: Estes et al., op. cit.
[7] Estes et al., op. cit., p. 996.
[8] adapted from Avery, T. Eugene. 1968. Interpretation of Aerial Photographs. Second Edition. Burgess Publishing Company. Minneapolis, Minnesota. p. 75.
[9] Rabben et al., op. cit., p. 116.
[10] *ibid.*
[11] Lillesand and Kiefer, op. cit., p. 193.
[12] Estes et al., op. cit., p. 1010.
[13] *ibid.*, p. 1019.
[14] *ibid.*, p. 1026.
[15] A current trend is to incorporate cartographic information from digital geographic information systems into the analysis. This is typically used to provide information regarding crop type or other feature for a particular location, rather than to provide spatial information, such as the shapes of fields in that specific area, for the analysis.
[16] Nagao, Makoto and Takashi Matsuyama. 1980. A Structural Analysis of Complex Aerial Photographs. Plenum Press. New York, N.Y. pp. 5-6.

CHAPTER VIII

PLATFORMS AND RELATED EQUIPMENT

Almost anything capable of flying could be used as a platform for reconnaissance equipment, from balloons to specialized high altitude reconnaissance aircraft. Platforms and their related equipment are suited to a limited range of missions and therefore must be chosen to match specific requirements. The suitability of a platform for a particular sensing mission depends upon a variety of factors including [1]

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

8.1 Aircraft

Aircraft are available with a wide range in capabilities and cost. Aircraft which cost more to purchase and operate are typically able to operate in larger "envelopes." They will provide higher altitude ceilings, more all-weather capability, and better navigation systems. Typical operating altitudes for a number of potential aircraft is illustrated in Figure 8.1. It is more cost effective to purchase or lease an aircraft suited to the task at hand, rather than trying to "make do" with an aircraft which will have to operate outside of its performance envelope.

Piston-powered aircraft are the least expensive to operate. They may be single-engined or twin-engined. These aircraft are most useful for local operations, where long transits from one location to another will be minimized. They are more maneuverable than larger aircraft, reducing the time required for turning and approaching flight lines. Twin-engined aircraft provide heavier payloads, improved range and speed, and higher service ceilings than those with a single engine. Single-engined aircraft should not be used for missions which will require flying over large bodies of water, mountainous terrain or other areas where safe landings will not be possible if there is an engine failure.

Piston-engined aircraft can be turbo-charged, using exhaust gases from the engine to drive a turbine, pushing high-pressure air into the air intakes to increase the performance of the engine. Turbo-charged aircraft have higher capital and operating

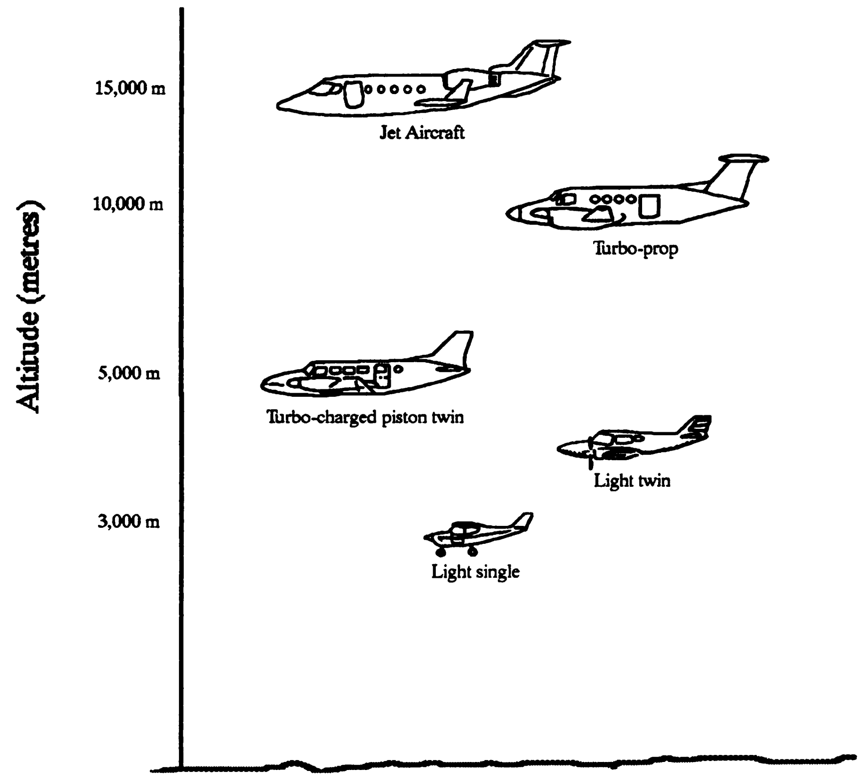


Figure 8.1 Typical operating altitudes for aircraft which might be useful for verification-related overflights. (Redrawn from Ron Graham and Roger E. Read, Manual of Aerial Photography, p. 163, by permission of Focal Press.)

costs, but climb better and have higher service ceilings. Turbo-charged aircraft perform better from high-altitude airstrips and in hot climates than regular piston-engined aircraft.

Turbo-propeller engines are jet engines with a turbine-driven propeller producing thrust to augment that provided by the jet exhaust. Turbo-prop aircraft use the same kind of fuel as jets such as commercial airliners. This type of fuel is more commonly available and less expensive in some countries than the aviation fuel used by piston-engined aircraft. Turbo-prop aircraft provide the largest payloads, highest speeds and longest ranges of the propeller-driven aircraft and come in single- or twin-engine varieties (Figures 8.2, 8.3 and 8.4).

Executive jet aircraft provide higher operating speeds and service ceilings than propeller-driven aircraft. They also have higher stall speeds, restricting the ability to collect large-scale imagery. Typically these aircraft have been originally intended to carry ten or more passengers. They usually have capacity for several sensors with operators and accompanying gear (Figure 8.5).

Military reconnaissance aircraft perform a similar task, in some respects, to what would be required for verification. A major concern for military missions, however,

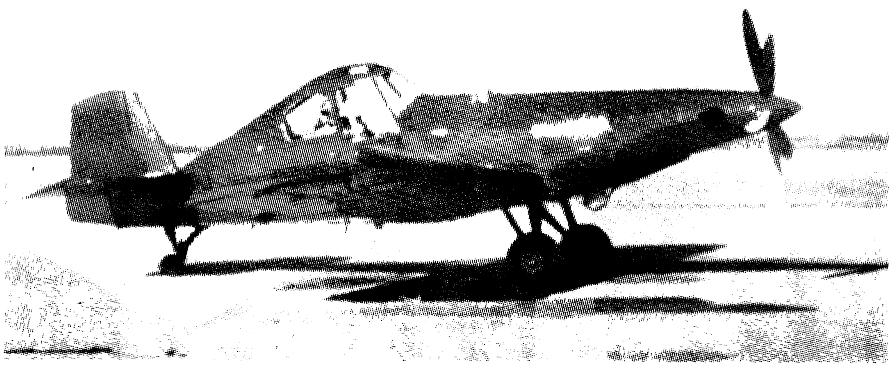


Figure 8.2 Ayres S2/R Turbo Thrush with Honeywell Mark II Gimballed Mini-FLIR. The Turbo Thrush combines low operating cost and ease of modification and maintenance with high performance flight characteristics. Equipped with a Pratt and Whitney PT6A-65 1230 HP Turbine Engine and a five-bladed propeller, the aircraft can circle around a ground target in a 1.5 mile (2.4 km) radius at speeds as low as 60 knots (110 km/hr), avoiding being heard by personnel on the ground. The S2/R has a seven hour endurance on a fuel load with a 60 knot (110 km/hr) low-level reconnaissance mission speed and 160 knot (290 km/hr) cruise speed. It can operate from short field unimproved airstrips. (Courtesy David Dorschner, Aviation Resource Management)

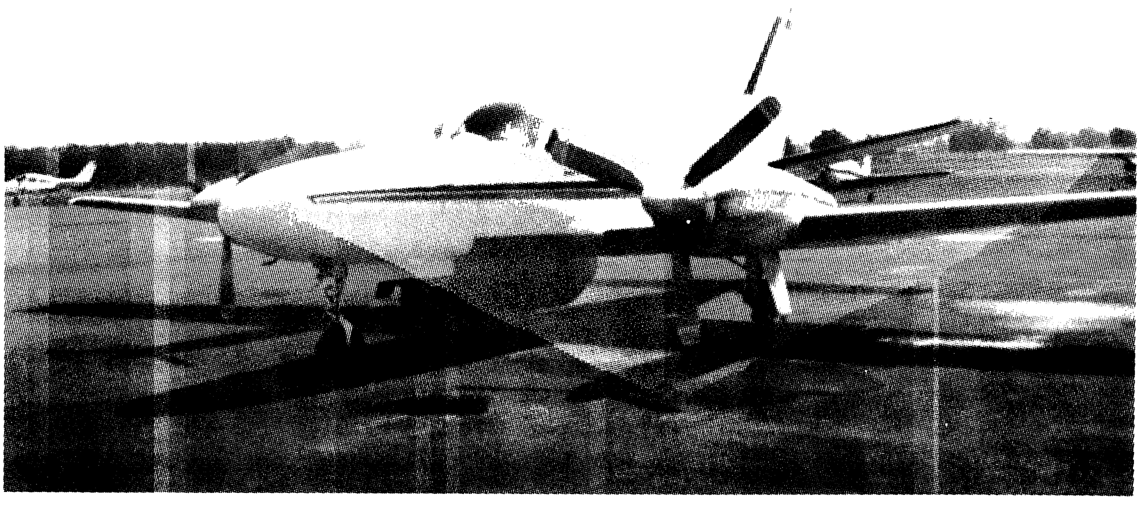


Figure 8.3 Twin-engined Cessna Conquest equipped with synthetic aperture radar. The Conquest is a cost-effective platform which delivers the altitude, range and speed capabilities required to operate a SAR. The Conquest provides a service ceiling of about 11,275 metres and has a maximum range of about 4,000 kilometres when flying at 10,000 metres. The aircraft would also make a good platform for an infrared linescanner and/or camera system. (Courtesy Intera Technologies Ltd.)

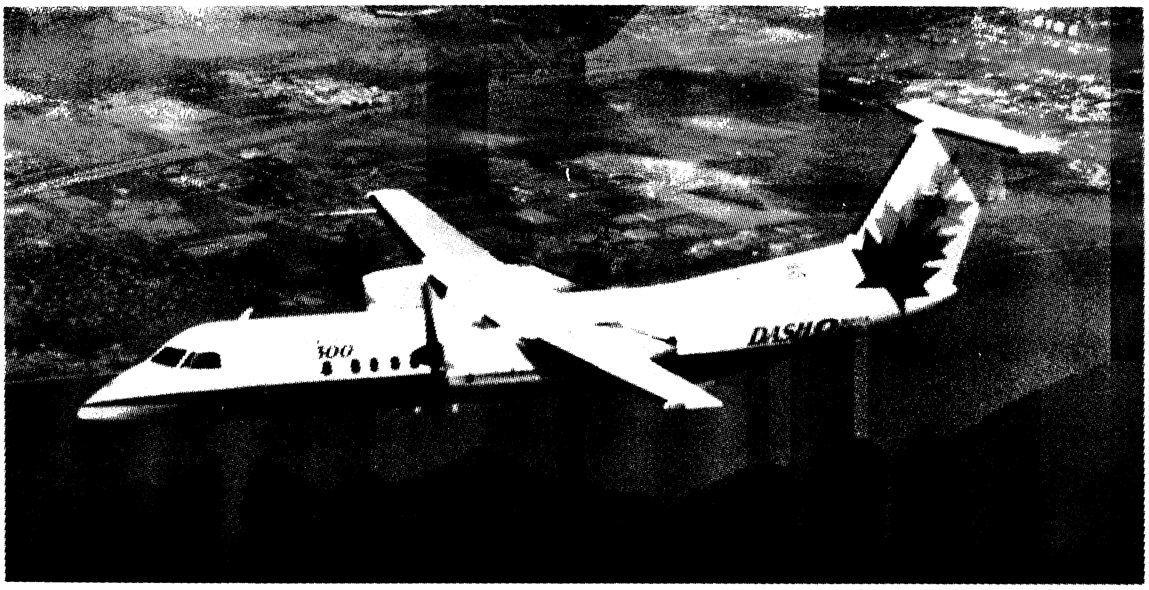


Figure 8.4 The Boeing Dash 8 Series 300 provides a large volume platform, with room for 16 passengers or more as well as a full complement of sensors. The aircraft could be used to transport personnel for on-site inspections in addition to being a sensor platform. Based from a central location in Europe, the Dash 8 could reach any target within the "Atlantic to the Urals" region within six hours and without refueling. The Dash 8's airfield performance would permit operations from most airfields in Europe. (Courtesy of Boeing Canada, de Havilland Division)

Figure 8.5 The Canadair Challenger 600 has a service ceiling of 11,300 metres. At a speed of 400 knots and with a 900 kilogram payload, it has a maximum range of over 5,000 kilometres. A jet aircraft such as the Challenger would be appropriate for verification missions involving long-distance flights. The aircraft in this photo has been equipped for ice reconnaissance with two SARs, providing two 100 km wide swaths of radar coverage at once (as shown in Figure 6.8). The system can acquire 800,000 square kilometres of radar imagery in one mission. (Photo courtesy of D. McClure, MacDonald Dettwiler and Associates)

is to avoid detection and interception. For this reason, strategic reconnaissance aircraft typically fly at high altitudes and at high speed. This has the added benefit of allowing such aircraft to collect imagery over vast areas in short periods of time. For example, the SR-71 could reportedly photograph 259,000 square kilometres in one hour and cover the entire continental United States in just three overpasses.[2] Imagery collected using National Technical Means, and the sensors used to acquire it, are considered very sensitive. Nevertheless, it may be possible for such aircraft to participate in multilateral verification missions in some circumstances. The SR-71 was apparently used by the United States for verification of the Sinai Disengagement Agreements and the Egypt-Israel Peace Treaty.[3]

8.2 Helicopters

Helicopters are very useful for low altitude photography. They can be flown at slow speeds while close to the ground, minimizing any blurring of photographs because of image motion. If the helicopter is moving at a speed of about 30 knots while the photographs are taken, potential problems due to vibration of the helicopter will be minimized. There is more vibration when the helicopter is hovering or travelling at high speed.[4]

Figure 8.6 Bell Jetranger 206-B equipped with a fixed-base photography system. Two Hasselblad MK70 cameras are installed at either end of the camera-boom attached beneath the helicopter. The camera system operator can be seen through the side door, using the on-board laptop computer interfaced to control the cameras and tracking video camera. (Courtesy of TIMBERLINE)

Helicopters also provide an option to slow down for a careful visual examination of something which appears to be suspicious. If appropriate, an inspection might be carried out on the ground immediately, after finding a nearby landing spot for the helicopter. Unlike most aircraft, helicopters do not require airfields to land.

Helicopters have good ground visibility. Side doors can be removed on some models to provide an unobstructed view for hand-held camera systems. The use of helicopters with pointable sensors makes it possible to carefully examine an area from many angles.

Figure 8.6 shows a helicopter outfitted with a camera boom for fixed-base photography. The system is designed to acquire stereo photography with scales as large as 1:200 for detailed photogrammetric measurements. The low-altitude and low-speed capabilities of helicopters make them an ideal platform for such a system.

8.3 Unmanned aircraft

There are two major categories of unmanned aircraft. Drones fly on pre-programmed flight paths and do not require a communications link to a controller.[5] Remotely piloted vehicles (RPV) are controlled from the ground or a manned aircraft using a real time communications link.

Drones can be used to collect imagery over a specific target, along a straight-line flight path, or over an area using multiple flight lines. They can carry photographic cameras or electronic sensors. Response times, from mission request to delivery of the imagery, can be one hour or less when a drone is pre-positioned within range of the site. Many drones can be launched using ramps from unprepared launching sites. Others use landing gear similar to manned aircraft and must be launched from prepared sites. A few are launched from aircraft in flight. Recovery after the mission is often by parachute or net.

Remotely piloted vehicles are more sophisticated than drones. They can respond to commands from a controller in real time during the flight. RPV's are usually equipped with television or FLIR systems for real-time data acquisition. The controller can investigate potential anomalies by moving closer or looking from other directions. Some RPV's are designed like a mini-helicopter, using contra-rotating rotors, rather than the conventional fixed wing design (Figure 8.7). These systems can take off or land in virtually any terrain and can fly in any direction while their data link antennas remain pointed toward the control station. A disadvantage of RPV's is that they must usually have an unobstructed line of sight between the data link antenna and the control station. An RPV can be pre-programmed to increase its altitude if the data link is lost or to return to the point where it lost the link.

Figure 8.7 The Canadair rotary-wing CL-227 Sentinel remotely piloted vehicle can be launched and recovered in virtually any terrain. The contra-rotating rotors allow the CL-227 to fly in any direction without altering the orientation of the fuselage. The system is highly manoeuvreable and has the ability to hover. The CL-227 would be most suitable for missions involving shorter distances since its speed and endurance over longer distances do not match those of RPV's with the more conventional fixed-wing design. (Courtesy of the Surveillance Systems Division, Canadair Defence Group, a Division of Bombardier Inc.)

8.4 Balloons

Balloons and airships could be useful for a variety of arms control verification missions. Whereas time on station for helicopters and airplanes is limited by their fuel supply to periods of several hours, lighter-than-air craft can remain aloft for periods of several days. As well, balloons do not require runways like most reconnaissance aircraft.

There are three major categories of balloons: free balloons, tethered balloons and powered balloons or airships. Free balloons are allowed to drift freely with the wind. Although they can remain within a general area by "station-keeping,"[6] free balloons are more suited to missions which are less site-specific than those usually required for verification. Tethered balloons and airships are more likely to be useful within a verification context.

Tethered balloons provide stable, stationary platforms for remote sensors. Various configurations are possible including tri-tether balloons as low-altitude platforms and multiple balloon systems for high-altitude applications. Balloons also come in different shapes. Spherical and naturally-shaped balloons are less expensive than streamlined balloons but are more susceptible to the wind. A balloon system must be selected to suit the operational requirements of each mission. Factors such as environmental conditions, type and frequency of ground handling operations, service life, flight endurance, lift, altitude, number of launch and retrieve cycles, number of inflations and deflations, and packaging must all be considered to provide an optimum balloon system for a particular mission.[7]

Airships also provide stable platforms. Unlike tethered balloons, they are moveable. Unlike more conventional aircraft, they are largely vibration-free, facilitating the acquisition of high resolution imagery. On-board equipment is put under fewer stresses from vibration, heavy G-forces and temperature changes. Failure rates and maintenance for equipment are correspondingly reduced. Airships provide lots of space for equipment which would be too large for smaller platforms. Such equipment can be housed inside the balloon envelope, offering almost unlimited space.

8.5 Navigation systems

Remote sensing is more demanding with regards to navigation system requirements than normal air traffic. Navigation systems must be capable of supporting the needs of a full range of potential on-board sensors in addition to those required to navigate the aircraft. General air traffic requirements involve coordinates of position, direction, time and speed. Reconnaissance missions are also concerned with sensor orientation, involving three coordinates (position X and Y, altitude Z) and three angles (roll (ω), pitch (ϕ) and yaw (κ)).[8 9]

The navigation system must be capable of operating inside or outside of a commercial air traffic control environment. It may have to perform under adverse weather conditions, during the day or night, and may be required to operate over long distances or for extended periods of time. The navigation system may be required to record the positions of targets. These data can be recorded as marginal data in the photograph at the time of exposure (for example, see Figure 3.16 on page 46).

Navigation can be divided into four categories:[10]

- contact navigation or "pilotage,"
- deduced reckoning or "dead reckoning,"

• position fixing, and
• the use of integrated systems.

Contact navigation is the visual guidance of an aircraft along recognizable features (such as a river or a road) or along a visually defined path (as outlined on a map). If maps are unavailable for the area or outdated, preliminary reconnaissance may be required for planning. There are several techniques, including high-level overfly, tie-strip flying, side-line navigation and next-line sketching.[11] Of course, contact navigation requires the ground to be visible and therefore cannot be relied upon for an all-weather sensor such as radar.

Deduced reckoning (DR) involves extrapolation of a known position to a future time using direction and distance.[12] Instruments for DR include compasses, airspeed indicators, drift meters, Doppler radar and inertial navigation systems (INS). These are all "self contained" and propagate serious errors over time or distance. INS error propagates with time and therefore is best for fast aircraft. Doppler is the better system for slow aircraft because its error propagates with distance.[13] These errors can be reduced by updating with periodic position fixes.[14]

Position fixing is the determination of a platform's position by pinpointing, using two or more lines of position or using three or more surfaces.[15] Pinpointing, the observation of identifiable landmarks, can be done with sufficient accuracy using a navigation sight. The most common method of position fixing, however, is through lines of position using methods of radio navigation.

Lines of position involve measurement of distance or direction to a ground station. An example is the VLF/Omega long-range navigation system, which makes use of a global network of sixteen very-low-frequency radio transmitters to provide reasonably accurate positional data. Errors may range from 400 metres to 1500 metres at the 95 percent probability level.[16]

The satellite-based Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS) has been developed by the U.S. Department of Defense to provide continuous all-weather global navigation. It is an example of the third method, using intersection of surfaces. The operational system will have 18 satellites with six orbital planes of three satellites each. The satellite orbits will be near-circular, inclined to about 55 degrees, to provide 12-hour periods. This configuration will ensure that at least four satellites will be above the horizon and visible to a GPS receiver at any time. The system specifications require accuracies of 16 meters in instantaneous position and 0.1 meter/second in instantaneous velocity with respect to a global coordinate system.[17]

Information from several navigation aids can be integrated by computer to provide the pilot with a single output. There are numerous advantages to using an integrated, or hybrid, navigation system rather than any single, or even several, individual aids. The accuracies of integrated systems are greater than those achieved by the components individually by using one of the components to correct for errors in other components. Examples include Doppler/inertial hybrids which use an INS to improve the performance of a Doppler and vice versa. There is also a GPS/INS hybrid which uses the high positional accuracy of NAVSTAR to update an INS.[18]

Notes to Chapter VIII

[1] Colvocoresses, Alden P. *et al.*, "Platforms for Remote Sensors." IN: Reeves, Robert G. (ed.) 1975. Manual of Remote Sensing. American Society of Photogrammetry. Falls Church, VA. p. 548.
[2] Bates, Colonel E. ASA, Jr. 1978. "National Technical Means of Verification." RUSI 123(2) p. 67.
[3] Siilasvuo, Ensio. "Verification activities in UNEF II in Sinai." IN: Dahlman, Ola. 1985. Symposium on Verification of Disarmament in Europe. Stockholm. Swedish National Defence Research Institute (FOA) Report A-20036-T3. p.71; Mandell, Brian S. 1987. The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management. Arms Control Verification Studies No. 3. Arms Control and Disarmament Division, Department of External Affairs. Ottawa, Canada. p. 5, 13.
[4] Spencer, R.D. 1979. "Fixed-base large-scale photographs for forest sampling." Photogrammetria 35. p. 127.
[5] Many systems, however, use a real time sensor data link to avoid delays in the delivery of imagery.
[6] A minimum wind layer can be found between adjacent layers of stratospheric easterlies and westerlies which will permit a balloon to hover, or station-keep, over a relatively small area for an extended period. By alternately raising and lowering the altitude of the balloon, it is possible to use the opposing atmospheric flows to permit the balloon to drift back and forth over an area of interest.
[7] Myers, Philip F. 1968. Tethered Balloon Handbook. U.S. Air Force Cambridge Research Labs., AFCRL-69-0017. Prepared by Goodyear Aerospace Corp. p. 14.
[8] If the sensor is a photogrammetric camera, it has nine elements of orientation: the six outlined above as well as three elements of inner orientation, the position x,y of its principal point and the value c of its principal distance or calibrated focal length together with its associated distortion function.
[9] Corten, François L.J.H. 1984. "Navigation and sensor orientation systems in aerial photography." ITC Journal 1984-4 p. 296.
[10] *Ibid.*
[11] Graham, Ron and Roger E. Read. 1986. Manual of Aerial Photography. Focal Press. London, England. pp. 270-278.
[12] Corten, 1984. op. cit. p. 296.
[13] *Ibid.*, p. 301.
[14] *Ibid.*, p. 297.
[15] *Ibid.*, p. 296.
[16] *Ibid.*, p. 298.
[17] Kleusberg, Alfred. 1986. "GPS positioning techniques for moving sensors." Progress in Imaging Sensors, Proc. ISPRS Symposium, Stuttgart, 1-5 September 1986. ESA SP-252. p. 201.
[18] Corten, 1984. op. cit. p. 301.

CHAPTER IX

MAINTENANCE AND SAFETY

9.1 Aircraft maintenance

The cost of aircraft maintenance is one of the largest costs related to the operation of an aircraft. Maintenance costs will probably equal or exceed the cost of fuel. Piston-powered aircraft are usually the least expensive to maintain because of their relative simplicity. Turbo-prop aircraft are several orders of magnitude more expensive to maintain. Maintenance for jet aircraft and helicopters will involve even higher costs.

There are two generally accepted scheduling methods for aircraft maintenance: fixed period and progressive.

Fixed period maintenance is usually used for lighter aircraft. Regular inspections are performed at intervals of 50, 100, 500, and 1000 hours or at some other pre-defined intervals or calendar dates. At the end of each period the aircraft is technically grounded until the inspections have been performed by a certified engineer and the aircraft log book is signed out as airworthy. This system functions well when aircraft readiness at short notice is not required. A major inspection will involve several days of down-time, assuming that any necessary replacement parts are readily available.

The down-time related to inspections can be reduced through "progressive inspections." Using this approach, the aircraft is divided into sections which are inspected at different times called "events."[1] A full cycle, involving all of the scheduled events, must be completed each year. The main advantage of progressive inspections is that the aircraft spends less time out of service for each event. This form of maintenance is especially useful when an aircraft may be required on short notice since, in theory, there is no time at which the aircraft must be grounded.

Progressive maintenance schedules can be tailored to meet an operator's requirements. Mechanics working on a night shift can complete an event in one night and have the plane ready again the next day. Progressive maintenance programs are often computer-controlled and can be useful in projecting aircraft costs and maintenance requirements. The aircraft manufacturer is usually responsible for preparing a maintenance program and getting it approved. Aircraft without computer maintenance programs already available can be very costly to initiate for a single aircraft operation. If the user wishes to change or modify a program, it is necessary to prepare a new schedule and get it approved by the local governing body. This can be a very involved and expensive project.

The inspection program will be complicated further if extensive modifications to the aircraft are required to accommodate sensor packages. This could include cutting camera ports or installing racks to hold the equipment which will have to go into the aircraft cabin. The equipment must be electrically isolated from the aircraft's electrical systems so that neither the airplane nor the sensors will be adversely affected by the operation of the other. Such major modifications to the aircraft will require submission of engineering drawings, analysis by a certified aeronautical engineer, and approval by the governing body before a Certificate of Airworthiness can be issued for that specific aircraft. The modifications could necessitate extra inspections of the aircraft and shorten the overall life of the aircraft.

Some aircraft maintenance is unscheduled. This could be required because of component failures or to comply with airworthiness directives, service bulletins and service letters. The requirement for unscheduled maintenance will partly be determined by the maintenance standard set by the operator. With a low standard of maintenance practice, the aircraft will eventually reach the point where it is only marginally serviceable at any time. This will lead to a disproportionately large amount of unscheduled maintenance. It will reduce the reliability of the operation by increasing the risk of component failures during a mission and that the aircraft will be unserviceable when required.

The facilities required for maintenance of an aircraft depend upon the type of operation and aircraft being considered. Much of the routine servicing may be done on the airport ramp between flights, but there will be times when hangar space will be necessary for mandatory service checks. The type of facility, and the amount of space and time required, will vary with the type of check to be completed. Depending upon the number of hours to be flown and the general condition of the aircraft, a major service facility may only be required in the case of a catastrophic component failure. Provisions should be made with a local service facility to make hangar space and shop facilities available if required. Documented control over any maintenance is mandatory. The work must be carried out by an engineer licensed in the country of the aircraft registry or by a service facility authorized by that country. This country would generally have to be a member of the International Civil Aviation Organization (ICAO).

Field operations can often be conducted so that maintenance requirements are met while not unduly disrupting the mission. If the aircraft is taken to a larger maintenance facility on an annual basis and other maintenance is performed whenever the required facilities are available, a high quality of maintenance can be provided. Inspections in a field operation usually include the airframe, engine, landing gear and control surfaces. Avionics are not touched unless they fail or have reached the manufacturer's maximum recommended time before overhaul. These components are replaced with spares and returned for repairs or overhaul.

Aircraft working away from the main base of operations should carry more spare parts for the aircraft and its equipment. This increases operating costs, but also enhances aircraft serviceability. It is not possible to carry spares for everything, so the operator will have to select the most frequently required parts. A "pipeline" should be established for operations in remote areas to ensure that required parts can be expedited to the site.

Most aircraft will operate under a wide range of conditions without trouble. Nevertheless, the location and climatic conditions must be considered. Extremely high or low temperatures can create problems for flying operations. A temperature of -40°C can prevent engines from starting and shrink wheel rims so that tires go flat. Sensors with moving parts will not function without extensive preheating, but the preheating may create condensation on camera lenses and mirror surfaces. The aircraft might have to be continuously supplied with power to maintain reasonable temperatures inside the aircraft and ensure sensor stability. High temperatures reduce payloads, increase the required runway length for safe operation, and may cause engine distress. Aircraft may need an air-conditioning system to regulate temperature levels in the cabin for any on-board computer systems.

Depending upon the type of operation, aircraft, sensors and navigation systems used, an auxiliary power unit (APU) may be necessary. An APU reduces the requirement for ground support equipment. Some larger aircraft require a half hour warm-up period for the aircraft systems. The required power for the warm-up period will cost less when using an APU, rather than running the main engines. An APU may also be used to supply power for any preflight calibration or servicing required for the sensor package.

9.2 Sensor maintenance

Remote sensing equipment and the platform they are to be mounted in must be compatible. A high performance aircraft will necessitate sensors and other equipment which are of equivalent capability. As well, the equipment must perform well under operational conditions. Sensors will have to accomodate large variations in temperature and atmospheric pressure, vibrations in the aircraft, voltage surges in the electrical supply and interference from radio transmitting equipment.[2] The sensors should be electrically isolated from the plane and have their own electrical power supply or be on separate fuses to prevent power losses to any of the plane's equipment.[3]

Many modern sensors are built to be largely maintenance-free. Nevertheless, there is a wide range of available sensors with considerable variation in required maintenance. Each piece of equipment will have its own weaknesses, with parts which are prone to failure. Manufacturers usually provide a general maintenance schedule and a list of recommended spares.

An experienced operator or technician should be present when operating or servicing new sensors. Sensors should be operated on a test bench before being put into an aircraft. Once a sensor is deemed serviceable, it should be put back into its packing case for shipment or until it is installed in an aircraft. Once installed, a test flight should be done to operate the sensor and determine if everything functions properly. Most problems from a new installation will become apparent during the first 25 to 50 hours of operation.

Aerial cameras usually require little maintenance once they have been installed. The major consideration is to keep the optical surfaces clean and free from scratches. They should be regularly inspected for contaminants such as dirt, oil or fingerprints. Many sensors have solid state components and require even less maintenance than aerial cameras. Moving parts, such as gears in a paper magazine for a printer or the scan mirror of a linescanner, must be lubricated. Regular inspections should be done to look for screws and bolts which have been loosened by vibration and deterioration of cables or connectors. After the initial "burn-in" of a system, most problems can be traced to bad cables or connectors. These kinds of maintenance can be performed on-site by a qualified electronics technician. Some maintenance must be done by the manufacturer. For example, the tape drives used to record data must be shipped back to the manufacturer to be checked and calibrated.

It may not be possible for an operator to do anything about a major malfunction of a sensor. Such a problem may have to be dealt with at the "black box" level by replacing an entire faulty unit with a spare. Even this can be difficult if testing equipment cannot be carried with the aircraft. If a spare is not available on-site, a replacement will have to be ordered from the manufacturer. This could take weeks or months if arrangements have not been made in advance for shipment of replacement parts. Components will often have a "mean time between failure rating," usually stated in hours. Equipment should be returned to the manufacturer for overhaul as it approaches its service life, rather than run the risk of a breakdown.

Local climate has an important influence upon the maintenance requirements for equipment. In dry and dusty areas, cooling fans and filters may become clogged and should be inspected regularly. Motor bearings and moving parts must be sealed or cleaned frequently. Mildew and condensation can form on sensor components, such as circuit boards inside cabinets, if the aircraft is parked outside at night in a humid coastal environment. Fungus can grow on a lens surface after only a few days. The salt in maritime environments encourages corrosion of untreated metal surfaces and damages optical surfaces. All exposed optical surfaces should be cleaned before and after each flight. If a system is not flown daily, it should be powered up for an hour or more each day to "dry it out." If the system will not be used for several days, easily removed equipment should be stored in an air conditioned room rather than in the aircraft.

A daily equipment log should be maintained to keep a record of equipment downtime, the causes of the failures and repairs or maintenance performed on the equipment. This is important if more than one person will be operating and servicing the equipment. It allows recurring problems to be anticipated and perhaps avoided through preventitive maintenance.

9.3 Safety equipment

All aircraft are required to carry safety equipment. The kinds of equipment depend upon the weight and classification of the aircraft. The aircraft should have an Emergency Locator Transmitter (ELT), life jackets if the survey area includes locations over water, and a ration kit for each member of the crew. Standard four-person, eight-day survival packages are available. Portable emergency communication equipment is also recommended. All crew members should be able to use the emergency radio and ELT, and be familiar with emergency first aid procedures. In addition, the aircraft should carry region-specific emergency supplies. Desert operations require extra amounts of water. Arctic operations require heavy clothing, sleeping bags, solid fuel heaters, cooking stove, tent, and snowshoes.

Notes to Chapter IX

[1] McClellan, J. 1982. The Pilot's Guide to Preventive Aircraft Maintenance. Doubleday & Company, Inc. Garden City, N.Y. p. 20.

[2] Lamers, G.L. 1977. "Operational aspects of remote sensing from aircraft." Symposium Luchtwaarneming. Delft, The Netherlands. National Aerospace Laboratory NLR MP 77036 U. (translation by the Department of External Affairs, Canada) p. 4.

[3] *ibid.*

CHAPTER X

INTERNATIONAL OPERATIONS

Conducting international airborne operations adds new dimensions of complexity to those done entirely inside national boundaries. Getting aircraft, crew and supplies into a foreign country, and then arranging for the necessary support facilities once inside, can cause delays which are costly for commercial survey operations. These difficulties might entirely compromise the effectiveness of airborne operations intended for verification of an arms limitation agreement.

Avoiding these operational problems will first require an understanding of what they are. Section 10.1 will examine some of the difficulties of getting into and out of foreign countries and operating in those countries for normal commercial survey operations. This will illustrate some of the problems which would be encountered by operations in a verification context if specific arrangements were not made to avoid them. Many of these arrangements will require cooperation from the State to be overflown. Therefore, they should be negotiated beforehand and included as treaty provisions. Section 10.2 will examine existing international agreements to see how similar problems have been avoided in those cases.

10.1 International commercial operations

a) *Getting in and out*

International movement of personnel, aircraft and equipment can be complex. Each country has it's own requirements to allow people, aircraft, and equipment in or out. The rules differ according to the nationalities of the personnel, intended lengths of stay in the country, type of work to be done, and who the work is to be done for. Some countries do not allow expatriates in without proof of onward destination. Failure to have such proof could result in being refused entry into a country.

Personnel should carry a valid passport and current vaccination certificate. Medical and visa requirements are not the same for every country. An embassy for the country in which the flying is to be done can provide the necessary information, for example, the type of visa required (if any), how long they will be valid for, whether they can be extended or renewed, and the documents and application forms needed to apply for them. Work permits may be necessary for each member of the crew. Embassies usually require 10 to 20 passport photographs of each individual for a visa. Crew members should carry 15 to 20 extra passport photos with them for use inside the country. Most embassies can issue a tourist visa within a period of several hours to several days, but business visas and work permits can take weeks. In many countries, it may take twice as long as local officials recommend to complete the necessary paperwork. Major religious or holiday seasons will require extra time and patience.

Many countries restrict the use of non-government aircraft. Before arriving, it is necessary to confirm that the local authorities will allow a foreign-registered aircraft to be imported and used in their airspace. Unless the necessary permits are secured before the aircraft arrives on-site, the aircraft may be refused entry or impounded when it arrives. Obtaining export permits to get an aircraft out of the country can also require substantial lead time. Customs bonds might have to be posted against the possibility of dutiable goods not being re-exported.

Shipments of material to the operating base should be divided into consumable and non-consumable goods. Consumable goods include office supplies, film, chart paper, aircraft maintenance items which are replaced or discarded during operations and items which may be left on-site. This will facilitate re-export and limit payment of duties. Customs officials can insist that the same number of boxes leave the country as went in, and that the contents of each box be the same as when imported, including the serial numbers on components. This can cause problems if a new part is installed and the defective part is put back into the box.

Customs officials may not allow certain types of equipment into the country. Equipment with descriptions including words such as "radar," "radio," "transmitter" or "camera" may be stopped in customs and could take weeks or months to extract. Items which customs will refuse import on when shipped separately may sometimes be imported in the aircraft itself if listed as part of the installed equipment. These items would enter the country under the general import documents of the aircraft and would have to leave the country in the same manner. Some equipment is not exportable to certain countries for security reasons. Any computer equipment or sensors which could be construed to have a potential military use, in particular, may not be exportable.

Physically getting the aircraft from its home base to the survey site can pose problems. While simple in theory, the practical aspects of getting an aircraft to a country several thousand miles away can be quite difficult. Care must be taken to avoid entering the host country from a country which is currently hostile to it. There are companies which specialize in ferrying aircraft. They are experienced in obtaining ferry and overflight permits and are aware of fuel availability and quality, areas to avoid and how to deal with local officials. A customs broker might be retained to meet the aircraft and personnel upon arrival, particularly if they are carrying anything which could be interpreted as commercial goods.

An advance team is required to liase with the local authorities. They will probably have to provide maps (if available) and details regarding planned overflights. Information which they will likely have to provide includes the number of personnel, expected length of stay in the country, types of aircraft and sensors to be used, purpose of the overflights and sponsor for the project. In many countries, government departments do not communicate with each other. Military clearance to fly will not necessarily mean civil permission or vice versa.

The advance team will also have to contact the local customs officials to determine local restrictions. If equipment will need to be installed or tested once the aircraft is in the country, the advance team will have to arrange for aircraft parking and access for the crew to the area. This will usually require security passes for the crew.

Some countries pay their officials very poorly. These officials will often supplement their income with bribes to get almost anything done. The advance team will need to find out how the local system works and be prepared to provide the appropriate sums of money to expedite things.

b) *Operating in foreign countries*

No two countries or missions are exactly alike. Conditions which applied last month may have little or no bearing on those in the same country at a later date. There is no substitute for having a crew with experience in the specific country. Well-placed local agents who are familiar with the details of local requirements are also necessary.

The local political situation needs to be considered before entering the country. In some countries, rapid changes of government or policy can occur. After such changes, it may simply be necessary to re-acquire the relevant entry, exit, and flying permits. However, it could also result in being asked to leave the country. A new government may not permit expatriates in the country or allow foreign aircraft to operate in their airspace. Aircraft have been impounded and the crew physically escorted out of the country in certain cases.

Some countries require a flight permit for each flight and authority to fly over any specific target. Officials need maps of the areas to be overflown and request notification of the particular area to be covered on each flight. Military authorities commonly insist upon having a security officer on-board the aircraft during each overflight. If the aircraft must make an emergency or unscheduled landing, the security officer can be useful to explain the situation to local officials. The military sometimes demand access to the recorded data or photography and to retain anything which they believe might infringe upon national security.

In some instances, it can be difficult for a foreign-registered aircraft to get permission to work. Local authorities may insist upon outfitting locally owned and operated aircraft for the work. They will also usually insist upon local people being involved in the daily operations. If local aircraft are used, but operated by the contractor's personnel, it will probably be necessary for the aircraft engineer and pilot to obtain local licenses. If the contractor's own aircraft is used, local authorities may insist that the aircraft registration be changed to local registry and that the aircraft be operated according to the standards set by the local civil aviation department. Any modifications made to the aircraft, such as camera ports, will need to be documented and approved.

When active sensors will be required for a survey, local authorities may impose operating restrictions upon where the instruments may be used. Minimum "safe" flying heights may be established for overflying populated areas or they may restrict use of the sensors entirely to unpopulated areas. Special permission may be necessary for low-level flying.

Copies of the Aeronautical Information Publication (AIP) will be required to select airstrips for use as operational bases or refueling stops during the survey. The type of aircraft, field elevation above sea level, runway length, and local temperatures will determine which airstrips are suitable. Many airfields may be too short, have poor security for aircraft or no facilities.

Fuel availability must be determined. Some airports stock only a limited amount of fuel, or even none at all. If Avgas is required, it may be necessary to pre-position fuel in drums or bladder tanks. Sufficient lead time must be allowed to purchase and pre-position fuel, although it may be possible to purchase fuel directly on an "as required" basis at major airports. Prior arrangements for payment should be made. Cash payment or payment in hard currency rather than local currency may be required in many places.

Unless the advance team determines that parts and service facilities which meet the requirements of the aircraft's country of registration are available, spares for the aircraft should be brought with the aircraft. A certified aircraft engineer should be included in the crew, since there may be no qualified local engineers or their license may not be recognized by the country of aircraft registry.

Accommodation is usually available in any place large enough to have an airport. However, the quality can range from luxury hotels to mud huts. If the project is to last more than two or three months in one site, it may be better to rent a furnished house. Meal times can then be suited to the needs of the aircrew and food quality can be more carefully scrutinized. Arrangements must also be made for office space.

Transportation within the country must be investigated prior to the crew's arrival. Reliable transportation can be costly, public liability insurance expensive or non-existent, and local driving practices can be terrifying. Hiring a car with a driver who can speak the same language as the crew may be better than using a rental car driven by crew members. Persons wishing to drive themselves will require a valid international driver's license, and may also have to acquire a local driver's license.

A communications network should be included for the base of operations. Telephone service to the outside world may be unreliable. Dealing with telephone operators who cannot speak the same language can be a problem. The operations base should be equipped with telex and/or FAX facilities. High frequency radios are recommended to maintain contact between the aircraft and the operations base. The advance team will need to contact the local communications department to arrange for operating permits and frequencies. In the event of an aircraft emergency, the aircrew can advise their operations base. In many countries, search and rescue facilities are non-existent and the operator must look after their own crew in case of an accident.

10.2 The arms limitation context

Many of the difficulties described in the previous section could be avoided. In the context of an arms limitation agreement, special measures would have to be negotiated to avoid many of these problems. These would include special customs clearance procedures for personnel and equipment, privileges and immunities for personnel, use of airfields and other support facilities, and freedom of movement for the aircraft and crew during inspections and at other times. Some of the provisions included in existing agreements can provide an indication of the measures which might be considered.

Special arrangements are typically included to prevent delays because of customs procedures. Members of United Nations peacekeeping forces are exempted from the normal passport and visa regulations, immigration inspection and restrictions on entering or departing the host State. Instead, they are provided an individual or collective movement order issued by the Commander or appropriate authority of the Participating State to which the member belongs and a personal identity card issued by the Commander under the Authority of the Secretary-General of the United Nations.[1] In the case of first entry, a personal military identity card issued by the appropriate authorities of the Participating State will be accepted in lieu of the Force identity card.[2] Safeguards inspectors of the IAEA use the United Nations *laissez-passer*, recognized by participating States as valid travel documents.[3] Applications for visas, where required, from officials of the Agency holding United Nations *laissez-passer*, when accompanied by a certificate that they are travelling on the business of the Agency, are to be "dealt with as speedily as possible" and those officials are to be granted facilities for speedy travel.[4] Under the terms of the Stockholm Agreement, inspectors are issued diplomatic visas and are to be allowed to enter the territory of the receiving State within 36 hours of the issuance of a request for inspection.[5]

Under the INF Treaty, each Party must provide a list of it's proposed inspectors and aircrew members to the other Party no later than one day after entry into force of the Treaty.[6] Each Party reviews the lists of inspectors and aircrew members proposed by the other Party and can reject any proposed individual within 20 days.[7] For those individuals who are accepted,

> "[w]ithin 30 days of receipt of the initial lists of inspectors and aircrew members, or of subsequent changes thereto, the Party receiving such information shall provide, or shall ensure the provision of, such visas and other documents to each individual to whom it has agreed as may be required to ensure that each inspector or aircrew member may enter and remain in the territory of the Party or basing country in which an inspection site is located throughout the in-country period for the purpose of carrying out inspection activities in accordance with the provisions of this protocol. Such visas and documents shall be valid for a period of at least 24 months."[8]

For inspections to be carried out on the territory of Basing Countries, the Inspected Party provides the Basing Countries with the initial lists of inspectors and aircrew members for approval, and then

> "[w]ithin 25 days of receipt of the initial lists of the inspectors and aircrew members or of any change to these lists, the Basing Country shall provide the persons, who have been given approval, visas and further documentation as may be necessary to enable each inspector or aircrew member to enter the territory and to remain in order to conduct the inspection activity according to the rules of the Inspection Protocol. Such visas and documents shall be valid for a period of at least 24 months."[9]

Aircraft can similarly be expedited into a country using special procedures. Aircraft used to transport inspectors for the INF Treaty are given a standing diplomatic clearance number which is subsequently included in the remarks section of flight plans along with the notation "Inspection aircraft. Priority clearance processing required."[10] The in-country escort is responsible for expediting the entry of the inspection team and aircrew, their baggage, and equipment and supplies necessary for inspection, into the country in which the inspection site is located.[11] Equipment and supplies accompanying the inspection team is exempt from import and export duties. It is subject to inspection. The provisions of the Protocol on Inspections of the INF Treaty specify,

> "Equipment and supplies which the inspecting Party brings into the country in which an inspection site is located shall be subject to examination at the point of entry each time they are brought into that country. This examination shall be completed prior to the departure of the inspection team from the point of entry to conduct an inspection. Such equipment and supplies shall be examined by the in-country escort in the presence of the inspection team members to ascertain to the satisfaction of each Party that the equipment and supplies cannot perform functions unconnected with the inspection requirements of the Treaty. If it is established upon examination that the equipment or supplies are unconnected with these inspection requirements, then they shall not be cleared for use and shall be impounded at the point of entry until

the departure of the inspection team from the country where the inspection is conducted."[12]

Designated "points of entry" facilitate passage into and out of the territory of the inspected Party. The Stockholm Agreement states that the receiving State should "designate the point(s) of entry as close as possible to the specified area" and that the "receiving State will ensure that the inspection team will be able to reach the specified area without delay from the point(s) of entry."[13] The INF Treaty lists specific points of entry in the text of the Protocol Regarding Inspections.[14] Aircraft must enter the country in which an inspection is to take place using an agreed international airway to one of the designated points of entry.[15] Points of entry can have trained personnel and facilities to expedite the entry or exit of an inspection team, aircraft and aircrew, baggage, and the equipment and supplies required for the inspection.

Arrangements for locally-obtained supplies and services or access to facilities and resources of the host country should be outlined in an agreement. A treaty can include provisions for accommodation, working areas, food, medical services, in-country transportation, and communications facilities. The INF Treaty requires the inspected Party to provide "parking, security protection, servicing and fuel" for the airplane of the inspecting Party which transported the inspectors into the country.[16]

In some cases, the host State is responsible for the cost of the arrangements while in others, the inspecting State or agency must pay for them. The Stockholm Agreement specifies that the inspection expenses will be incurred by the receiving State except when the inspecting State uses its own aircraft and/or land vehicles and that the travel expenses to and from the point(s) of entry will be borne by the inspecting State.[17] The INF Treaty states that "[a]ll the costs in connection with the stay of inspectors carrying out inspection activities ... on the territory of the inspected Party, including meals, services, lodging, work space, transportation and medical care shall be borne by the inspecting Party."[18] It also specifies that the inspecting Party must bear the cost of fuel and servicing for the airplane of the inspecting Party at the point of entry.[19] The Status of Forces agreement for U.N. peacekeeping forces specifies goods and services which are to be provided at no charge to the force, such as buildings,[20] and which will be provided at the normal rate, such as water, electricity and other public utilities.[21]

Personnel involved in inspections and similar activities are provided privileges and immunities. Inspectors under the Stockholm Agreement are granted the full privileges and immunities in accordance with the Vienna Convention on Diplomatic Relations.[22] Under the INF Treaty, inspectors are provided a limited set of privileges and immunities which includes only some of those outlined in the Vienna Convention.[23] Experts performing missions for the United Nations are provided privileges and immunities under the Convention on the Privileges and Immunities of the United Nations.[24]

Full diplomatic status provides more privileges and immunities than would be required by an inspection staff. Inspection personnel would probably be granted only those privileges and immunities which are necessary for the independent exercise of their duties. Immunity from legal process is granted to prevent potential harrassment of inspection personnel through civil or criminal court proceedings, and thereby to preserve the independence and immunity of the inspection organization itself. This is intended to permit personnel to carry out their duties with confidence, knowing that they are protected from personal liability with regard to their official acts. Similarly, personal inviolability may be granted so that personnel will not be liable to physical arrest or detention.

This does not mean that personnel involved in verification-related tasks can violate local laws with impunity. For example, the immunity granted to inspectors and aircrew under the INF Treaty may be waived by the Inspecting Party in those cases when "it is of the opinion that immunity would impede the course of justice and that it can be waived without prejudice to the implementation of the Treaty."[25] Personnel serving with peacekeeping forces are not subject to the criminal or civil jurisdiction of the host country.[26] They are subject, however, to the jurisdiction of the respective Participating States in respect to criminal matters[27] and to the jurisdiction of a "Claims Commission," a body established to settle civil disputes involving the Force or its members.[28]

Official and personal property of inspection personnel can be protected from search and seizure. All papers and documents held by the Representatives of Members of the United Nations and Experts on Missions for the United Nations are inviolable according to The Convention on the Privileges and Immunities of the United Nations.[29] In general, all documents belonging to or held by the United Nations are inviolable wherever they may be located.[30] Similarly, the papers and correspondence of inspectors and aircrew members under the INF Treaty enjoy the inviolability accorded those of diplomatic agents pursuant to Article 30 of the Vienna Convention on Diplomatic Relations.[31]

More generally, the premises and property of inspection staff should be provided protection from search or seizure by the agreement. The living quarters and office premises occupied by inspectors involved in continuous portal monitoring, as specified by Article XI, paragraph 6 of the INF Treaty, are provided the inviolability and protection accorded the premises of diplomatic agents pursuant to Article 30 of the Vienna Convention.[32] As well, the aircraft of the inspection team is inviolable.[33] Similarly, the premises used by U.N. peacekeeping forces for headquarters, camps or other uses are "inviolable and subject to the exclusive control and authority of the Commander, who alone may consent to the entry of officials to perform duties on such premises."[34]

Many areas to be inspected would normally be out of bounds for foreign personnel.

An agreement must provide inspection personnel with the freedom of movement to accomplish their task. At the same time, it must respect the security requirements of the inspected State. Arrangements for a particular agreement will depend upon factors such as the required lengths of stay for foreign personnel, the number of personnel and amount of equipment involved, and whether the agreement involves an "adversary" or "impartial" system of inspection.[35] Under an "adversary" system of inspection, freedom of movement is likely to be more constrained than for a "neutral" system.

Peacekeeping forces, are effectively granted complete freedom of movement:

> "The Force and its members together with its service vehicles, vessels, aircraft and equipment shall enjoy freedom of movement throughout Cyprus."[36]

> "The Force shall have the right to the use of roads, bridges, canals and other waters, port facilities and airfields without the payment of dues, tolls or charges either by way of registration or otherwise, throughout Cyprus."[37]

In contrast, freedom of movement for inspectors under the INF Treaty is controlled to provide access only to facilities which are relevant to the Treaty. Aircraft bringing inspectors into the country must use an agreed international airway and point of entry.[38] Once they have arrived in the country, inspectors are accompanied by an in-country escort and the aircrew of the inspecting Party is accompanied by a diplomatic aircrew escort.[39] There is total escort coverage at all times; billeting, transportation, inspection activities, meals, and any leisure activity is done under continuous supervision.[40] The inspectors are permitted access only to the agreed inspection sites, with one exception. Personnel involved in the continuous portal monitoring are allowed to travel within 50 kilometers of the inspection site for leisure activity "with the permission of the in-country escort, and as considered necessary by the inspected Party, shall be accompanied by the in-country escort."[41]

Regulations regarding how inspections are to be conducted under the INF Treaty are specified, in great detail, in the Treaty.[42] Inspectors are restricted to looking in buildings, vehicles or structures which could contain the smallest treaty-limited item. Manning boards, maintenance charts and posted instructions of any kind which have nothing to do with the Treaty are covered. Items which cannot be moved and are not related to the purposes of the inspection can be covered in such a way that the inspectors can assure themselves by making simple measurements that the item is too small to contain a treaty-limited item.[43]

The 1986 Stockholm Agreement permits the use of aircraft and helicopters for inspections, albeit primarily as platforms for human observers, not sensors. Nevertheless, the Stockholm Document provides an important precedent for the use of aircraft as well as for the kinds of provisions which must be included to ensure effective inspections:[44]

"(89) The inspecting State will specify whether aerial inspection will be conducted using an airplane, a helicopter or both. Aircraft for inspection will be chosen by mutual agreement between the inspecting and receiving States. Aircraft will be chosen which provide the inspection team a continuous view of the ground during the inspection.

(90) After the flight plan, specifying, *inter alia*, the inspection team's choice of flight path, speed and altitude in the specified area, has been filed with the competent air traffic control authority the inspection aircraft will be permitted to enter the specified area without delay. Within the specified area, the inspection team will, at its request, be permitted to deviate from the approved flight plan to make specific observations provided such deviation is consistent with paragraph (74) as well as flight safety and air traffic requirements. Directions to the crew will be given through a representative of the receiving State on board the aircraft involved in the inspection.

(91) One member of the inspection team will be permitted, if such a request is made, at any time to observe data on navigational equipment of the aircraft and to have access to maps and charts used by the flight crew for the purpose of determining the exact location of the aircraft during the inspection flight.

(92) Aerial and ground inspectors may return to the specified area as often as desired within the 48-hour inspection period."

Of course, new provisions will need to be considered if the use of airborne sensors for inspection is to be realized. These might include measures to define permitted and/or restricted sensors, where the sensors may or may not be used, and to outline how the data is to be handled after each overflight. As has been outlined above, however, most of the provisions will not be new, but variations of those which have been previously included in other agreements.

Notes to Chapter X

[1] For example, see Para. 7, p. 16, in "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." 31 March, 1964. Exchange of letters constituting an Agreement between the United Nations and the Government of the Republic of Cyprus concerning the Status of the United Nations Peace-keeping force in Cyprus. Annex I. Canada Treaty Series 1966 No. 4.

[2] *Ibid.*

[3] No. 5334. Agreement on the Privileges and Immunities of the International Atomic Energy Agency. Approved by the Board of Governors of the Agency on 1 July 1959. 374 UNTS 148, registered by the International Atomic Energy Agency on 13 September, 1960. Article IX(29). Also published as: Agreement on the Privileges and Immunities of the International Atomic Energy Agency. International Atomic Energy Agency INFCIRC/9/Rev.2. 26 July, 1967. Article IX(29).

[4] *Ibid.*, Article IX(30).

[5] Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe Convened in Accordance with the Relevant Provisions of the Concluding Document of the Madrid Meeting of the Conference on Security and Co-operation in Europe. Stockholm, 1986. Para. 79.

[6] Protocol Regarding Inspections Relating to the Treaty Between the United States of America and the Union of Soviet Socialist Republics On the Elimination of Their Intermediate-range and Shorter-range Missiles, signed in Washington on 8 December, 1987. Article III. 2.

[7] *Ibid.*, Article III. 3.

[8] *Ibid.*, Article III. 5.

[9] Treaty of Berlin, 11 December, 1987. Article IV. 2.; The Brussels Treaty, 11 December, 1987. Article IV. 2. QUOTED IN: Sur, Serge. 1988. Verification problems of the Washington Treaty on the elimination of intermediate-range missiles. United Nations Institute for Disarmament Research. Research Paper No. 2. p. 48 and 52.
[10] Protocol Regarding Inspections, op. cit., Article IV. 3.
[11] *Ibid.*, Article V. 1.
[12] *Ibid.*, Article V. 4.
[13] Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe, op. cit., para. 81.
[14] Protocol Regarding Inspections, op. cit., Article I. 7.
[15] *Ibid.*, Article III. 8.
[16] *Ibid.*, Article V. 6.
[17] Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe, op. cit., para. 96.
[18] Protocol Regarding Inspections, op. cit., Article V. 5.
[19] *Ibid.*, Article V. 6.
[20] For example, see Para. 19, p. 20, in "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." op. cit.
[21] See Paras. 34-36, p. 28, in "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." op. cit.
[22] Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe, op. cit., para. 85.
[23] Provisions on privileges and immunities of inspectors and aircrew members, Annex to the Protocol Regarding Inspections of the Washington Treaty.
[24] Convention on the Privileges and Immunities of the United Nations. 1 UNTS 15 and 90 UNTS 327 (corrigendum to vol. 1), adopted by the UNGA on 13 February, 1946.
[25] *Ibid.*, Article 4.
[26] For example, see Para. 12(a), p. 18, in "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." op. cit.
[27] *Ibid.*, Para. 11, p. 16.
[28] *Ibid.*, Para. 38(b), p. 30.
[29] Article IV. 11(b) and Article VI. 22(c).
[30] Article II. 4.
[31] Provisions on privileges and immunities of inspectors and aircrew members., op. cit., Para. 3.
[32] *Ibid.*, Para. 2.
[33] *Ibid.*, Para. 3.
[34] For example, see Para. 19, p. 20, in "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." op. cit.
[35] An impartial system is based upon personnel involved in verification activities having no prior commitment to the interest of any party to the agreement but only to proper functioning of the agreement. The organization and its personnel must be perceived by the inspected states as neutral. This might involve participation of neutral governments, selection of individuals who are considered neutral by the inspected states, or creation of an organization to be staffed by "international civil servants." An adversary system involves direct use of the personnel and resources of national governments which have entered into an arms control agreement and have direct interest in the compliance of other parties to the treaty. Personnel involved in "adversary" inspections remain under the control of their national governments. Alternative organizational principles for arms control verification are discussed in Linde, Hans. "Organization of a 'Mixed' National and International Inspectorate." IN: Institute for Defense Analyses. Verification and Response in Disarmament Agreements. Woods Hole Summer Study, Annex Volume II, Part II, Appendix A. Washington, D.C. November, 1962. pp. 72-84.
[36] "Letter from the Secretary-General of the United Nations to the Minister for Foreign Affairs of Cyprus." op. cit., para. 32, p. 26.
[37] *Ibid.*, para. 33., p. 28.
[38] Protocol Regarding Inspections, op. cit., Article I. 7. and Article III. 8.
[39] *Ibid.*, Article V. 1.
[40] "Insights of an On-Site Inspector." Interview conducted by Robert Travis Scott with Brigadier General Roland Lajoie, Director of the U.S. On-Site Inspection Agency (OSIA). Arms Control Today 18(9). p. 6.
[41] Protocol Regarding Inspections, op. cit., Article VI. 6.
[42] *Ibid.*, Articles VII to IX.
[43] "Insights of an On-Site Inspector," op cit., p. 4.
[44] Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe, op. cit., paras. 89 to 92.

CHAPTER XI

CONCLUSIONS

Aerial reconnaissance has been used extensively for many years to gather information regarding military forces. To the limited extent that it has been used for verification-related activities, aerial reconnaissance has been considered very useful. Overflights by the American SR-71 were an important part of the verification regime of the Sinai Disengagement Agreements and the Egypt-Israel Peace Treaty of 1979. More commonly, aerial reconnaissance has been used by one country to gather intelligence about another's military forces. Examples from the well-documented history of the U.S. reconnaissance program clearly illustrate how airborne systems would be useful for verification-related purposes. Aerial reconnaissance provided data which alleviated fears regarding the "bomber gap," and afterwards, the "missile gap." It provided crucial early indications of the introduction of medium-range ballistic missiles into Cuba and then provided the required intensive imagery coverage throughout the Missile Crisis. In 1978, SR-71 overflights were used to confirm Soviet assertions that MiG-23E interceptors, and not the visually-similar MiG-23F nuclear-capable ground attack aircraft, had been delivered to Cuba.

The limited use to date of aerial reconnaissance for arms limitation purposes has, at least in part, been due to the requirement for consent by the subjacent State. The legality of aerial reconnaissance depends upon the locus of the activity. Peripheral reconnaissance is permissible since it is done from international airspace. Penetrative reconnaissance, done from within national airspace, is illegal in the absence of consent. For safety, overflights for verification must only be conducted with the consent of those States overflown. Each State has complete and exclusive sovereignty over the national airspace above its territory. But a State can consent at any time to overflights by any aircraft, including military aircraft of foreign States. Such permission, however, cannot be assumed. Once provided with the necessary permission, the aircraft must still comply with any restrictions which the subjacent State might place upon its freedom of movement.

There are numerous types of relevant sensors, each with their own particular advantages and disadvantages. Photographic systems provide the highest spatial detail but have limited spectral characteristics. They require photographic processing and are primarily restricted to daytime use and clear sky conditions. Thermal infrared systems produce images which can often be used to detect human activity, since heat is typically associated with human activity. They can be used during the night as well as the day, but also need clear skies. Multispectral sensors can distinguish subtle spectral differences between surfaces, but cannot match the spatial detail which can be provided by aerial photography. Once again, clear skies are required. Radar can be used regardless of cloud cover. It can also be used in the daytime or at night. However, it is incapable of recording fine spatial detail.

For most operations, commercially-available twin-engined turboprop or turbo-charged piston-engined aircraft will be the best, all-round platforms. Jet aircraft can be used for high altitude missions or when long transit distances are required. Helicopters are good for low altitude work in rough terrain. They can hover in one spot, allowing human observers time to carefully examine a target, and can land at unprepared sites for further investigation on the ground. Balloons can provide a high capacity platform and can remain stationary over a particular area for long periods.

Historically, aerial reconnaissance systems have been considered too intrusive for most verification applications. However, it is possible to limit the intrusiveness to protect the security interests of an inspected State. Host country personnel can accompany the aircraft during overflights. If required, overflights can be restricted to specific areas. Aircraft can be inspected prior to an overflight to ensure that only agreed sensors are being used. Finally, a copy of the acquired data might be supplied to the inspected State for their review.

Airborne systems are suited to a multilateral environment. The technology for airborne reconnaissance systems is more generally available than that required for satellite-based systems. Civilian remote sensing systems can probably suffice and may even be preferable to the more sensitive military systems. The cost to acquire an airborne capability for verification purposes will be less than what would be necessary to develop a space-based system. Low-cost airborne systems could be used to produce useful data, although more sophisticated sensors would probably do a better job.

Aerial reconnaissance systems are flexible. Sensors and platforms can be selected to provide imagery suited to a particular task. Scale of the imagery can be varied; large scale imagery to see fine details and smaller scale images to cover large areas. Acquisition of imagery can be scheduled to provide coverage at a specific time. Many sensors can use a downlink to provide real-time data. Otherwise, the imagery can be recorded during the overflight on magnetic tape or film and the interpretable image produced once the aircraft returns to base. Finally, aircraft and the sensors on board can be repaired or replaced more easily than comparable space-based systems.

Since U.S. President George Bush proposed that the 1955 "Open Skies" Plan be reconsidered, there has been renewed interest in the potential of aerial reconnaissance systems for verification and confidence building. Airborne systems have, potentially, a major role to play in the verification of multilateral arms limitation agreements. General acceptance of aerial reconnaissance as a legitimate tool for verification will put the means of gathering overhead imagery for verification within the financial and technical reach of more countries. In this respect, it has the potential to fundamentally alter the climate in which multilateral arms limitation takes place.

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Disarmament: Problems related to Outer Space, Geneva, UNIDIR, 1987, 190 p. United Nations publication, Sales No. GV.E.87.0.7. Existe aussi en français: *Désarmement: problèmes relatifs à l'espace extra-atmosphérique.*

Interrelationship of Bilateral and Multilateral Disarmament Negotiations/Les relations entre les négociations bilatérales et multilatérales sur le désarmement, Proceedings of the Baku Conference, 2-4 June 1987/Actes de la conférence de Bakou, 2-4 juin 1987, Geneva, UNIDIR, 1988, 258 p. United Nations publication, Sales No.GV.E./F.88.0.1.

Disarmament Research: Agenda for the 1990's/La recherche sur le désarmement: Programme pour les années 90, Proceedings of the Sochi Conference, 22-24 March 1988/Actes de la conférence de Sotchi, 22-24 mars 1988, Geneva, UNIDIR, 1988, 165 p. United Nations publication, Sales No. GV.E/F.88.0.3.

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Les forces classiques en Europe et la maîtrise des armements, par Pierre Lellouche and Jerôme, Paolini eds., (IFRI), 1989, 88 p. Publication des Nations Unies, numéro de vente: GV.F.89.0.6. Also available in English: *Conventional forces and arms limitation in Europe.*

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Forthcoming/ à paraître

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