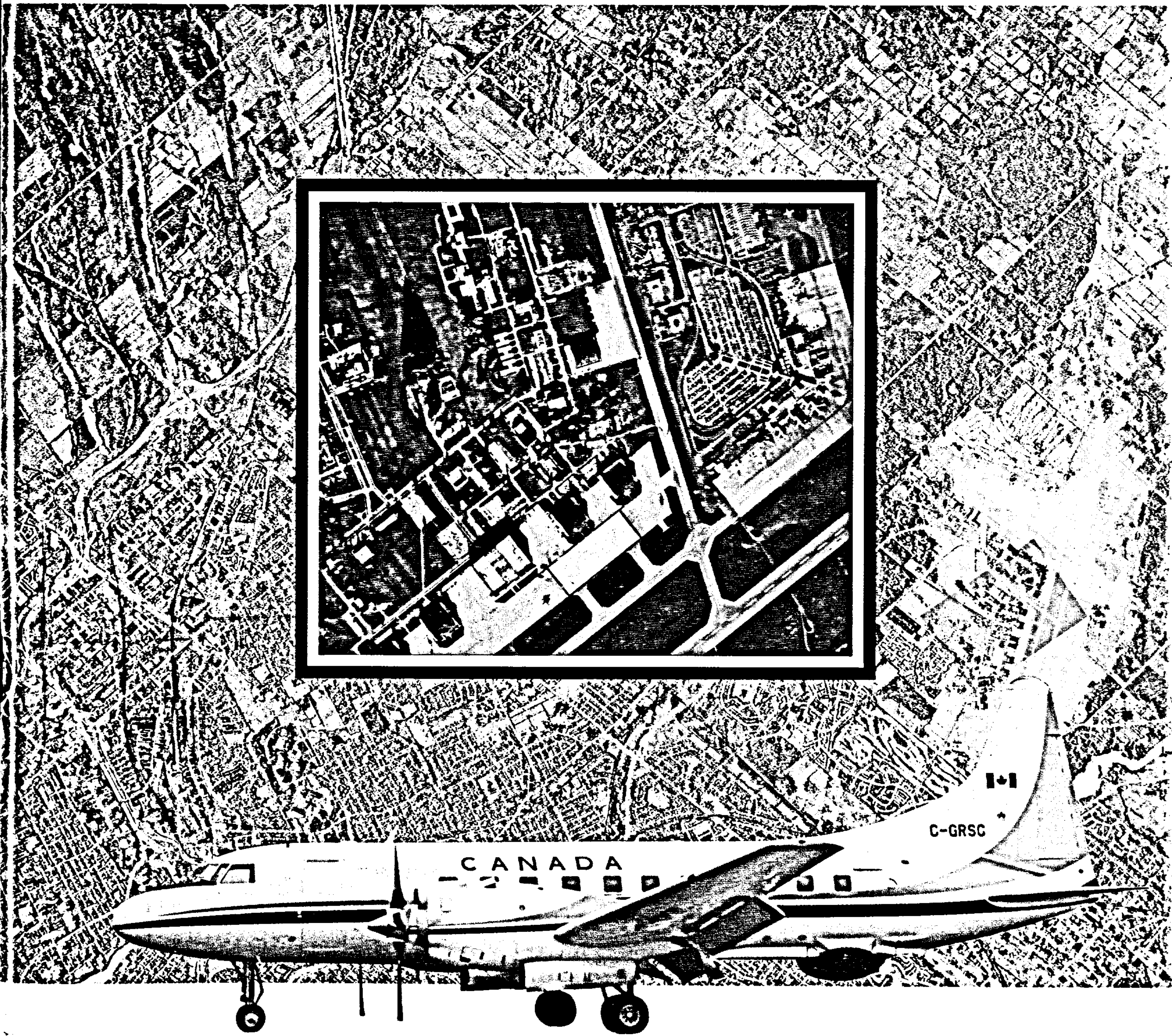
OPEN SKIES

BACKGROUNDER NO. 5

SECOND TRIAL OVERFLIGHT · JANUARY 1992



OPEN SKIES

BACKGROUNDER NO. 5

CANADA/HUNGARY OVERFLIGHT

JANUARY 1992
OTTAWA, ONTARIO

The image on the cover was obtained using a synthetic aperture radar (SAR) and covers the metropolitan area of Ottawa including Ottawa International Airport. Although there is a tendency to view SAR imagery as being similar to regular aerial photography, they are significantly different for interpretation purposes because of the technical means by which the images are acquired. The insert on the cover is an air photo of the terminal at the airport.

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Open Skies: Canada/Hungary Overflight

1.0 Introduction

In September 1989, Prime Minister Brian Mulroney announced that Canada would host the first international conference with the purpose of negotiating an Open Skies regime. The conference on Open Skies was scheduled to begin in Ottawa on 12 February 1990, and was opened by foreign ministers from 23 nations of NATO and WTO. In preparation for this conference, Canada and Hungary conceived the idea of a trial overflight of Hungary.

This first Canadian-Hungarian Open Skies flight took place on 6 January 1990. A Canadian Forces CC130 Hercules transport aircraft flew a large figure eight pattern over Hungary covering a number of Hungarian and Soviet military facilities. It was agreed, by both sides, that a reciprocal flight would occur, in Canada, when there would be significant progress in the negotiations.

A second conference, hosted by the Hungarian government, was held in Budapest from 23 April to 10 May 1990.

Although a number of fundamental principles were agreed at these conferences, substantial differences persisted in certain areas and the pace of negotiations slowed considerably.

Canada and Hungary continued to coordinate their efforts in promoting a new round of negotiations, which began in Vienna in September 1991.

On 6 December 1991, the Secretary of State for External Affairs invited Hungary to conduct a reciprocal trial overflight of Canadian territory involving an enhanced technical program. This would include the use of sophisticated sensors such as synthetic aperture radar (SAR), low light level television (LLLTV) and fixed optical camera. The Hungarian delegation arrived in Ottawa on 13 January 1992 to commence a one week program.

2.0 Aim

The aim of this joint program was to contribute to the negotiations by demonstrating some of the sensor capabilities and limitations, by simulating the exchange of flight recorded data, and by presenting the results to negotiators in Vienna. It also provided a unique opportunity to test some operational Open Skies procedures still under negotiation in Vienna.

The Hungarian notification for the Open Skies trial overflight was sent to Canada through the CSCE communication network. The mission plan was submitted by Hungary and accepted by Canada.

3.0 Trial Overflight Program

Preceding the airborne part of the program were two days of briefings, technical discussions and demonstrations that helped set the stage for the flight trials. These events provided the opportunity to representatives of both countries to exchange views and further develop their mutual understanding on the technical requirements of Open Skies missions.

The subjects discussed and briefed were:

a. Synthetic aperture radar (Appendix A),

b. Aerial photography,

c. Mission planning (Appendix B),

d. Sensor development and aircraft modification engineering (Appendix C).

The airborne part of the program involved two flights. The first one, on 15 January 1992, was an orientation/familiarization flight carried out using a CC115 Buffalo transport aircraft. It flew the same routing as the sensor flight of the next day and allowed for visual observation and recognition of the sensor targets (FIGURE 1). A total of fourteen observers from both countries participated. This flight also tested procedures for the notification and clearance of restricted areas. The aircraft overflew Canadian Forces Air Base Trenton, Canadian Forces Army Base Petawawa, two commercial nuclear power plants and a major industrial automobile manufacturing facility in Oshawa.

The flight planning for the second, sensor-equipped flight was executed by the Canada Center for Remote Sensing (CCRS) based upon the agreed mission plan (FIGURE 2). Routings and altitudes were modified by CCRS to make optimum use of the sensor capabilities and aircraft restrictions. The aircraft used was a Convair 580 equipped with:

a. CCRS synthetic aperture radar (C-band with a 6 metre resolution);
b. Fixed optical camera (RC-10 with a 152 millimetre focal length lens);
c. Low light level TV (RCA TC 1030/H); and
d. Standard colour video camera.

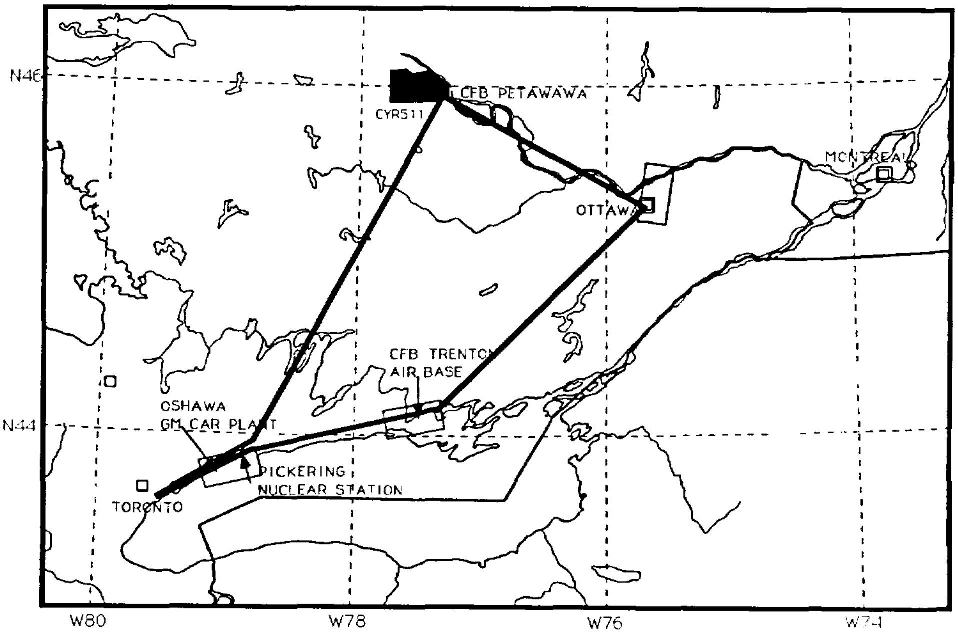

FIGURE 1

Map showing the flight path of the CC115 Buffalo transport aircraft for the orientation/familiarization flight.

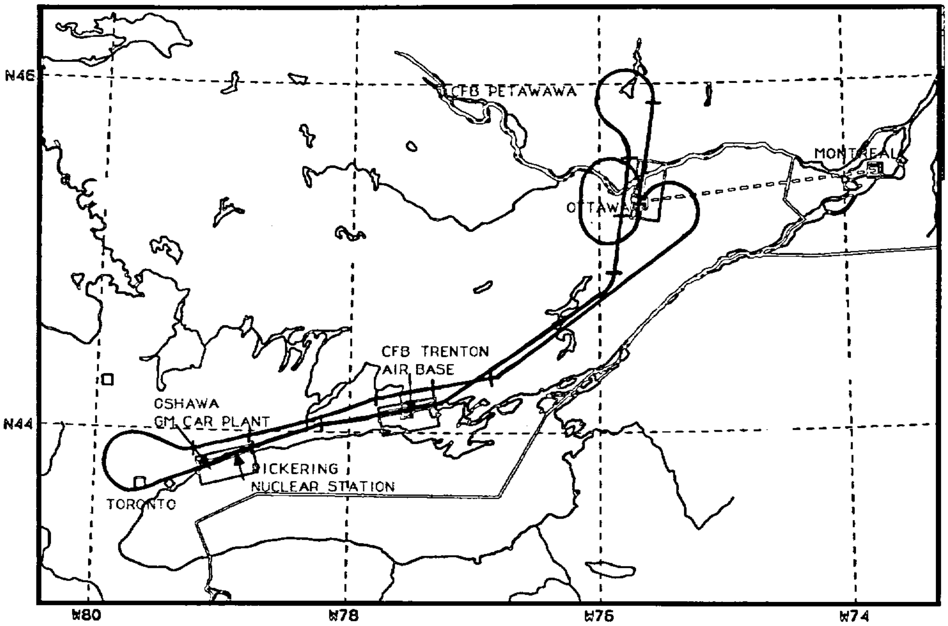

FIGURE 2

Map showing the flight path of the CCRS Convair 580 for the sensor-equipped overflight.

The observation aircraft carried five CCRS crew members consisting of two pilots, one mission manager and two sensor specialists. Flight representatives included one cockpit/navigation observer from Hungary, and two Hungarian and one Canadian sensor specialists as observers.

This overflight was conducted on 16 January 1992 from Ottawa. The aircraft took off from Ottawa International Airport at 11:35 am and landed again at Ottawa International Airport at 2:40 pm. TABLE 1 provides a summary of the flight lines completed during the mission. Appendix D outlines technical information regarding the overflight. Appendix E supplies cost information.

SAR data collected during the overflight was recorded onto a 14-track high density digital tape (HDDT) for processing after the overflight. A real time "quicklook" product was produced on-board to supply an imagery product for immediate evaluation.

Measures were taken during the overflight for testing of the film to ensure optimum quality. An additional fifteen photo exposures were taken after the last photo line to provide for initial calibration and verification of the processing. As well, several frames of unexposed film were used for photolab exposure of step wedges.

TABLE 1 Summary of the Flight Lines Flown During the Open Skies Trial Overflight of 16 January 1992.

Location	Line	Feet AGL	Sensor	Target
Trenton	1	20,800	SAR	CFB Trenton
Oshawa	2	20,800	SAR	GM car factory
Pickering	2	20,800	SAR	nuclear power plant
Pickering	5	4,700	Photo	nuclear power plant
Oshawa	5	4,700	Photo	GM car factory
Trenton	4	5,900	Photo	CFB Trenton
Ottawa	3	20,800	SAR	City
Ottawa	6	5,900	Photo	City

Notes:

1. SAR line altitudes are at the optimum for the CCRS aircraft.
2. The planned altitude to acquire the aerial photography was 5,900 feet (1,800 metres) AGL which would correspond to 30 cm ground resolution with the RC-10 aerial camera.

Because of the short turnaround time required, the SAR data and aerial photographic film were immediately processed on a commercial basis by two companies; Intera Kenting (SAR) and IMc Photographic Services Inc. (photography). The SAR imagery and photographic prints were delivered by noon on 17 January 1992, providing a turnaround of less than 24 hours.

4.0 Results and Discussion

This section of the report provides examples of the photography and SAR imagery collected during the trial overflight.

FIGURE 3 shows Rockcliffe airfield in Ottawa. Many small aircraft are parked on the north side of the taxiway. Some larger aircraft are parked on the east side of the large triangular hangar. Aircraft can be detected but they are not recognizable using the SAR imagery. For example, there is some rubble located in the middle of the field southeast of the triangular hangar. In the SAR imagery, the return from this rubble appears very similar to that from the larger aircraft beside the hangar. Using the photography, aircraft are clearly recognizable but they may not be identifiable (for example, as a Piper Navaho or Cessna Conquest). The small aircraft are widely spaced and can be counted using the SAR imagery. However, individual aircraft might not be distinguishable if they are more closely spaced. The aircraft by the hangar are closer together and therefore more difficult to separate in the SAR imagery.

FIGURE 4 shows the Pickering nuclear power facility on Lake Ontario near Oshawa. Once again, the aerial photography is easier to interpret than the SAR imagery. The eight large reactor buildings are not evident in the SAR imagery because the curvature of their tops scatters the microwave pulse in many directions, resulting in a small return signal. It is also difficult to distinguish between the water in the L-shaped con-

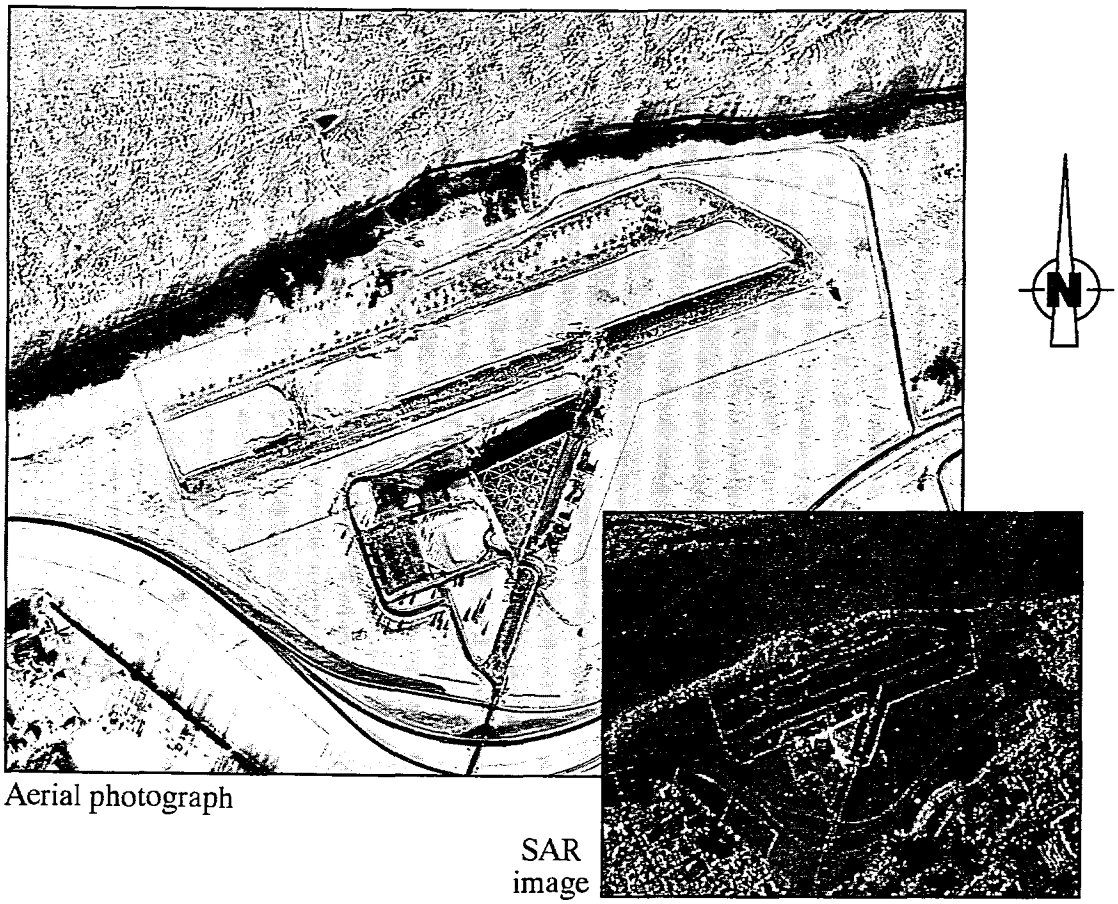

FIGURE 3 Aerial photograph and SAR imagery of Rockcliffe airfield.

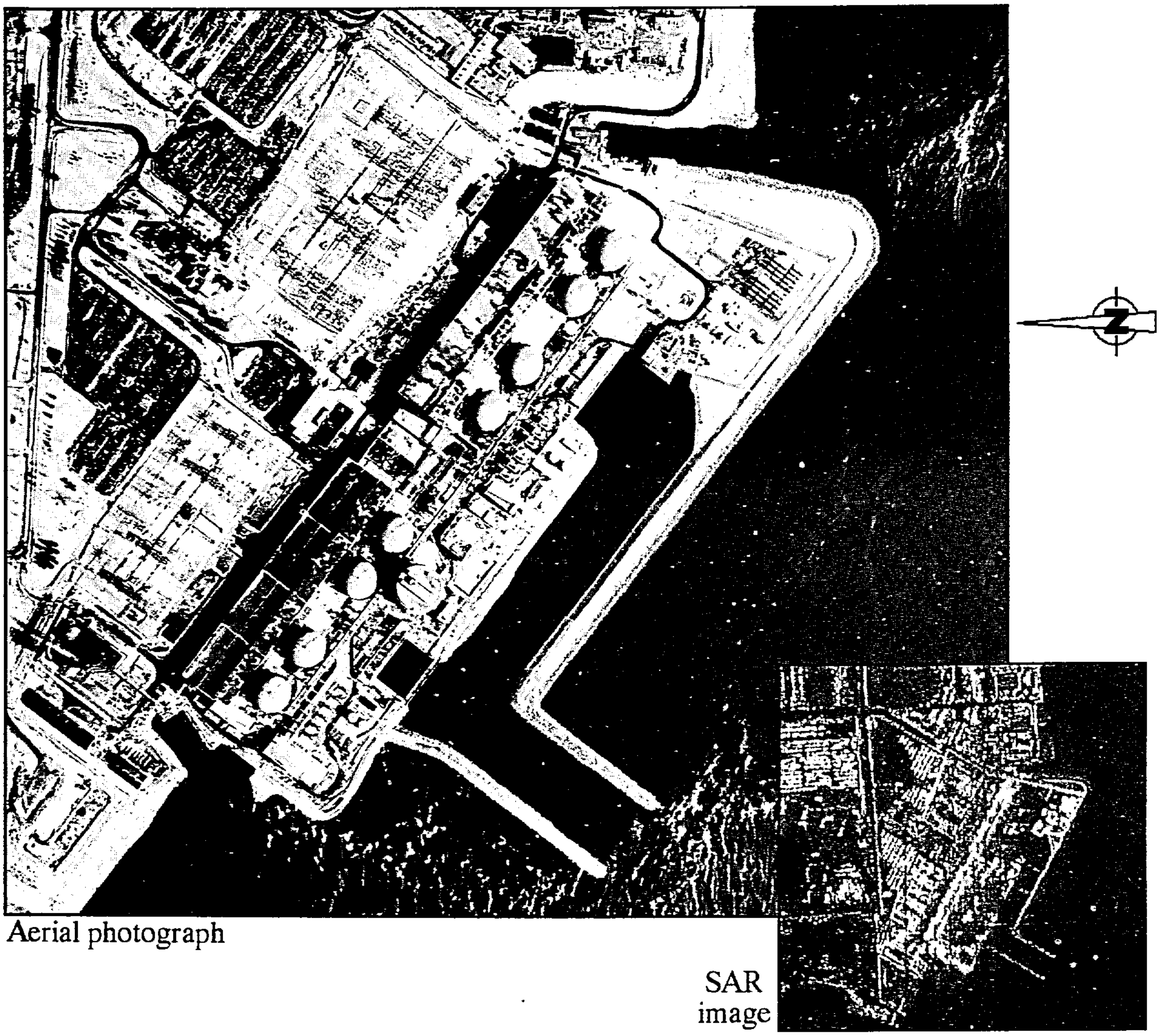

FIGURE 4 Aerial photograph and SAR image of the Pickering nuclear power station.

denser cooling water channel and nearby ground surfaces. At the same time, however, the switch yards, northeast of the reactor and turbine buildings, can be interpreted as clearly using the SAR imagery as with the aerial photography. The many metal towers in the switch yard provide strong radar returns but are not very visible in aerial photographs.

FIGURE 5 shows the General Motors automotive plant in Oshawa. Details in the plant area are much more difficult to interpret using the SAR imagery than using the photography. In the holding lots located west of the plant, there are many bright returns in the SAR imagery resulting from the rows of cars. While it is clear that something is there, it would not be possible to recognize the targets generating these returns. For example, there are some railcars sitting in a north/south direction on

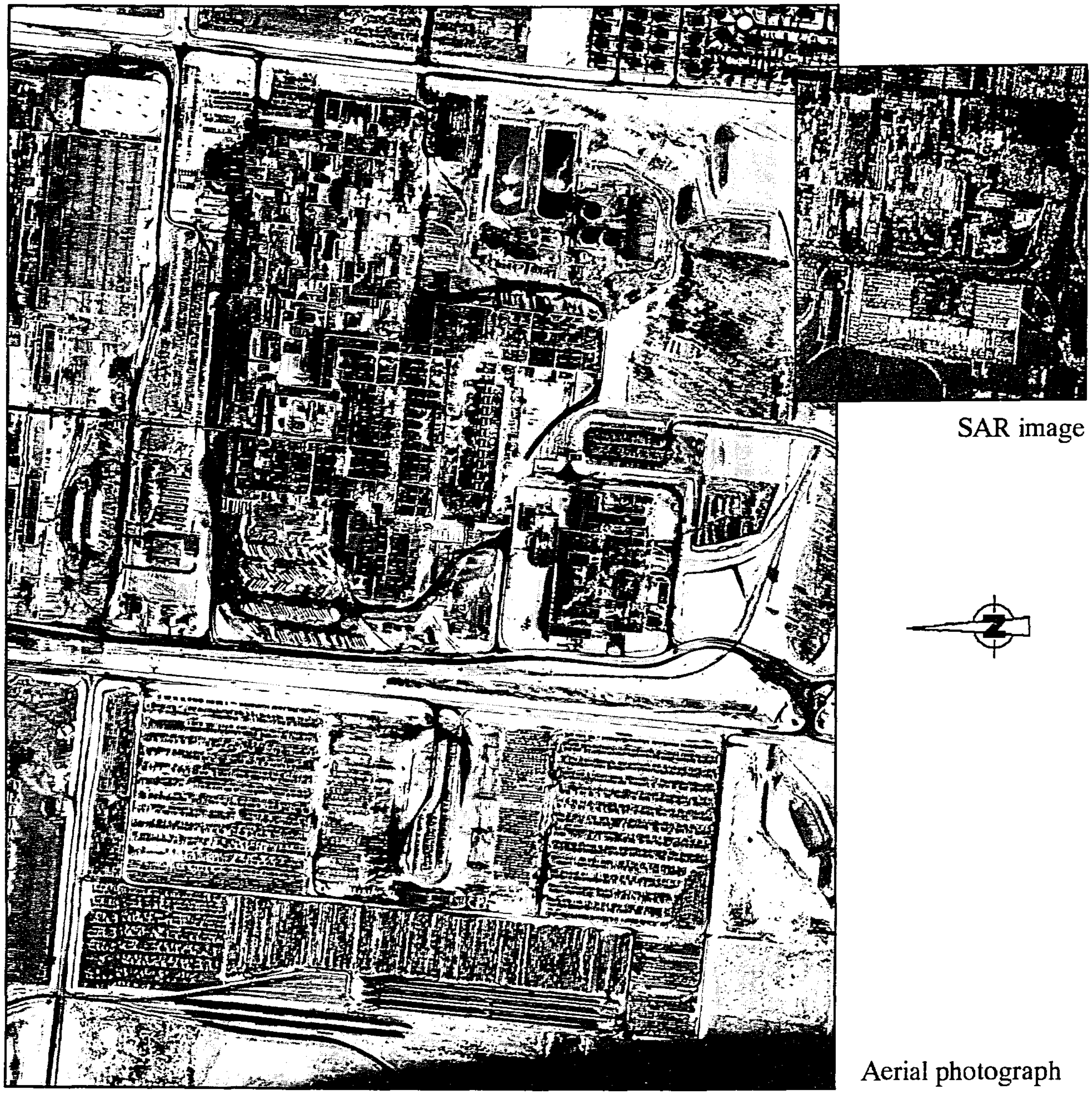

FIGURE 5 Aerial photograph and SAR image of the GM automobile manufacturing plant in Oshawa.

some sidings on the west side of the holding lot. In the SAR imagery, the railcars are indistinguishable from rows of cars which are similarly oriented.

5.0 Conclusions

The high level of cooperation necessary for the successful conduct of an Open Skies observation flight is, in and of itself, an important means of confidence-building.

5.1 Sensor Resolution

The resolution presently being proposed in the negotiations limits the effectiveness of the regime. In particular:

a. 30 centimetre resolution proposed for optical and electro-optical sensors limits aircraft ability to fly under cloud cover; and

b. 3 metre resolution on SAR imagery produces a limited amount of information which may be insufficient to justify the high costs involved.[1]

5.2 Costs

The relatively high costs of aircraft and sensors make cooperation highly desirable. Joint flights, leasing of equipment, and reduction of costs by sharing information on a commercial basis are all important ways of making the regime more cost-efficient. The treaty should provide a flexible framework allowing all possible ways of cooperation.

5.3 Data Sharing

Possible ways for data sharing in the case of SAR are:

a. Dry silver print-out;

b. Video tape of real time display;

c. Provision of raw data (in view of gradual standardization, a special software capable of processing data from various types of SAR can be developed relatively cheaply and quickly).

1. The SAR used during this Trial Overflight provided 6 metre resolution imagery. An improvement in resolution by a factor of two, to 3 metre resolution, would not significantly enhance the interpretability of the SAR imagery for the Open Skies application.

5.4 Navigation

Combination of different types of navigation equipment fitted in the aircraft ensures optimal results. The treaty should allow use of any navigation equipment necessary for exact navigation and processing of sensor data. Detailed maps and charts, provided by each participating State, are necessary to aid navigation.

5.5 Aircraft Inspection

In the process of certification, detailed technical information on the sensors should be provided for effective inspection. Nevertheless, a short training course for technical experts from all participating States, organized by the Open Skies Consultative Commission, would be helpful.

5.6 Air Safety Considerations

a. The overflight of nuclear power stations demonstrated that, as a rule, the establishment of a minimum safe altitude is sufficient in most cases of restricted airspace; and

b. In every country, a system is required to ensure timely clearance for Open Skies observation flights.

APPENDICES

APPENDIX A

CCRS C-Band Airborne Radar: System Description and Test Results

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ABSTRACT

A new generation Synthetic Aperture Radar (SAR) has been commissioned into the CCRS Convair - 580 aircraft. This paper gives a condensed technical description of the system and then presents test results which show the system performance.

This is a digitally-controlled, two-channel radar, operating at C-band (5.30 GHz), transmitting, either H or V polarizations, and receiving both polarizations simultaneously. The system features an onboard, 7-look, real-time processor and display for one receive channel with data acquisition in three nominal geometric modes: nadir, narrow swath, and wide swath. The nadir and narrow swath modes have high resolutions (6 x 6 m) while the wide swath resolution is lower (20 x 10 m). In all cases, 4096 range pixels are processed across the swath.

Test results include measurements of the impulse response function, noise equivalent sigma naught, geometric fidelity, speckle statistics, ambiguity figures, and assessments of the overall image quality and data consistency. Examples of imagery from the various radar modes are given.

Le radar aéroporté à bande-C du CCT: description du système et résultats des tests

RÉSUMÉ

Un radar à ouverture synthétique de nouvelle génération a été mis en service dans l'avion Convair-580 du CCT. Le présent exposé donne une brève description technique du système avant de présenter les résultats d'essai qui témoignent du bon rendement du radar.

Il s'agit d'un radar à deux canaux à commande numérique fonctionnant dans la bande C (5,30 GHz) transmettant en polarisation H ou V et recevant dans les deux polarisations simultanément. Ce système comporte un processeur de données en temps réel à 7 visées et un affichage pour un canal de réception avec une acquisition des données dans trois modes géométriques nominaux: vertical, couloir étroit et couloir large. Les modes de visée verticale en couloir étroit produisent une résolution élevée (6 x 6 m), supérieure à celle du couloir large (20 x 10 m). Dans tous les cas, 4096 pixels sont traités sur la largeur du couloir.

Les résultats d'essai sont composés entre autres des valeurs de la fonction de réponse impulsionnelle, du zéro sigma de l'équivalent bruit, de la fidélité géométrique, des statistiques de mouchetage, des figures d'ambiguité et des évaluations de la qualité globale des images et de la cohérence des données. Des exemples d'imageries recueillies par divers modes radar sont présentés.

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Keywords/Mots-clés: airborne sensing, instrument design, microwave system, radar, SAR

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1 Introduction

In 1978, CCRS began flying a Synthetic Aperture Radar (SAR) developed by the Environmental Institute of Michigan (ERIM) [14] on its Convair 580 aircraft. This radar, which became known as the SAR-580 system, was taken over by the Centre in 1980 and its development continued until 1985 in preparation for a completely new radar system. This paper describes the new C-band SAR developed for CCRS as a modern research tool, with MacDonald, Dettwiler and Associates (MDA) as prime contractor.

The new system is a digitally controlled, two-channel radar, operating at C-band (5.30 GHz), transmitting either H or V polarizations, and receiving both polarizations simultaneously. The system features an onboard, 7-look, Real-Time SAR Processor (RTSP) and display for one receive channel with data acquisition in three nominal modes: nadir, narrow swath, and wide swath. General specifications for the system are listed in Table I.

This paper is divided into two main sections. In Section 2, a brief system description gives an overview of the main design and processing features. Section 3 gives a set of test results which show the quality and characteristics of the imagery produced by the system. A summary is given as the concluding section.

2 System Description

2.1 Conceptual Design and Architecture

During the conceptual design phase of the CCRS C-band SAR, it was decided to create a research radar system that would:

- Offer a variety of imaging parameters to cover foreseen SAR remote sensing research needs;
- Minimize the probability of operator error;
- Be calibratable;
- Function as a test bed for further SAR development research;
- Be field maintainable.

The radar developed to meet these goals. To cover the range of incidence angles and swath widths required for remote sensing research, two resolution cell sizes were incorporated into three imaging modes to provide high resolution (~6×6 m) capability from nadir to 82° with a 16.4 km (slant range) swath and low resolution (~20×10 m) capability from 45° to 87° incidence angle with a 61 km swath. These modes are shown diagramatically in Fig. 1. Through extensive use of digital technology and microprocessors, the other design goals of potential calibration, ease of operation and maintenance, and future development potential have largely been met.

Table I: C-band SAR Specifications.

TRANSMITTER		
• frequency	5.30 GHz	(5.6 cm)
• radiated peak power	27 kW	
• polarization cross coupling	<-49 dB	
• PRF	208 Hz	to 382 Hz
• estimated noise equivalent σ_o	-40 dB	
	Narrow Swath	Wide Swath
• chirp length	7 μs	8 μs
• chirp bandwidth	42.0 MHz	11.4 MHz
• nominal average power	90 W	100 W
• chirp coding	non-linear FM	linear FM
RECEIVER		
• minimum range	3.0 km	
• maximum range	68.0 km	
• fine gain control range	63.5 dB	
• coarse attenuation range	42.0 dB	
	Narrow Swath	Wide Swath
• range pulse width	40 ns	120 ns
• input noise floor	-95 dB	-102 dB
• noise figure	5.2 dB	3.7 dB
ANTENNA	H-polarization	V-polarization
• azimuth beamwidth[a]	3.6°	4.2°
• elevation beamwidth	23°	27°
• peak gain	24 dB	22 dB
REAL-TIME PROCESSING		
• 1-7 looks processed for 1 channel		
• slant or ground range presentation		
• 8-bit detected signal per pixel		
• 4096 range pixels/line		
	Narrow Swath	Wide Swath
• azimuth resolution	6 m	10 m
• range resolution	6 m	20 m
• look beamwidth	0.3°	0.19°
GROSS		
• power consumption	5 kW	
• weight[b]	450 kg	

[a]Azimuth beamwidths will be modified to 3.04° in April, 1988.
[b]Weight excluding antenna and peripherals.

The radar can be divided into the major subsystems illustrated in Fig. 2. The SAR Transceiver Subsystem (STS), described in Section 2.2, provides for the coherent generation, transmission and reception of the radar signals. The STS contains fast programmable gain control to reduce the very large dynamic range of the radar returns prior to digitization. This Sensitivity Time Control (STC) system is described separately in Section 2.4. Radar control is described in Section 2.3. Section 2.5 is a terse description of the the motion compensation system. The RTSP (Section 2.6) performs the digital processing required to produce high-resolution SAR imagery. Sections 2.7 and 2.8 contain descriptions of user accessible modes and outputs respectively.

2.2 SAR Transceiver System (STS)

The radar signal flow begins in the Exciter/Receiver Unit (ERU) of the STS. There, expanded range pulses (chirps) are produced by one of two Surface Acoustic Wave (SAW) devices, depending on the chosen mode of range resolution. The chirps, derived from a stable local oscillator (STALO), are up-converted to the C-band transmission frequency, and amplified by a Travelling Wave Tube (TWT). A peak power of over 40 kW is achieved at the output of the transmitter. This signal is passed through a pressurized waveguide to the antenna subsystem and then transmitted by the selected antenna (H or V polarization) over the swath to be imaged. The antenna platform is stabilized in two axes by the antenna positioner, which is controlled by the motion compensation system.

Because of the relatively high average power transmitted (Table I) and low PRF, no pre-summing is required and the data can be processed directly as received. This has direct practical importance in several applications such as ocean wave work where Doppler spectral information needs to be preserved.

Two separate but nominally identical receivers are used to amplify and range compress the like- and cross-polarized radar returns. The Radio Frequency (RF) signals are input to low-noise amplifiers and down-converted using single-sideband mixers and oscillators also locked to the stable oscillator. Range compression is performed using SAWs having inverse functions to the expansion SAWs, and the output signal is separated into in-phase and quadrature (I and Q) components by a video network. Both channels process data simultaneously.

The four video signals (I and Q for channels A and B) are fed to the RTSP, where they are digitized, motion-compensated and one pair is azimuth compressed to produce digital imagery in real time. The dynamic range of the received signals is matched to those of the ADC's (Analogue-to-Digital Converters) by means of STC's in the intermediate frequency amplifiers of both receivers. (See Section 2.4.)

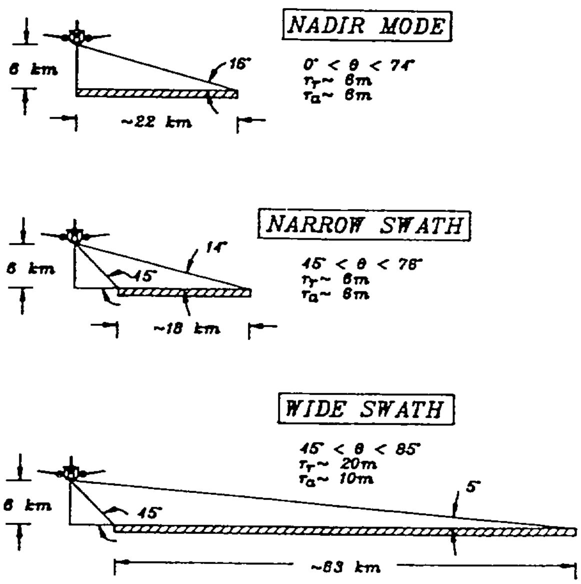

Figure 1: Radar Imaging Modes.
The three imaging modes of the system are shown for a port-looking configuration at a nominal flying altitude of 6000 m (20000 ft). The ground swath imaged is indicated in each case by the cross-hatched portions and the depression angles at the near and far edge of the swath are marked. The table at the side gives the range of incidence angles imaged and the pixel resolution in slant range and azimuth for each mode.

2.3 Radar Control

The radar is controlled by a custom built computer and software system which uses input from feedback measurements, from external peripheral devices (Inertial Reference Unit, Master Clock *etc.*) and operator keyboard entries to generate commands and data base values and to distribute these to the radar modules. All operator entries are stored in non-volatile memory so that only modifications to the current radar configuration need to be entered by the radar operator. Soft screen interactive displays are used to restrict control commands to available, valid choices and to provide operator prompts for required actions. The operator station is shown in Fig. 3.

A complete set of radar and navigation parameters are recorded on computer compatible tape in a peripheral data logging system known as MAID [11,9].

In addition to performing the SAR module control, operator interface and data logging functions, the control computer also performs data routing and self test functions. All radar module control settings are computed for the desired configuration at the start of each data acquisition line. The main control computer also controls the timing of module operations and acts as bus master for control communications and provides powerful signal monitoring capabilities. Self testing is automatically performed for the entire radar on start-up. Operation is constantly monitored for errors, and automated diagnostic tests at a detailed level are also provided. The control system makes extensive use of the signal monitoring capabilities. Data can be sampled from many points in the system, and a variety of test signals can be injected, for example, at the receiver inputs. Real-time signal level calibration and displays are provided which allow the operator to view and adjust the along- and across-track energy profiles. The control system also automatically fine-tunes the antenna pointing within a fraction of a degree.

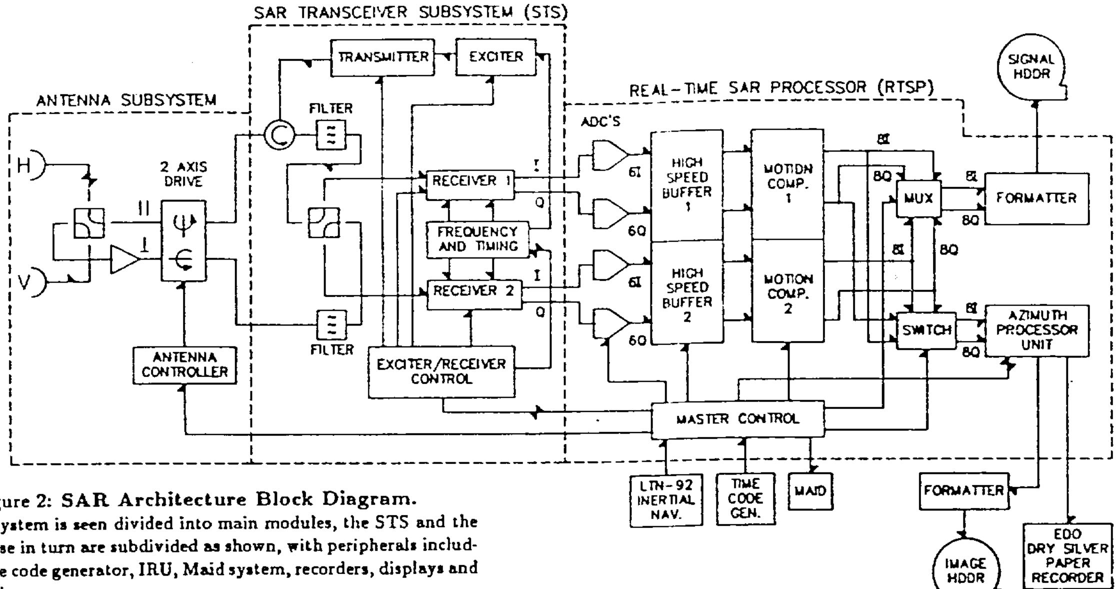

Figure 2: **SAR Architecture Block Diagram.**
The SAR system is seen divided into main modules, the STS and the RTSP. These in turn are subdivided as shown, with peripherals including the time code generator, IRU, Maid system, recorders, displays and antenna drive.

2.4 Sensitivity Time Control (STC).

The principle behind STC in radar systems is discussed in [17] for real-aperture radars. SAR receivers in which the range pulses are compressed prior to the ADC must accommodate the large dynamic range of the range-focussed, radar returns. Large variations are possible depending on the terrain type, radar viewing geometry, and antenna gain pattern. ADC modules whose bandwidths are sufficiently large to accomodate the received signals typically have 30 to 40 dB dynamic ranges. The gain of the radar receiver is therefore varied in time to compensate for the deterministic (and quasi-deterministic) elements of the radar range equation.

These elements, each depending on geometry, include: the two-way antenna elevation pattern $G_t G_r$; the $1/R^3$ fall off with slant range; the variation of radar reflectivity with incidence angle (θ), $\sigma_o/sin\theta$; and the atmospheric attenuation, $exp(-\alpha R)$. They in turn enter the radar range (and thus the signal power) equation as a product which is integrated over the azimuth beam pattern of the antenna.

For the purposes of dynamic range matching, a simple model approximation is used for the gain control equation. The terrain is assumed to be uniform with an average incidence angular dependent backscatter. The reflected power can then be represented to be proportional to:

$$\frac{1}{g_{STC}} = \frac{G_T(\theta-\theta_o)G_R(\theta-\theta_o)\sigma_o(\theta)e^{-\alpha R}}{R^3\sin(\theta)} \qquad (1)$$

Here, g_{STC} is the Sensitivity Time Control (STC) function which is then applied to the incoming signals for ADC dynamic range control. Provided that the antenna patterns and terrain type are well modelled, two desirable effects are produced:

1. The dynamic range of the signal lies within the dynamic range of the ADC most of the time; and
2. Systematic variations in the processed image intensity with slant range are minimized.

If the radar is operating linearly and if the STC function is well known, quantitative relationships between the radar returns and the scene are retrievable by removing the STC function from the processed image.

The elevation bore sight angle θ_o is selected from a look-up table in the radar processor which has been optimized for minimum dynamic range and maximum signal to noise (SNR). The antenna pattern is represented as a 4th order polynomial in dB. The following equation is used to model [13] the distributed target SNR for the optimization.

$$SNR = \frac{P_o G_t G_r \lambda^2}{(4\pi R)^3} \times \frac{\sigma_o(\theta)}{kTBFL} \times \frac{\Delta R\beta}{sin\theta} \qquad (2)$$

Here P_o is the peak power of the transmitted pulse; λ is the radar wavelength; ΔR is the uncompressed pulse length; β is the azimuth beam width; k is Boltzman's constant; B is the equivalent rectangle measure of bandwidth; F is the receiver figure of noise; L is the Ohmic loss in the radar system and atmosphere; and T is the receiver noise temperature.

The STC is implemented as 5 possible selections: TEST, LAND, Smooth WATER, Rough WATER and ICE. The TEST mode corresponds to an STC of 1, resulting in no modification to the received signal as a function of range. The other modes correspond to nominal terrain reflectance laws modelled for their respective types. In each of these cases, an antenna pattern is chosen to be either VV or HH depending on the transmitted polarization. STC is computed by the SAR control computer at flight configuration time for the altitude, swath mode, antenna polarization, and STC law. The same law is used until a new configuration is applied.

A test was carried out to verify that the theoretical STC gain was achieved in the hardware of the system. A CW (Continuous Wave) test noise signal from the ERU built-in-test-equipment (BITE) was run through the receiver/processor system and recorded. Over 1400 lines were averaged at half resolution, to obtain a good estimate of the applied STC correction[1].

Figure 4 is a comparison of the theoretical and system response for the LAND STC for a configuration height of 20000 ft (6048 m) and antenna depression angle of 22.1°. The agreement of the modelled parameters and the actual implementation is better than 0.5 dB.

2.5 Motion Compensation System

Real-time processing of airborne SAR data obtained from straight, level and constant speed flight is, in itself, difficult. Processing with simultaneous correction for random angular, linear and turbulent aircraft motion represented a major challenge requiring unique modules for high speed calculations as well as development of large and complex software packages. Such correction is necessary to maintain good focus and correct illumination. The motion compensation system compensates the phase of the returned signals and controls antenna stablization.

Acceleration, velocity, aircraft attitude, track and heading data from a Litton 92 inertial reference unit (IRU) are used by the motion compensation computers. This unit uses laser ring gyros and has five times better angular measurement accuracy and reliability than previous mechanical gyro platforms. The motion parameters such as aircraft vertical and across-track acceleration are output on a digital bus.

Phase corrections must be related to the motion of the aircraft relative to the reference track. A real-time digital pipeline processor corrects the phase of the radar signal according to the motion calculated from the INS platform by the motion compensation module.

Digital motion compensation is more accurate than analogue phase shifting in the transceiver and delivers better performance over a wide swath because it allows the data to be delayed and modified after the corresponding motion measurements have been determined.

2.6 Real-Time SAR Processor (RTSP)

The RTSP is divided into two processing units: the Preprocessor and Control Unit (PCU) and the Azimuth Processor Unit (APU). The I and Q video signals produced by the STS Exciter-Receiver are fed, together with timing signals, to the ADC module in the PCU, where the signals are sampled into range lines of digital data. High speed buffers expand each range line in time, to allow processing to be spread over most of a pulse repetition interval (PRI). The start range of digitization and the phase of the I,Q data are compensated by the motion compensation system, described in Section 2.5, in real time for motion occurring within a synthetic aperture. The compensated data are sent to the APU, and a special interface provides for recording of the range-compressed data by a High Density Digital Recorder (HDDR). The software is designed to cope with the increase in processing load with increases in flight speed. (The same processing is performed for each PRI and the pulses are equally spaced on the ground.)

Within the APU, the azimuth bandwidth is separated into looks by a set of azimuth filters using complex frequency translators and digital filters. Time-domain azimuth compression is performed for each look in parallel by the correlator module which also outputs range lines of detected looks. A look-summation module performs summation to superimpose all data corresponding to the same pixel on the ground.

Real-time signal monitoring is also provided for outputs after detection. The output module appends annotation data to each range line of data, as well as optionally overlaying bit-mapped annotation. The radar imagery is fed to a strip recorder and video display for immediate viewing as indicated in Section 2.8.

2.7 User Accessible Modes

The CCRS C-band SAR has been designed as a flexible research instrument which allows a wide range of parameters in the three viewing geometries. The majority of the parameters are selectable from an interactive CRT display and define radar operating states. Each state defines a possible radar configuration and is automatically logged during acquisition together with a number of dynamic flight parameters to aid in image definition and later analysis. The operating states of interest to radar data users as *Standard Configurations* are defined by one selection from each row of each path in Table II.

In Table II, the entries marked with an asterisk (*) are derived from the user description of the measurement mission. Entries marked with a dagger (†) are normally set to default values chosen to produce the best results for the measurement problem as far as these are known. Careful description of the measurement problem at the flight request stage will usually result in the most suitable choice of the standard configuration used. The table is largely self explanatory; however, the following points may be of interest.

[1] The same method, using the actual ground returns, allows quantitative work to be carried out in determining the terrain reflectance model (knowing the other terms in the STC equation).

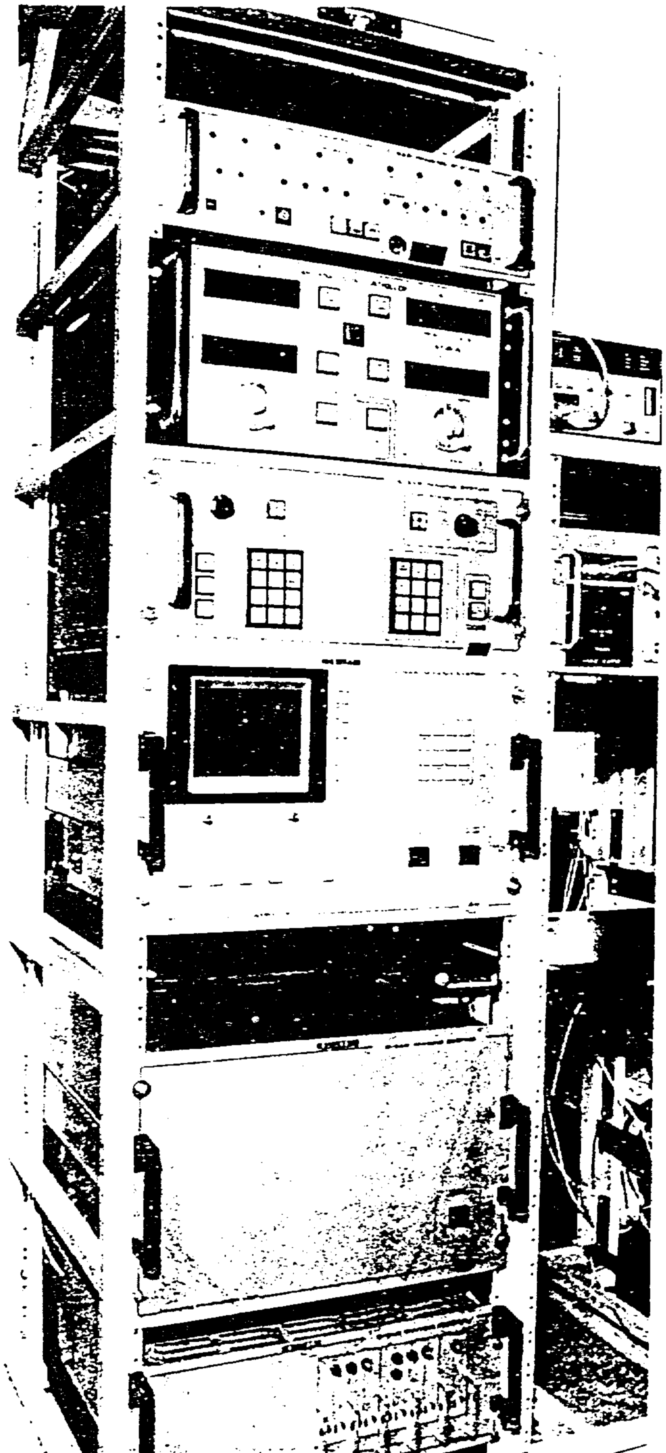

Figure 3: SAR Operator's Console.
The main operator interface with the radar control system is from this location and is accessed from a series of menu selections from the CRT screen in the centre of the rack. Seen also is the monitor panel for the RF system (developed under a subcontract to Canadian Astronautics Ltd.); the antenna drive and power supplies for the control electronics. An oscilloscope is provided for monitoring various signals from the radar from switch selections made by the operator. Empty rack space is for a companion X-band radar to be installed in 1987.

- The pulse repetition frequency to velocity ratio (PRF/V) defines the ambiguity level in the image for a specific SAR antenna. It also defines the maximum ground speed of the aircraft for the RTSP image formation since the PRF maximum is 382 Hz.
- The receiver fine gain is normally set to minimize output image saturation at the ADC while maintaining an acceptable output dynamic range. Other criteria for both coarse attenuation and fine gain can be used for special mission objectives.
- The STC law selected for a mission is matched to the primary targets in the radar scene as described in Section 2.4.
- The range gate delay offset is normally maintained at its default value of zero, but may be adjusted in special cases.
- The terrain altitude (in feet ASL) is required for both STC law and ground range conversion. For high relief terrain, a *reference altitude* is required and slant range presentation may be preferred.

The operating envelope of the aircraft is described in Table III.

2.8 Outputs

Figure 5 shows schematically the possible outputs from the C-band SAR. The upper portion of the diagram shows the airborne *in flight* outputs; while the lower portion shows outputs which are generated after acquisition and are termed *ground outputs* in the diagram.

Two different signal sets can be recorded simultaneously.

1. Either the like- or cross-polarized receiver channel is processed to an image in real time and normally recorded on three forms of media: image HDDT, at both full and half resolution, comprising 5 HDDT tracks; dry silver paper scroll; and video cassette (VCR). This is the 8-bit magnitude data set output by the azimuth processor of the RTSP and depends on the processing option set selected during acquisition.
2. The range compressed, motion-compensated signal data can be recorded as 8-bit, I and Q data over 14 tracks of an HDDR at the rate of one range line per radar pulse. The recording can be either the full swath at one polarization or the near or far range half swath for both receive polarizations. This data stream does not constitute a detected image until further azimuth correlation is accomplished at a later time on a ground-based processor.

In flight outputs also include data from the MAID system. This system receives sensor parameters from the IRU and the RTSP to provide a paper log with entries every 2 minutes as well as a CCT containing more densely sampled data. A strip chart record of several key parameters is generated on the RMS recorder fully annotated with scale and time. In flight imagery outputs are summarized in Table IV.

The *ground outputs* include reproduction of the RTSP data on a high quality photographic media using the MDA, FIRE-240 or transcription to computer compatible tape (CCT). It also includes flexible processing of the signal data using the MDA, G-SAR processor on the C-SHARP system [3]. Many users will find the RTSP CCT's and their FIRE-240 images will be a quick-turn-around high quality product, ready for image analysis work. MAID CCT data can be recovered for further analysis and track recovery. Work is currently underway on development and enhancements to these outputs including precision geometric and radiometric corrected products.

The format of the signal HDDT is given in [10]; the format of the Signal CCT's generated from this HDDT is given in [2]; and the format of C-SHARP image CCT's is given in [6]. The format of the Image HDDT is given in [15]; and raw image CCT format generated from this HDDT is described in [7]. All CCT's are in Standard format [16].

Table II: C-Band SAR Standard Configurations.

LOOK DIRECTION*	Starboard | Port
TRANSMITTER POLARIZATION*	Horizontal | Vertical
PRF/V (1/m)†	2.57 | 2.32
RECEIVER COARSE ATTENUATION (dB)	0 | 6 | 12 | 18 | 24 | 30 | 36 | 42
RECEIVER FINE GAIN (dB)	0 to 63.5 in steps of 0.5
TRANSMITTER OUTPUT†	Test | Full
STC LAW*	Test | Land | Ice | Ocean rough | Ocean smooth
ANTENNA ELEVATION OFFSET (deg)	-20 to 20 in steps of 0.1
RANGE DELAY OFFSET* (μs)	-190 to 20 in steps of 0.1
NOMINAL TERRAIN ALTITUDE* (ft) ASL	-32000 to 35000
IMAGING MODE* (Resolution)	Nadir (high) | Narrow (high) | Wide (low)
REAL-TIME AZIMUTH PROCESSOR	
Processor Gain	6 Values 1/16 to 8
Channel*	∥ | ⊥
Presentation	Ground | Slant
Active looks	1-7
HARDCOPY OUTPUT IN AIRCRAFT	All modes; Wide Swath
Imaged Swath*	Full
Subswath*	1 | 2 (All modes); 1 | 2 | 3 | 4 (Wide Swath)
RECORDING RANGE COMPRESSED SIGNAL	
Swath	Full; Half
Polarisation	∥ ⊥ (Full); ∥ | ⊥ (Half)
Subswath	near | far (Half)

3 TEST RESULTS

3.1 Impulse Response

In this section, some preliminary results on the impulse response of the RTSP imagery are given. These measurements were made by stripping the image HDDT to CCT (Fig. 5) and then using the image analysis capability of the C-SHARP system, to evaluate the point target[2] response.

In the analysis, the point target is selected and inspected for suitability centred in a small subimage of approximately 8 × 8 raw data pixels. This subscene is then converted to a power representation by squaring the input data values and interpolated to give results as shown in Fig. 6. Peak values, distribution widths, point target to clutter ratio, and integrated side lobe can then be determined from the interpolated impulse response.

Table V is a set of results for the three imaging modes of the radar taken from scenes of the Ottawa area acquired on May 8, 1987. The results are very close to the design goals presented in Table VI of Section 3.3 and show that the radar is performing very well. In each case, the range refers to slant range and both azimuth and range resolu-

[2]The targets identified were probably metal lamp posts or other small strong scatterers in the imagery.

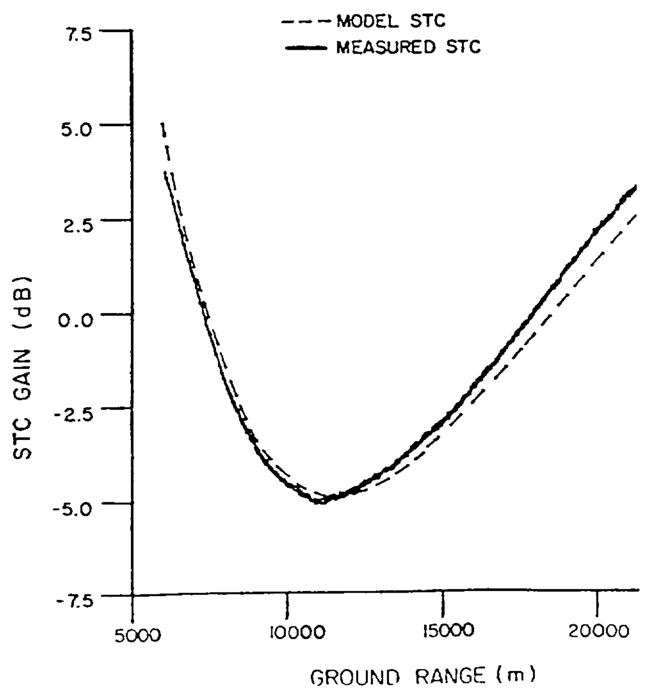

Figure 4: STC Gain for Narrow Swath Mode, Land Terrain Reflectance Model.
The STC gain is shown in dB as a function of radar ground range. The dashed curve is the theoretical STC model using equation (1) and the full line is the test results using ERU BITE noise processed by the RTSP. The agreement in the two results is better than 0.5 dB and shows that the model is well reproduced by the system hardware.

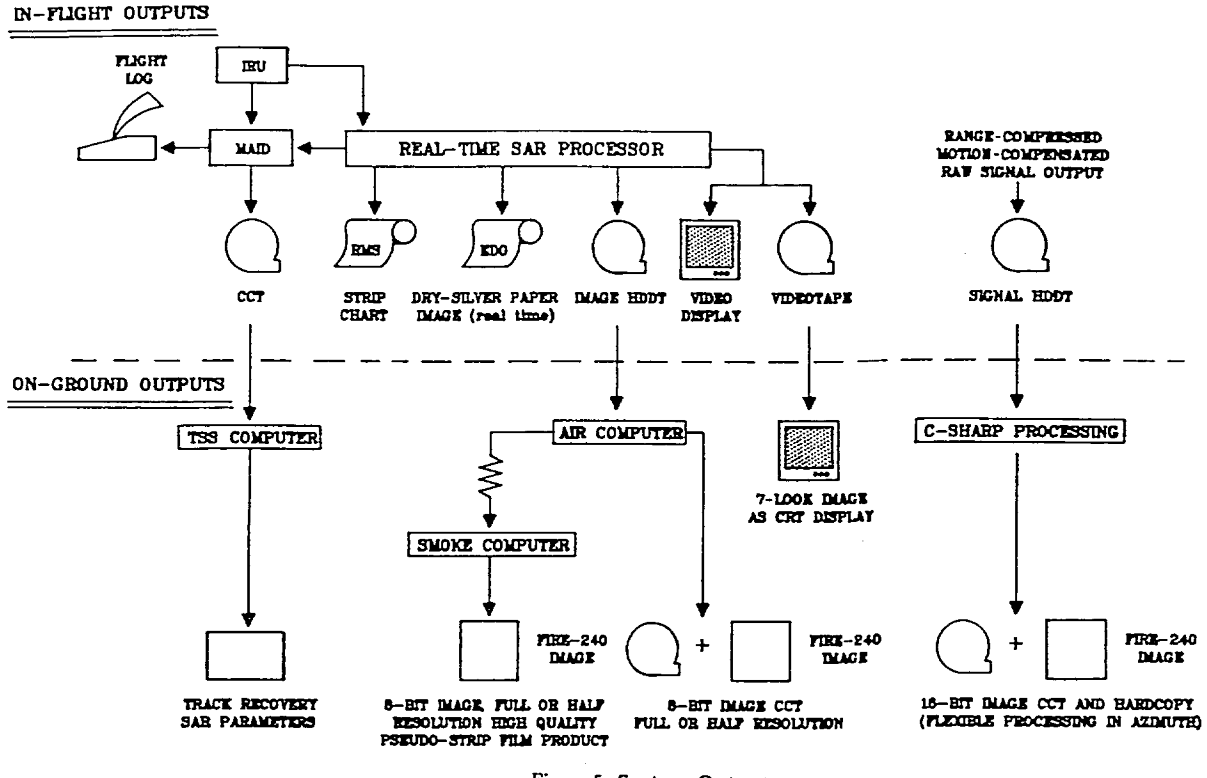

Figure 5: **System Outputs.**
The possible outputs from the C-band SAR are shown. The upper portion of the diagram shows the airborne *in flight* outputs; while the lower portion, *ground outputs*. The *in flight* radar outputs include: a dry silver image scroll, HDDT, and VCR all of the RTSP image; and an HDDT of the range-compressed, motion compensated signal data. *Ground outputs* include hardcopy using the MDA FIRE-240 or transcription to CCT from the RTSP image HDDT, or flexible processing of the signal data using the MDA G-SAR processor available on the C-SHARP system.

tions indicate the 3 dB widths. (Only the nadir mode data were taken from a slant-range image. This may account for the slightly better performance than expected for the range resolutions in the narrow swath and wide swath cases even though the usual adjustment for slant/ground range conversion was applied to the results.)

3.2 Noise Equivalent σ_o

A convenient way of characterizing the radar performance for imaging weak distributed targets is to calculate the backscattering coefficient which would lead to unity signal-to-noise ratio at the receiver output. By rearranging equation (2) for σ_o using $SNR = 1$, the *noise equivalent* σ_o can be obtained.

For narrow and wide swath modes, it is normally difficult to achieve good SNR for the far swath region because of the strong drop off in the terrain scatter and the extended range to the target. Substitution of the appropriate parameters (flying altitude of 10000 ft and VV polarization) yield far swath *noise equivalent* σ_o figures of approximately -35 dB and -28 dB for narrow and wide swath respectively. A low noise pre-amplifier is used close to the antennas on the cross-polarized channel thus reducing the loss term in (2) and improving the *noise equivalent*

Table III: **CV-580 Operations Parameters for SAR Acquisitions.**

Maximum Altitude (ASL)	23000	ft	7000	m
Maximum Ground Speed				
PRF/V=2.32	280	knots	144	m/s
PRF/V=2.57	254	knots	131	m/s
Minimum True Airspeed[a]				
H =20000 ft	210	knots	108	m/s
H =10000 ft	170	knots	87	m/s
Maximum Fuel to dry tank	6.5	hr		
Maximum Acquisition time[b]	4.5	hr		

[a]This is a still air reading. It is not atypical to have winds at 60 knots so that ground speeds could drop to 150 knots at 20000 ft.
[b]Maximum acquisition times will vary radically with weather and alternates.

Table IV: C-band Display and Recording Systems.

DISPLAY SYSTEMS	
HARDCOPY	VIDEO DISPLAY
• dry silver	• CRT monitor
• ~2000 pixels/line	• 512 pixels/line
• full header annotation	• full header annotation
• time & position blocks	• time & position blocks
• 16 grey levels	• 255 grey levels
• full or half narrow swath	• zoom to 2/1, 1/1, 1/2, 1/4 or 1/8
• full, 1/2, or 1/4 wide swath	• histogram display of full and/or zoom
• several display LUT's	• linear stretch or histogram equalization
• Edo Western	• Knudsen Engineering

RECORDING SYSTEMS		
SIGNAL	IMAGE	VIDEO
• 14-track HDDT	• 14-track HDDT	• video cassette
• all tracks used	• 5 tracks	
• variable speed	• 30 ips*	
• PCM coding	• PCM coding	• NTSC format
• 4096 range cells	• 4096 range cells	• 512 range cells
• time and Nav tagged	• time tagged	• time tagged
• range compressed	• fully compressed	• fully compressed
• 8-bits I and Q	• 8-bits amplitude	
• Bell and Howell	• Bell and Howell	

*To be increased in January, 1988 to 37.5 ips.

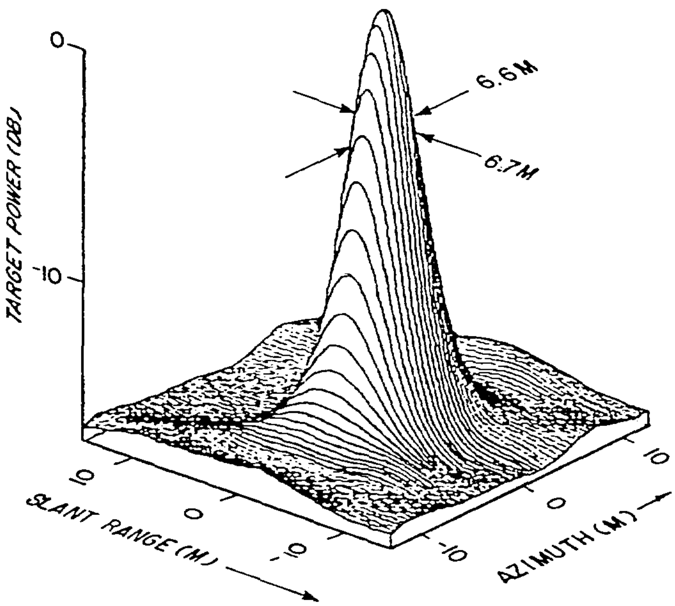

Figure 6: RTSP Impulse Response Function.
The 3-dimensional impulse response shown was taken from a nadir-mode RSTP image acquired on May 8, 1987. A point target was selected and the function generated by interpolating the radar response from a 8x8 pixel subimage around the point target. The full widths of the distribution at the 3 dB point are indicated.

Table V: Impulse Response Measurements from RTSP Imagery.

RADAR MODE	RESOLUTION Azimuth (m)	RESOLUTION Range (m)	INCIDENCE ANGLE (degrees)	TARGET RANGE (km)
Nadir	6 6	6.7	72.3	20.0
Narrow Swath	6 1	4 9	54.7	10.6
Wide Swath	9 5	18 9	79.9	34.7

σ_o by approximately 3 dB. These values are excellent. A 10 dB SNR will be obtainable even for cross-polarized narrow swath investigations of weakly scattering areas.

The high transmitter power is somewhat unusual. This is to satisfy the design goal to produce a flexible, research radar that could be used, for example, at shallow grazing angles over water and for quantitative research into cross-polarized signatures. Further, in the nadir mode, the angular range over which good data are required is $\sim 70^o$ and is much wider than the antenna elevation pattern. Again the high transmitted power allows us to use the STC to meet the very difficult design goal of imaging, *e.g.* the ocean, over a wide incidence angle range.

Some data acquired over marginal sea ice during the LIMEX experiment [1] have confirmed the potential of the radar for low backscatter research. When using a low power transmitter mode (test) with a peak transmitter output power of 0.4 kW (-20 dB from the nominal), narrow swath SNR's of 6-7 dB and 9-10 dB were obtained for far and mid-swath respectively. By extrapolating our C-band scatterometer results (measurements 10^o from to 60^o) to the far swath incidence angle ($\sim 74^o$) and comparing with backscatter data over this ice type, the probable σ_o at HH-polarization is -15 to -20 dB. These preliminary results yield a *noise equivalent* σ_o at full power to be in the -41 to -47 dB range. As there is a slight enhancement of the image SNR in relation to the receiver SNR for this radar [13] these values confirm the excellent performance for low backscatter scenes.

3.3 Geometric Fidelity

The on-board real-time processor sends data as indicated in Fig. 5 to a dry silver image recorder and to HDDT. This section is concerned with the geometric fidelity of these raw image outputs.

The dry silver product is automatically scaled and annotated to preserve the proper aspect ratio. Measurements from this output show that aspect ratio, averaged from 25 km section imagery, is correct to within 0.5%. In the recorded data stream, the aspect ratio is not unity as indicated in Table VI because the data are sampled at different rates in range and azimuth. The resolutions may also be different in these dimensions.

There are a number of reasons that the raw real-time processor imagery should have geometric distortions beyond those related to pixel sampling. The errors inherent in the RTSP products are small, but should be considered. Typical performance is listed in Table VII. The sources of error include: terrain elevation; azimuth processing skew; and in addition, small amounts of uncompensated motion or bias related to IRU or antenna pointing or moving scatterers within the scene.

Estimates can be made of the errors in each flight and with precise track recovery, post-flight correction may be attempted. A study is underway for a correction procedure based on the success of geometric correction with other airborne sensors [4].

To evaluate the gross geometric fidelity of the raw data product, four narrow swath scenes in ground range presentation that contained Lac Deschênes, near Ottawa, were studied. Each ~16 × 16 km scene contained about 15 evenly distributed Ground Control Points (GCP's) at road intersections measured in a UTM (Universal Transverse Mercator) coordinate system. The terrain height variation over the whole scene measured was less than 50 m. Line and Pixel coordinates for each GCP were obtained on the TRIAD system [12]. A simple linear model was then used to fit the data which contained an offset, an overall rotation, a skewness correction, and a sample scaling factor in the line and pixel directions. For the scene chosen, the results are summarized in Table VII. Using the derived transformation, UTM coordinates were determined for comparison at the GCP's so that average displacements could be found. These results show that the RTSP delivers a product which agrees with the design specification, generally has inherent skewness[3] of less than 2° and in which uncompensated errors residual errors can range from 2 to 8 pixel diameters.

Table VI: **Design Parameters for RTSP Pixel Resolution and Spacing.**

MODE	RESOLUTION (m)		—PIXEL SPACING (m)—			
			PRF/V = 2.32 (1/m)		PRF/V = 2.57 (1/m)	
	Range	Azimuth	Range	Azimuth	Range	Azimuth
Nadir	4.8	6.8	4.0	4.31	4.0	3.89
Narrow Swath	4.8	6.8	4.0	4.31	4.0	3.89
Wide Swath	18.7	10.9	15.0	6.90	15.0	6.22

Table VII: **Gross Geometric Distortions in Real-time Data Product.**

PRF/V	ALTITUDE	——SCALING——			SKEWNESS	DISPLACEMENT
		Range		Azimuth		
		Ground	(Slant)			
(1/m)	(ft)	(m)	(m)	(m)	(deg)	(m)
2.32	10000	4.24	(3.99)	4.28	1.52	17.0 ± 2.8
2.32	12000	4.29	(4.00)	4.35	1.18	8.8 ± 0.8
2.57	16000	4.33	(3.97)	3.91	0.76	9.1 ± 1.5
2.57	16000	4.35	(3.98)	3.89	2.19	34.8 ± 4.3

3.4 Speckle Statistics.

Radar image pixel intensity variability (speckle) is an inevitable consequence of the coherent summation of the scattered field from randomly placed scattering centres. For high resolution SAR systems, speckle is always present in the images of areas *e.g.* fields, for which the backscatter is uniform. The radar has been designed with a multi-look, real-time processor which reduces the effect of speckle while maintaining adequate resolution for civilian remote sensing applications. The RTSP creates separate images by bandpass filtering the azimuth spectral data and then summing these appropriately to create a final output image.

The output pixel values for each of the seven looks are proportional to the scattered field intensity, not to scattered power. Consequently, if we assume Rayleigh type scattering [5] from a uniform terrain area, with N looks, the following relation can be shown [17] between the standard deviation, S, of the pixel values; and the mean, $< V >$.

$$\frac{S}{< V >} = \frac{0.523}{N^{\frac{1}{2}}} \tag{3}$$

The looks are not entirely statistically independent and thus the effective number of looks is always slightly less than the number selected.

Figure 7 shows a comparison of the actual data (small circles) compared to a continuous curve representing the probability density function predicted for averaging 6 independent looks. The good agreement indicates that in practice the radar has achieved six independent looks with 7 looks processed.

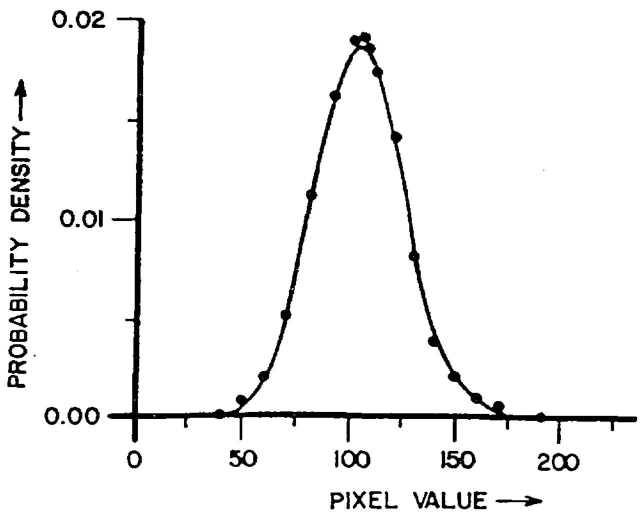

Figure 7: Speckle Statistics from the RTSP.
A comparison is given of actual RTSP data (small circles) obtained from a featureless field in a narrow swath image and a theoretical Rayleigh distribution of 6 looks. The theoretical distribution was calculated using a random number generator with zero mean and appropriate standard deviation to simulate the I and Q components of the scattered field. The actual data is marginally narrower and higher than the theoretical distribution indicating the RTSP has achieved slightly in excess of 6 looks.

3.5 Ambiguity Figures.

The Doppler history of a target passing through the SAR azimuth beamwidth can only be observed correctly if there are enough pulses (i.e. phase measurements) to sample the full range of the Doppler frequencies. Using the Nyquist criterion, this means that the radar PRF must exceed the azimuth Doppler bandwidth. As the maximum Doppler is proportional to aircraft ground speed,

[3]The skewness is a result of look-summation delay. In the implementation used in the CCRS radar, this delay is discontinuous and results in ~ 20 *jaggies* across the swath.

V, it was convenient to design the radar using a constant PRF/V ratio which fully satisfied the Nyquist criterion for the main lobe of the antenna. Because of antenna sidelobe illumination, some power will be received by the radar with large Doppler frequencies and these are aliased and observed with a Doppler history equal to their true frequency minus the PRF. Consequently, a very strong target can produce antenna sidelobe images on either side of the *real* image which correspond to these aliases.

In a VV-polarization image from the RTSP (using a PRF/V=2.32), ambiguities were estimated to be -14 and -19 dB below the levels from the unambiguous beam. With the narrower H-pol antenna beam, azimuth ambiguities were too small to measure accurately.

The addition of a second PRF/V ratio (2.57) with slightly overlapping looks reduces the ambiguities for most applications at both polarizations to levels which are now acceptable. In the future (April, 1988), the antenna azimuth beamwidths for both C-band antennas will be narrowed to 3° which will allow work at lower PRF/V ratios. The antenna was contracted by CCRS to Antech Engineering of Montreal[4], and will be modified by this company to the new specification.

With the swath and sampling used, range ambiguities are negligible.

3.6 Imagery Examples.

Three RTSP images are shown in Figs. 8, 9, and 10. They are each from the Ottawa test line taken on May 8, 1987 and demonstrate the three imaging modes of the radar: narrow, nadir, and wide swath at 7 nominal looks using the LAND STC. In each case, the radar was operating in *test* transitter mode at 1/10th maximum power with a PRF/V of 2.57. Despite the reduced power, the overall impression is that the radar imagery is excellent with good focus across the entire swath showing the motion compensation system is performing well.

The Ottawa river is centred across the swath. The lake portion of the river is Lac Deschênes with the town of Aylmer, Quebec bordering it in the north and the cities of Nepean and Ottawa in the east. To the west of Lac Deschênes, is an L-shaped array of corner reflectors used for calibration. It is apparent that the combination of urban and agriculture development as well as the calm river is a difficult imaging situation because of the large dynamic range. Consequently, some cultural targets are saturated; however, the optimum gain stategy is still under investigation and this should be further reduced.

The nadir and narrow swath images are in VV-pol while the wide swath image is in HH-polarization. Subtle differences can be seen in between polarizations. For instance, the marshy shoal regions appear brighter at HH-than at VV-polarization. The wide swath image gives a panoramic view of the area from which the geological features are more easily discerned. In wide swath, at the far edge, the radar emphasizes the roughness features (fence rows, shrub boundaries *etc.*) and radiometric contrasts seem reduced.

4 SUMMARY

The CCRS C-band SAR system commissioning on the CV-580 represents an exciting first stage in the development of a flexible, multichannel research facility. A companion, dual-channel, X-band system has recently been completed and is scheduled for installation. It is hoped ultimately to add an L-band system as well.

Extensive use of digital technology has ensured that the system can be well characterized, will operate linearly over a relatively wide dynamic range and, therefore, is calibratable. The accuracy to which a SAR can be calibrated is in general unknown, but we have begun SAR-scatterometer comparison experiments as well as using a calibration site equipped with corner reflectors of known cross section and an active reflector.

Under consideration for the future are plans which include acquisition of a fast ferrite switch for polarimetric mode research, the addition of a second offset antenna to create an interferometric mode, and comparison of this approach with stereo SAR for digital terrain model research in a study of SAR data for mapping purposes.

In summary, a very versatile SAR system has been developed with exciting performance characteristics offering a wide range of imaging and research opportunities.

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Figure 8: Narrow Swath Image of the Outaouais Region.
This C-band image in VV-polarization shows the Ottawa river and surrounding area at the full resolution of the radar in a ground range presentation. The data were taken at 20000 ft so that the area included is approximately 16 × 16 km.

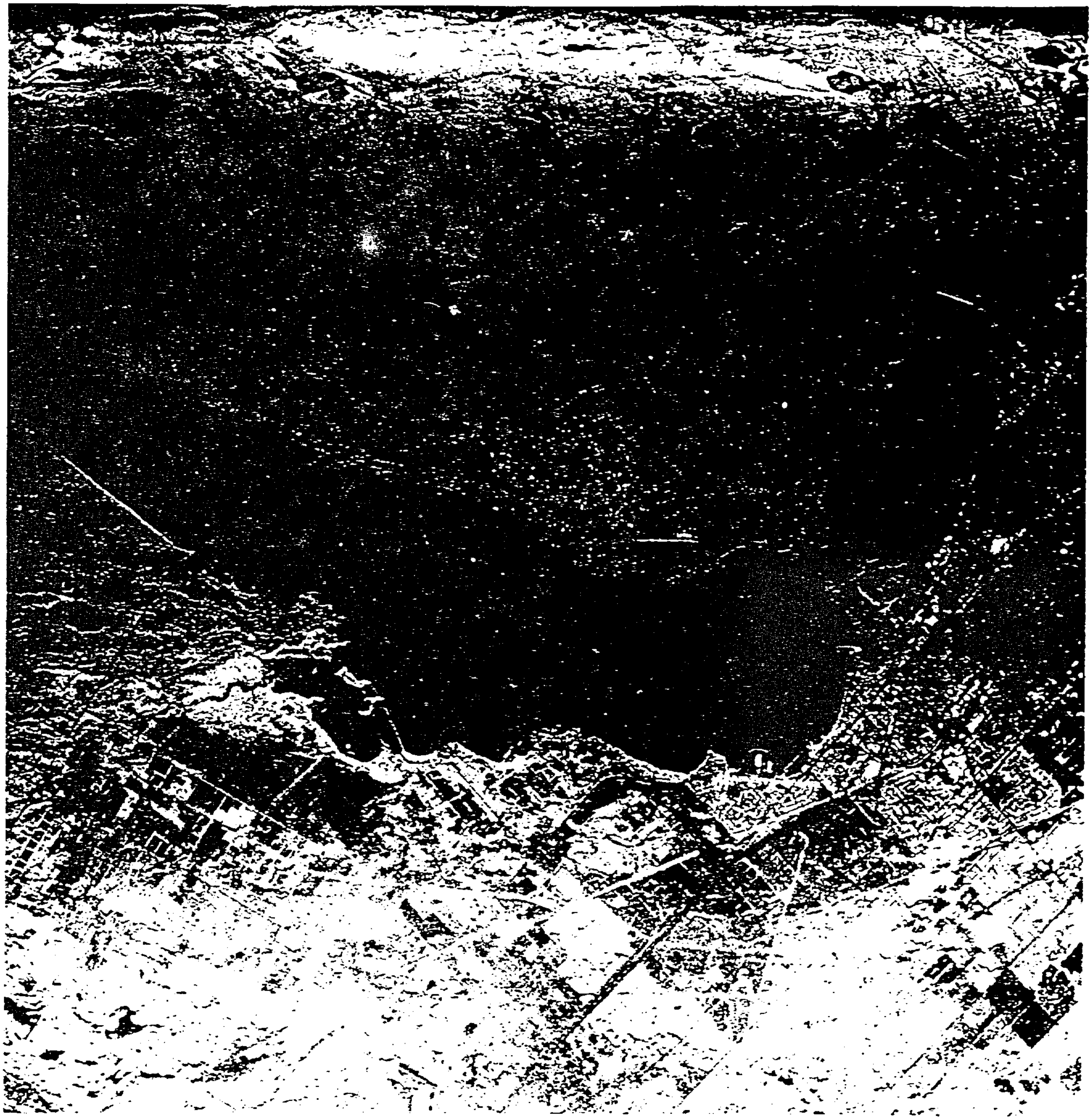

Figure 9: Nadir Mode Image of the Outaouais Region.
Similar to Fig. 8, in C-band VV-polarization, the image is shown in slant range presentation. This is quite visible in the urban development near nadir. It should be noted that incidence angle varies extremely quickly near the nadir edge in this mode. In this case, the incidence angles from 0 to 30° occupies only 10% of the swath.

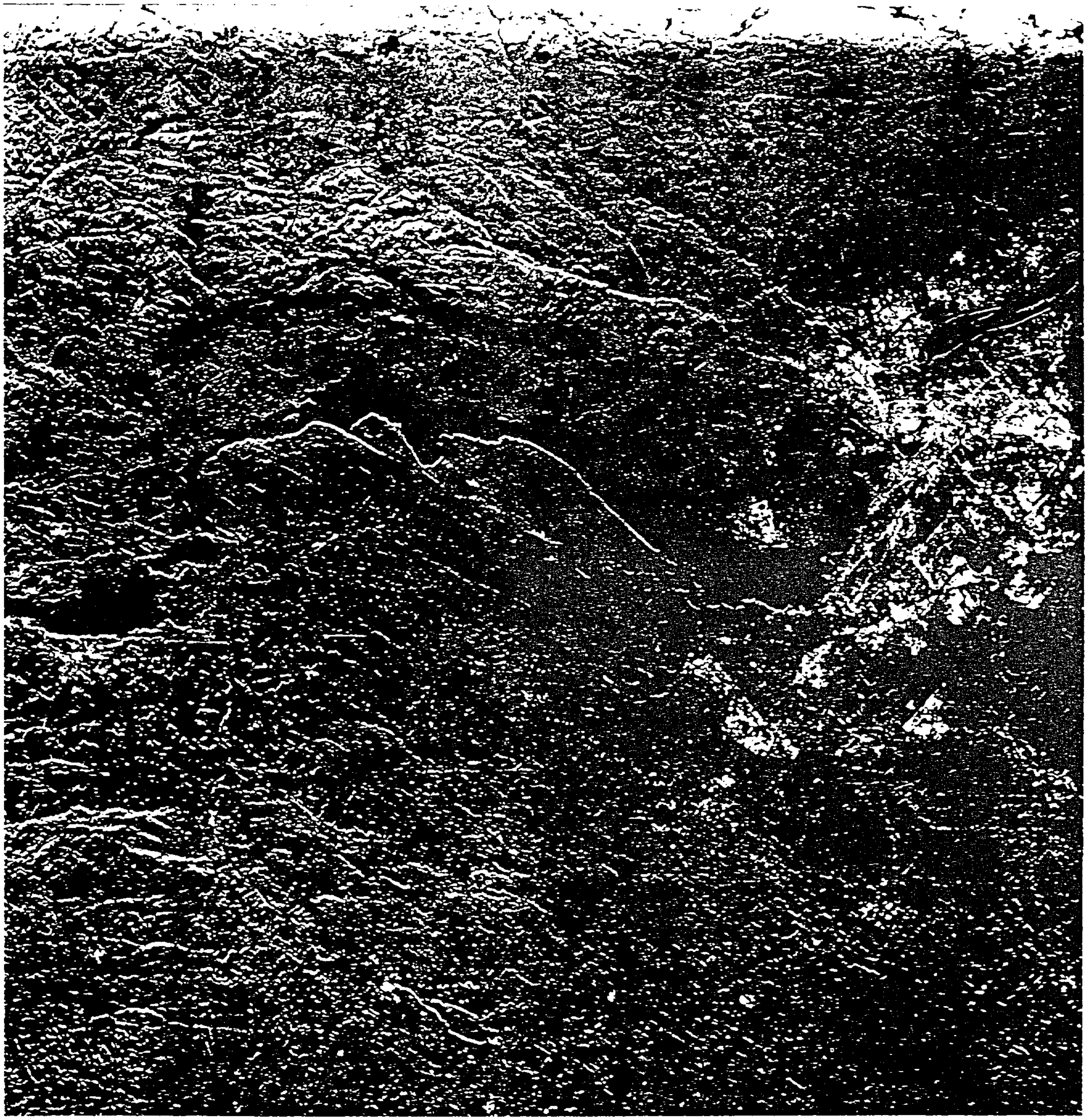

Figure 10: Wide Swath Image of the Outaouais Region.
The 61 km swath of the radar in this C-band, HH-polarization image gives a panoramic view of the gross geologic detail that is unavailable from smaller scenes. Gains were selected for experimentation on agricultural areas, and consequently, the strong cultural targets in the scene are saturated.

Charles E. Livingstone received the B.Sc. degree in physics in 1965 and the M.Sc. degree in geophysics in 1967 from the University of British Columbia; he received the Ph.D. degree in physics in 1969 from the University of Western Ontario.

From 1969 to 1976, he was an Assistant Professor of Electrical Engineering at the University of Western Ontario. Since 1976, he has worked at the Canada Center for Remote Sensing. During this time he has been involved in the specification and development of hardware for radar remote sensing and has led a number of research projects on the microwave signatures of sea ice. His present activities are focussed on the commissioning of an advanced remote sensing SAR operating at X- and C-band.

A. Laurence Gray (M'85) graduated in physics and applied mathematics from Queens University, Belfast, in 1964. He received the M.Sc. degree in biophysics in 1966 and the Ph.D. degree in experimental physics in 1971, both from the University of Calgary.

Between 1971 and 1974, he worked on laser light scattering in the Physics Department of the University of Guelph, Ontario, Canada. In 1974, he joined the Canada Center for Remote Sensing and has worked since then principally on ice and cold ocean reconnaissance. On a leave of absence from CCRS during 1979-1980, he was a Guest Professor at the Technical University of Denmark, and from 1980 to 1983, was chairman of the CACRS Ice Working Group. He was one of the principal investigators in the Shuttle Imaging Radar (SIR-B) experiment. Between 1981 and 1987, he was a member of the AMI team advising the European Space Agency on the design and use of the SAR-Scatterometer sensor system known as the Active Microwave Instrument, which will be flown on the ESA remote sensing satellite ERS-1.

APPENDIX B

MISSION: AIRBORNE REMOTE SENSING PROJECT PLANNING SOFTWARE

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ABSTRACT

Intera has developed an IBM-PC compatible based software product for airborne remote sensing project planning. The software, called MISSION, assists in both planning and operational aspects of airborne remote sensing data acquisition projects. MISSION includes two modules which automate the following tasks:

1) Mission Planning - sensor and sensor geometry parameter definition, determination of data acquisition lines to achieve desired ground coverage.

2) Flight Planning - integrating specified data acquisition lines with takeoff, landing, and alternate airport data and aircraft characteristics.

Intera has used MISSION to support all phases of remote sensing projects in ice-reconnaissance, satellite simulation, radar mapping, geophysics, search and rescue and infrared survey application areas.

INTRODUCTION

Intera has been conducting and managing airborne remote sensing data acquisition projects for over 15 years. Sensors that have been used include: cameras, infrared linescanners, various geophysical sensors, single side-looking synthetic aperture radars (SARs) and dual sided SARs and side-looking airborne radars (SLARs). These sensors have been mounted on platforms ranging from single engine Cessnas to a Challenger jet. Application areas in which Intera has been involved cover the entire range of airborne remote sensing: traditional air photo, infrared heat loss surveys, forest fire mapping, geophysics, radar terrain mapping, ice surveillance and patrol, satellite simulation research and development, and search and rescue.

It became apparent to Intera several years ago that traditional manual mission planning methods were time-consuming and inaccurate, being based on drafting data acquisition lines or ground swaths on a map and interpolating coordinates from the map grid. The use of side-looking SARs further complicated the process by introducing more complex sensor geometries where the flightline (the aircraft track) is shifted sideways from the image line (the centre of the sensor ground swath). Furthermore, the introduction of high performance jet platforms operating in remote areas made the flight planning component of project planning a far more critical element than it had been previously. The potential for errors inherent in manual calculation of waypoint coordinates and detailed fuel usage projections increased the level of risk for these projects.

The factors mentioned above, combined with the widespread availability of powerful personal computers with high quality graphics capabilities, led Intera to develop MISSION, a software package designed to automate all mission and flight planning tasks. The capabilities of the MISSION package were later expanded to include modules for in-flight tracking of mission performance and post-flight comparison of planned, reported, and actual data acquisition. These modules are not described in the current paper.

The remainder of this paper discusses the general hardware requirements and software design goals of the MISSION system and a detailed description of the capabilities of the various components.

HARDWARE REQUIREMENTS AND SOFTWARE DESIGN

Designed for use by both field and office based personnel, MISSION operates on a variety of MS-DOS based personal computers. Minimum system requirements include a hard disk, numeric coprocessor, and graphics capability. Intera uses MISSION on computers ranging from 8088 based laptops with low resolution graphics to powerful 80386 desktop machines with colour VGA graphics. Full mouse support is provided, however, a mouse is not required to use the software effectively. MISSION produces two types of output: text based reports such as costing summaries and flight plans, and graphical map representations such as ground coverage and flight routings. Text based output can be viewed on the screen, printed with any PC compatible printer, or stored in DOS text files which can be imported into word-processing software. In addition to screen display, graphics output can be produced directly on Hewlett-Packard plotters or other devices which can interpret Hewlett-Packard Graphics Language (HPGL) commands, such as the Hewlett Packard LaserJet III. Graphics output can also be written to text files, from which it can be imported into a variety of word-processing and desktop publishing packages.

MISSION is intended to be used by marketing staff, project planners, managers, and pilots. It is a tree-structured menu-driven system, designed to be "user-friendly" and accessible to all users. Each menu deals with logically distinct data or processes. All menus appear in separate windows on the screen. These windows are nested to provide a visual indication of the menu tree structure. In addition, there is a description of every menu available through on-line help which can be viewed at any time with a single key-press. A common criticism of menu based systems is that they slow down the more experienced user. To avoid this pitfall, MISSION was designed so that many of the more frequently used menus could be accessed with "short cut" keys.

MISSION PLANNING

The Mission Planning program (MP) is used to specify the sensor(s) and sensor geometry to be used on a project and the ground coverage to be attained. MP is designed to be used primarily by project planners. The program is also suitable for use by marketing staff who can use the program for project bidding and costing purposes.

MISSION supports three general classes of sensors: down-looking or nadir mode, single-side looking, and dual side-looking. Examples of nadir mode sensors include: air photo, infrared linescanner, and most geophysical sensors. A schematic of a typical nadir mode sensor is shown in figure 1. Single-side and dual-sided sensors are usually side-looking radars such as SARs or SLARs. Figure 2 illustrates a typical single-sided sensor. Dual-sided sensors are identical to single sided sensors except that they look out both sides of the sensor platform at once. In addition to their class, sensors are defined by their operational altitude limits, and other parameters which affect the size and position of the ground swath. MISSION has sufficient flexibility to allow definition of nearly any sensor. Data bases of sensors can be created so that all defined sensors are available for easy access and use.

After a sensor has been selected, the project specific sensor geometry parameters are entered. These data consist of altitude in above ground level (AGL) terms and the values for sensor varying parameters, if any. When the geometry is set, the sensor can be used for laying out data acquisition.

Because MISSION is designed for planning many different types of projects, it offers considerable flexibility in specification of data acquisition lines. Lines can be described in terms of the end coordinates of the image line, or, by the coordinate of the target (the middle of the image line) in conjunction with the line length and the line heading, or, by the start and end coordinates of the aircraft flight track.

Coordinate data can be typed in, or entered graphically on a map display using a cross-hair cursor driven by a mouse or the keypad cursor keys. Line shifting capabilities are available so that the image line or target can be placed at specific incidence angles or at offsets from the centre of the ground swath. With these facilities, the user can enter lines in terms of the near or far edge of the ground swath coverage for side-looking sensors or at arbitrary incidence angles as required for satellite simulation.

Any number of lines can be entered for a single project, each of which can be specified using any of the three methods. Furthermore, the sensor type and geometry can be changed from line to line if required. MISSION has facilities for the automatic generation of lines at a predetermined spacing and heading, such as is required for mapping projects. After lines have been entered, they can be interactively edited using the map graphics facilities. Figures 3 and 4 show example mission plan outputs generated by MP. Figure 3 is an example of a mapping mission planned for the Intera STAR-1 radar in wide swath mode. The lines were generated to provide 20% overlap and the endpoints edited interactively to cover the land mass of the island of Newfoundland. Figure 4 shows a hybrid ice surveillance/coastal patrol mission planned using the Intera STAR-2 SAR. Lines L-1 and L-3 are planned in dual sided wide swath mode, while line L-2 is planned for single-sided narrow swath mode.

FLIGHT PLANNING

The Flight Planning program (FP) integrates aircraft performance characteristics with flight routing information derived from airport data and the data acquisition lines contained in the mission plan for a project. Flights can be based on all the lines in a single mission plan, several mission plans, or a subset of the lines from one plan. The intended users of FP are primarily pilots, although costing and routing information generated is extremely useful for project management, reporting, and bidding purposes.

Data required for flight planning includes pilot information, aircraft data, and routing data.

Pilot information consists of the name and license numbers of the pilot who will be flying a particular mission. This data is used only in generating formal flight plans for submission to air traffic control.

Aircraft data includes descriptive data such as tail registration number and aircraft owner, and performance data such as cruise speed, fuel burn rates, climb and descent rates, and nominal turn radius. Descriptive data is required only for creating formal flight plans. Performance data is used for time, fuel and distance calculations. Data describing a number of different aircraft can be maintained in a data base to simplify data entry.

The route for each flight in a mission is described by the takeoff, landing, and alternate airports, and by the data acquisition performed during the flight. After the airport data are entered or extracted from a NavAids data base, data acquisition lines are imported from a file previously generated by MP. The coordinates of run-in and run-out waypoints are calculated during this process and cruise altitudes above sea level (ASL) established based on ground elevations and sensor geometry altitudes (AGL). Wind speed and direction data can also be incorporated in the route plan. The route can be edited interactively on the map display to modify planned coverage to meet flight dictated constraints.

Output summaries are available to show time, fuel, and distance on a waypoint by waypoint basis, as well as total summaries showing transit time and distance, data acquisition time and distance, and total flight cost. Formal flight plans can be produced in Canadian Department of Transport (DOT), American Federal Aviation Authority (FAA), or International Civil Aviation Organization (ICAO) formats. Operational flight plans are available in a format suitable for in-flight use. Route map outputs can also be produced. As an example, figures 5 and 6 show the route calculated and the formal flight plan for the ice surveillance/coastal patrol mission from figure 4.

CONCLUSIONS

The MISSION software has proven to be extremely useful at Intera. It is being used in all phases of data acquisition projects from the first proposal to the client to the final data acquisition report. It has increased the effectiveness of the project planning and management staff by providing the facilities to generate a number of scenarios which can be compared to rapidly determine the most cost effective method of performing a project.

Pilot workload has been reduced and data acquisition accuracy increased when compared to the manual methods used previously. The accuracy of the calculated fuel usage and flight time estimates has been verified repeatedly, leading to increased pilot confidence in data acquisition plans generated by project planning staff.

ACKNOWLEDGEMENTS

The authors would like to thank Intera management and staff for the support and valuable advice given to the authors during the development of the MISSION software. Partial funding for MISSION development was provide by the Industrial Research Assistance Program (IRAP).

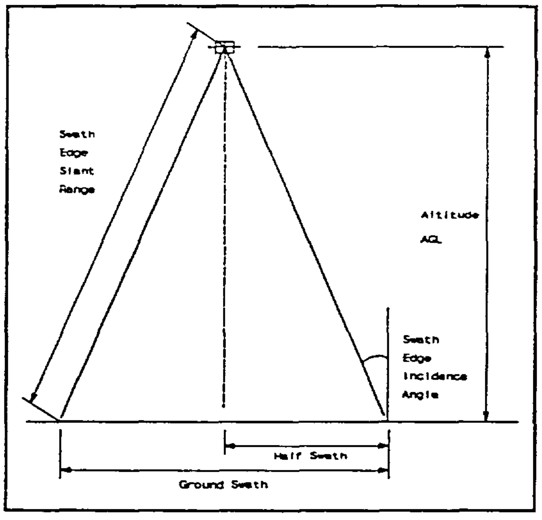


Figure 1 - Nadir Mode Sensor

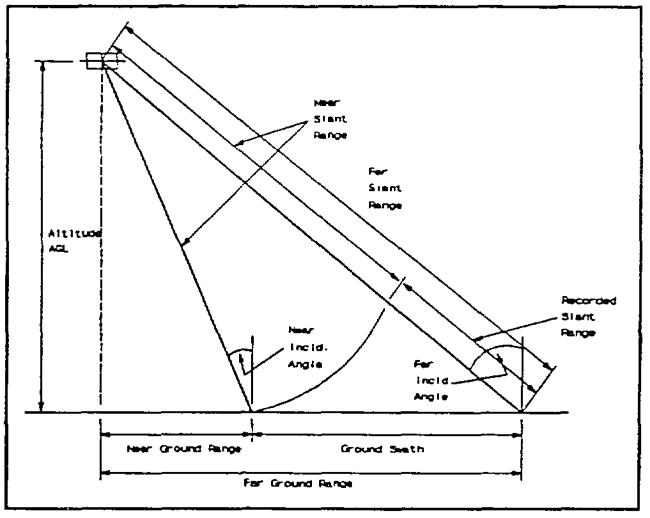


Figure 2 - Single Side-Looking Sensor

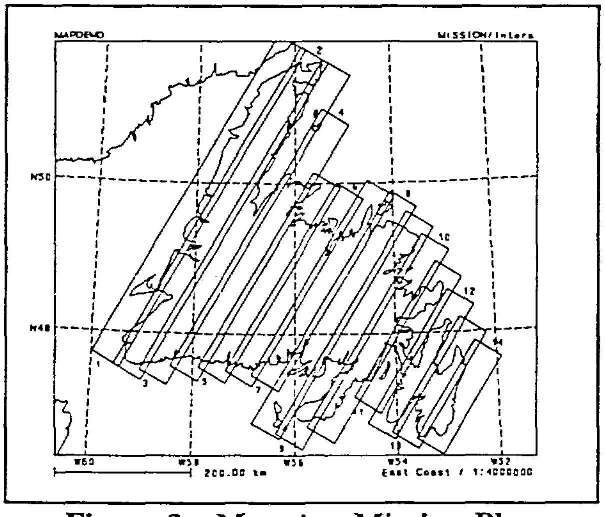


Figure 3 - Mapping Mission Plan

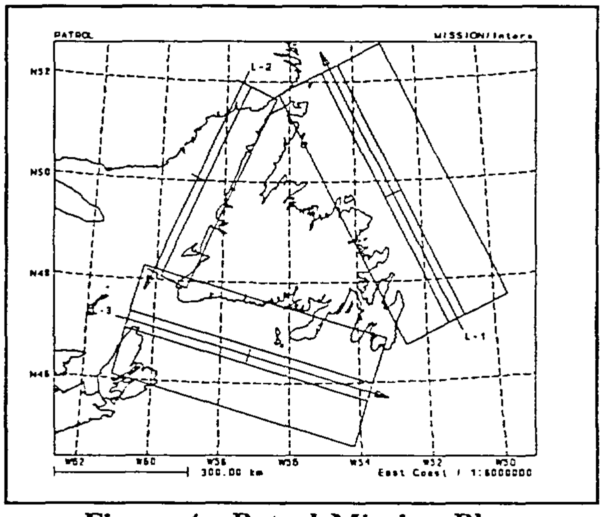


Figure 4 - Patrol Mission Plan

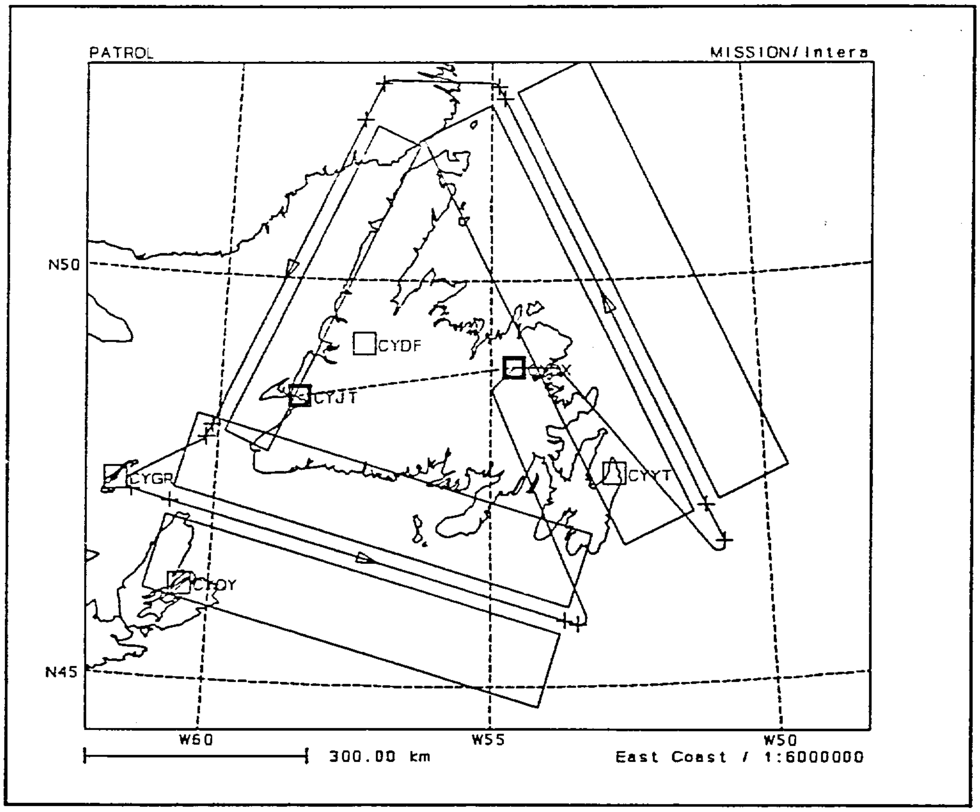


Figure 5 - Patrol Flight Routing

```
Flight Date: 09/OCT/90

Flight rules                                                  IFR
Aircraft Identification                                       CANICE-5
Type of Aircraft & Equipment                                  CL60/SCDHIMY/C
True Air Speed (knots) mach                                   400 [knots]
Point of Departure                                            CYQX
Flight Altitude/Level & Route                                 37000 [ft] / FL 370
     N46:44 W050:49  TO+00:35  /  N52:24 W054:51  TO+01:31
     N52:26 W057:11  TO+01:45  /  N47:59 W060:13  TO+02:28
     N47:18 W061:30  TO+02:39  /  N45:46 W053:28  TO+03:31
Destination Aerodrome                                         CYQX
Proposed Time of Departure                                    1200
Est. Elapsed Time                                             04+05
Alt. Airport/s                                                CYJT
Fuel on Board                                                 07+09
Type of Emergency Locator Transmitter                         FIXED
Communication Equipment                                       2VHF/2HF/1FM
Nav. & Approach Aids             2ADF/2INS/2VOR/2DME/1VLF/1LOR/1GPS/2FMS
Total No. of Persons on Board                                 3
Pilots Name                                                   Any Pilot
Name & Address of Aircraft Owner
     INTERA TECHNOLOGIES LTD.
     CALGARY, AB.
Aircraft colour                                               White and Tan
Pilots License No.                                            XXX-000000
```

Figure 6 - Canadian DOT Flight Plan for Patrol Flight

APPENDIX C

OPEN SKIES

HUNGARIAN/CANADIAN OVERFLIGHT

DIRECTORATE OF AVIONICS, SIMULATORS AND PHOTOGRAPHY BRIEFING

The Aircraft Modification Engineering Process

15 January 1992

I Introduction

1. The intent of this briefing/exchange is to outline what is involved from the Canadian Forces (CF) point of view in adding a sensor package to an inventory aircraft. I will give a comprehensive overview of the engineering process involved to establish a sensor mission kit available for use during Open Skies operations.

2. I will first look at the step of evaluating the acquired sensors to determine if their performance, as measured under laboratory conditions, meet the established Requirements Specification. The next step involves looking at all the intricacies of introducing this new equipment into the CF in the form of a modification design and implementation plan. Finally, I will outline the installation and testing requirements of this modification process

II Aim

3. The aim of this discussion is to illustrate that the installation of a sensor suite onboard an aircraft is not a trivial matter.

III Sensor Evaluation

4. In order to add a new sensor or sensor suite to an aircraft, previously unfitted, much work is involved from the conception of the idea to the effective completion of a mission using this new equipment. Let's take an overview of the process required to decide upon and install a sensor suite while maintaining flight safety and airworthiness of the aircraft.

5. From the Open Skies negotiations, certain sensors comprising a surveillance package are agreed upon. Their operating capabilities and minimal imaging resolutions are defined. Such performance definitions constitute a preliminary Requirements Specification with which the various country's delegations take away and begin acquisition of the equipment. The sensors may have to be procured and introduced into that country's armed forces, or if they already exist in that country's inventory, reallocated to the Open Skies role. Either way, sensor performance must be verified as applicable to the Open Skies Treaty.

6. The elements listed in Figure 1 form the basis of comparison between competitive systems which meet both the technical and operational Requirements Specifications.

The sensors must be evaluated in terms of:

a. Contractor's Performance Specifications (ie. intended and existing roles from other users, operating modes, resolution);
b. Reliability and Maintainability (ie.Mean Time Between Failures, past history);
c. Recording Medium (ie. film type/size, video formats/recorders, processing requirements);
d. Inter-system needs (ie. SAR and Navigation interaction);
e. Cost; and
f. Risk.

Figure 1. Sensor Evaluation

7. After all things are considered, the "short list" of sensors would ideally be tested and their performance compared, before the final sensor selection is made. The sensors should first be evaluated in a laboratory for the performances outlined in Figure 2.

A. <u>Aerial Cameras</u> - Test optical resolution (lens resolution & lens focal length) using a "bar chart" or electronic Modulation Transfer Function (MTF) equipment. Both the camera and lenses must be tested both on and off axis.

B. <u>Electro-Optic Sensors</u> - Test optical resolution of lenses (same way as cameras) which can then be compared with the theoretical detector resolution to determine the overall theoretical sensor resolution. Since in these sensors, the film has been replaced by detectors, the resultant video signal can be recorded. The recording equipment, including tapes, must also be tested in terms of imagery degradation effects.

C. <u>Infrared Sensors</u> - Measure resolution via the subjective measurements of Minimum Resolvable Temperature Difference (MRTD) tests. These tests use standard 4-bar targets, blackbody sources, and collimators under computer controlled conditions to combine the spatial and temperature resolution of the system in the correct way (albeit subjectively). The parameters measured include the MTF (system's ability to recreate the spatial frequency content of a scene), Noise Equivalent Temperature Difference (temperature difference between large objects in a scene required to produce a unity

Signal-to-Noise Ratio), Signal Transfer Function (relates temperature difference in scene and luminance difference on screen), Noise Power Spectrum, Uniformity (variations of luminance on display), and distortion (for each field of view).

D. Synthetic Aperture Radar (SAR) - Laboratory testing can only be carried out on the functionality of the individual components comprising the SAR. System performance testing cannot be adequately done on the whole system. For instance, the processing components can only be verified using "pre-generated" data inputs directly. Performance testing of the antenna/system in terms of range and cross-range resolution would have to be carried out during the prototype testing phase discussed later.

Figure 2. In-Laboratory Testing of Sensors

IV Aircraft Modification Process

8. Once the individual sensors are chosen after having met an acceptable compliance level against the above mentioned criteria, thoughts must now be turned towards installing these sensors as an integrated package into a specific aircraft. The installation itself can be completed in a variety of ways as highlighted in Figure 3. The designer must take these methods into account when contemplating the modification's design.

The sensor suite can be installed in one of three ways:

- Permanently (cannot remove the sensors and go flying)
- Semi-permanently (the sensors can be removed, yet the wiring etc remains under the aircraft skin)
- Strap-in (transparent - ie. all wiring harnesses are removed and no indication remains that a sensor was there).

Incorporating one of these installation methods, the sensors may be:

- Belly mounted
- Side mounted
- Wing mounted, or
- Nose mounted

Figure 3. Sensor Installations

9. The aircraft may be configured with the sensors internal or external to the aircraft skin. An external configuration may take the form of a pod.

10. It is not necessarily true that using a pod-type platform for the sensors would be easier than installing them into the "belly" of the aircraft. Both methods have specific concerns which must be addressed. The sensor suite is expensive and it is likely that the absolute minimum number will be procured. Therefore a removeable, semi-permanent package is ideal to maintain a degree of flexibility in the limited fleet of aircraft assigned to the Open Skies mission. It is also a fact that the fewer "holes" in the aircraft, the better if the sensor suite is to be removeable, as all aircraft in the fleet could potentially receive the modification kit.

11. The aircraft modification process is very involved and requires many levels of planning and review. The modification must be fully engineered and all logistic aspects analyzed prior to an actual prototype modification. In doing so, all design aspects listed in Figure 4 must be developed. The process begins with the definition of what is required to support this new equipment over its life, how will it be maintained, how will users and maintainers be trained on it, and how will this new capability be incorporated into present operations? These questions must be continually asked throughout the process as problems are encountered, contemplated, and solved.

The complete modification must be designed in terms of:

- Structures (aircraft, mounts, brackets)
- Flight Dynamics (related to structural additions)
- Electrical Power (both within sensor suite & aircraft)
- Electromagnetic Interference and Compatibility (EMI/EMC - within sensor suite and within aircraft avionics)
- Avionics integrity (hardware and software)
- Human Engineering (access to sensors, human interfaces)
- Standardization/Interoperability (ie. NATO standards)
- Photo/Imagery (interaction with existing systems)
- Aircraft Air-Conditioning (additional requirements)
- Weight and Balance

Figure 4. Design Considerations for Modification

12. All components (ie. wiring, connectors, rivets) required to create a modification kit must be identified with part numbers. Maintenance concepts must be proposed for all black boxes (sensor components) and subassemblies ie. what components will be repaired by CF technicians on the hangar floor and in the avionics workshops, or by civilian repair and overhaul contractors?

13. All expenses must be identified such as non-recurring costs (ie. engineering, civilian contractor representatives, prototyping), cost of kits or parts, installation costs, and logistic support costs. Supply aspects must be identified such as the primary procurement offices who will be responsible for buying the initial parts and subsequent spares. Also, items for special screening must be identified ie. long-lead and short-supply items. The logistic support elements listed in Figure 5 must all be addressed during the development of the modification proposal.

- Spare Parts (& disposal of old parts)
- Special Tools (ie. for installation and maintenance)
- Test Equipment (ie. for avionics workshops)
- Aircraft Maintenance Support Equipment (ie. additional equipment required)
- Software
- Training/Courseware (ie. training aids & equipment)
- Mission Support and Analysis
- Software Maintenance and Development
- Simulators/Trainers
- Production Tooling
- Drawings and Technical Data (ie. Initial Parts Breakdown list)
- Technical and Operating Manuals (including maintenance instructions, repair & test schemes, parts lists, logistic documents, diagnostic instructions, simulators, trainers, training manuals, software documentation, and wiring diagrams)
- Repair & Overhaul Turn-Around-Times and Costs
- Procurement/Supply (who will buy what components and when)

Figure 5. Logistic Support Elements

14. The modification schedule must be formulated to identify major milestones of the process, ie. engineering, development, provisioning, implementation, and logistic support elements.

V Review of the Modification Proposal

15. Once the modification has been engineered, the proposal requires an all encompassing review to ensure nothing has been omitted. These reviews cover more than just the actual installation of the sensors as detailed in Figure 6.

A. Technical Review - All Air Force technical specialists must review the applicable segments of the modification instruction (as per paragraph 6 above) to ensure accuracy and validity of design, and compliance to recognized standards.

B. Airworthiness Review - The modification must be evaluated in terms of effect on airworthiness.

C. Operational Review - The proposal is evaluated by operational requirements staff as to its impact on aircraft performance, handling, operating procedures, mission effectiveness, flight-essential systems. It must be remembered that aircraft, when not involved during Open Skies flights, may be used for other purposes. This proposal must also evaluated in terms of flight simulation. Aircraft operating instructions must be amended accordingly.

D. Flight Safety Review - The CF flight safety representatives must review the modification and determine any adverse flight safety effects. All review agencies, however, share this responsibility in their own areas of expertise.

E. Integrated Logistics Support Review - Logistic agencies must review the proposal to determine the level of effort required (including budget sourcing) for all the elements listed in Figure 4.

F. Final Review - The Aircraft System Manager (the senior engineering officer who controls the technical configuration of the aircraft fleet) must review the modification's impact on the whole aircraft system. All comments from the review agencies must be incorporated into the modification proposal to the satisfaction of the Aircraft System Manager before the proposal is submitted for approval.

Figure 6. Modification Proposal Review

16. Based upon total modification cost, the appropriate signing authority must grant approval before the proposal is accepted.

VI Installation and Testing

17. Once the paper exercise, which includes the design and implementation plan has been approved, a prototype installation is initiated. This prototype is intended to work out the practical problems which may have been overlooked during the design. It is here that the design drawings and documentation are finalized. Figure 7 outlines the process followed.

A. Implementation - Once the modification has been accepted, then the work begins ie. the assembly of the modification kit and the initiation of the implementation schedule. Much of the modification kit may be provided by the CF, but the installation would normally be carried out, with CF assistance, by the civilian firm which is responsible for the Repair and Overhaul of the specific aircraft type. The work location would be at the contractor's facility or by a civilian mobile repair party at a base.

B. Prototype Testing - A prototype modification is carried out. If the aircraft type has suitable avionics trainers then these are modified first, tested and proven before an aircraft is touched.

C. Ground Testing - Full ground testing procedures (functional, EMI/EMC, operational) are carried out on the prototype to validate the modification. If acceptable, this procedure is repeated on an aircraft. Experts from the CF aerospace engineering test establishment are involved to perform EMI/EMC testing (on ground and later in the air).

D. In-Flight Testing - Only after everything is acceptable on the ground does an in-flight test occur. CF flight test engineers and pilots carry this phase out and evaluate system operability, avionics interoperability, EMC, airworthiness and air safety. If acceptable an air worthiness certificate is issued, which allows the remainder of the aircraft fleet to be modified (if intended).

Figure 7. Installation and Testing Process

VII System Operational Evaluation

18. The new surveillance capabilities provided by this modification should then be evaluated in terms of operational performance. This type of test and evaluation would be carried out either as part of the in-flight acceptance testing or under a dedicated project (as it would normally encompass a more indepth scope than the initial flight testing for airworthiness). Detailed test procedures would be prepared for in-flight testing. For surveillance sensors, testing must be carried out under suitable conditions ie. large outdoor ranges. Targets must be designed and built for system resolution testing ie. bar targets for cameras, 4-bar thermal targets for thermal imagers, and corner reflectors for SAR. In-flight performance may vary from the in-laboratory performance and such deltas should be documented and incorporated into the aircraft operating instructions for this equipment.

VIII Open Skies: The Modification Process

19. This process can be completed in minimal time provided the project priority is assigned accordingly. All steps must be followed as far as proving the design and installing the equipment since airworthiness and flight safety are the highest concerns.

20. All modifications whether minor or major must follow this process. If the sensor suite was designed as a removeable, semi-permanent package, transportable between aircraft of similar type (ie. the aircraft are wired for-but-not-with the sensors), the aircraft configuration both with and without the sensors must be tested for airworthiness. If more than one type of aircraft is to be used, the complete aircraft engineering change process must be carried out for each.

21. Once the modification has been accepted for use, any change to it would require further airworthiness testing. Such an example would be the requirement for sensor covers (it sounds trivial, but aerodynamics of the aircraft could be affected). Since these covers must be removeable from the aircraft exterior, they pose flight safety concerns ie. foreign object damage (especially for jet aircraft).

IX Conclusion

22. It may be implied that this process is simply the application of common sense. This is true, although any error or oversight during one step of the process will result in serious detrimental effects on the sensor equipment during its lifetime aboard the aircraft. The whole process is not trivial and the level of effort is reflected in the bottom line - money. For instance recurring and non-recurring, civilian contracting, engineering, equipment, testing, maintenance, and training demand large amounts of personnel involvement. In order to establish an effective sensor package and its associated support infrastructure for an operation such as Open Skies, the essential ingredients are money, time (well organized), and skilled personnel.

Open Skies

Hungarian / Canadian Overflight

The Aircraft Modification Engineering Process

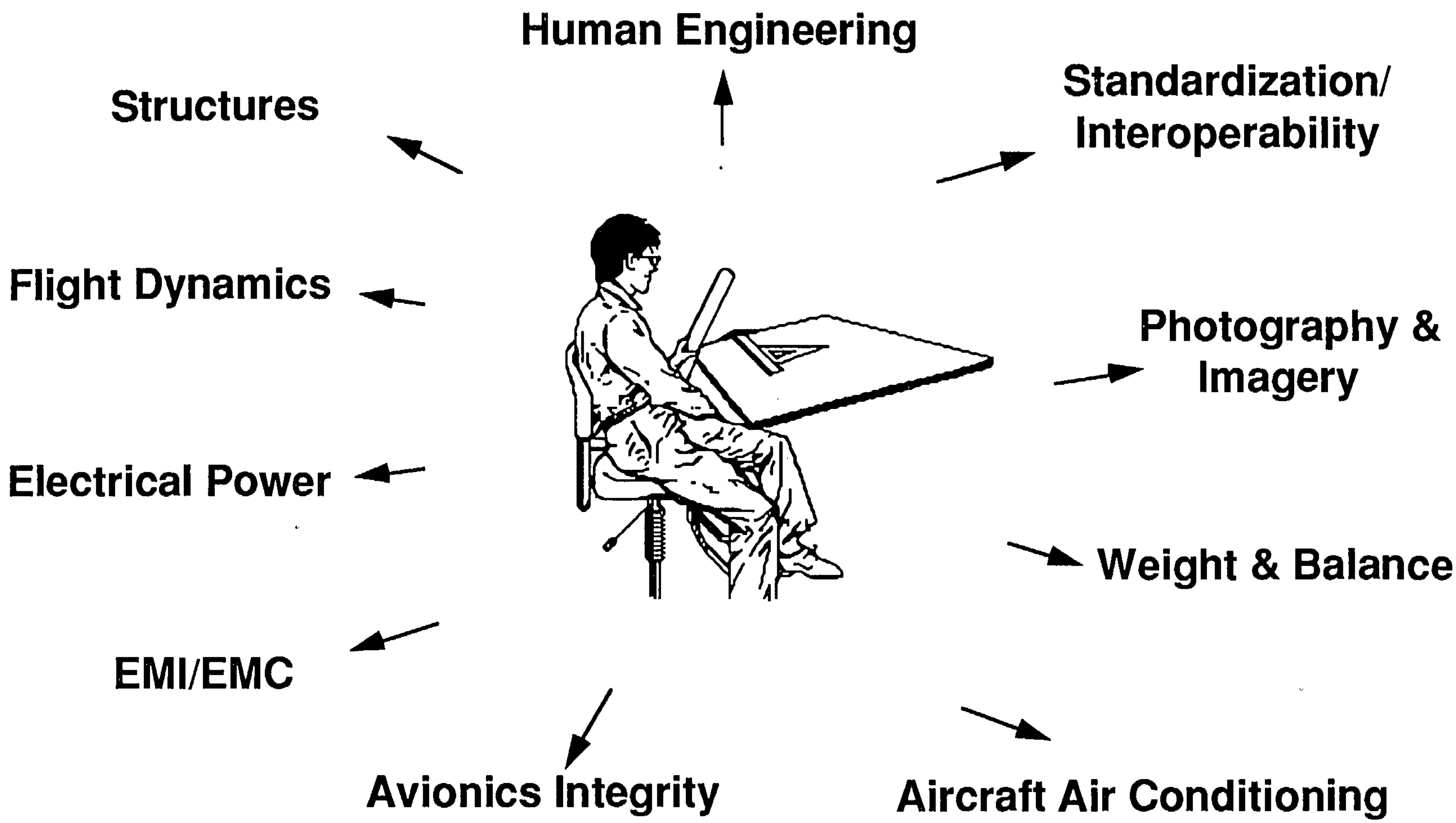
by

Major J. C. Croteau

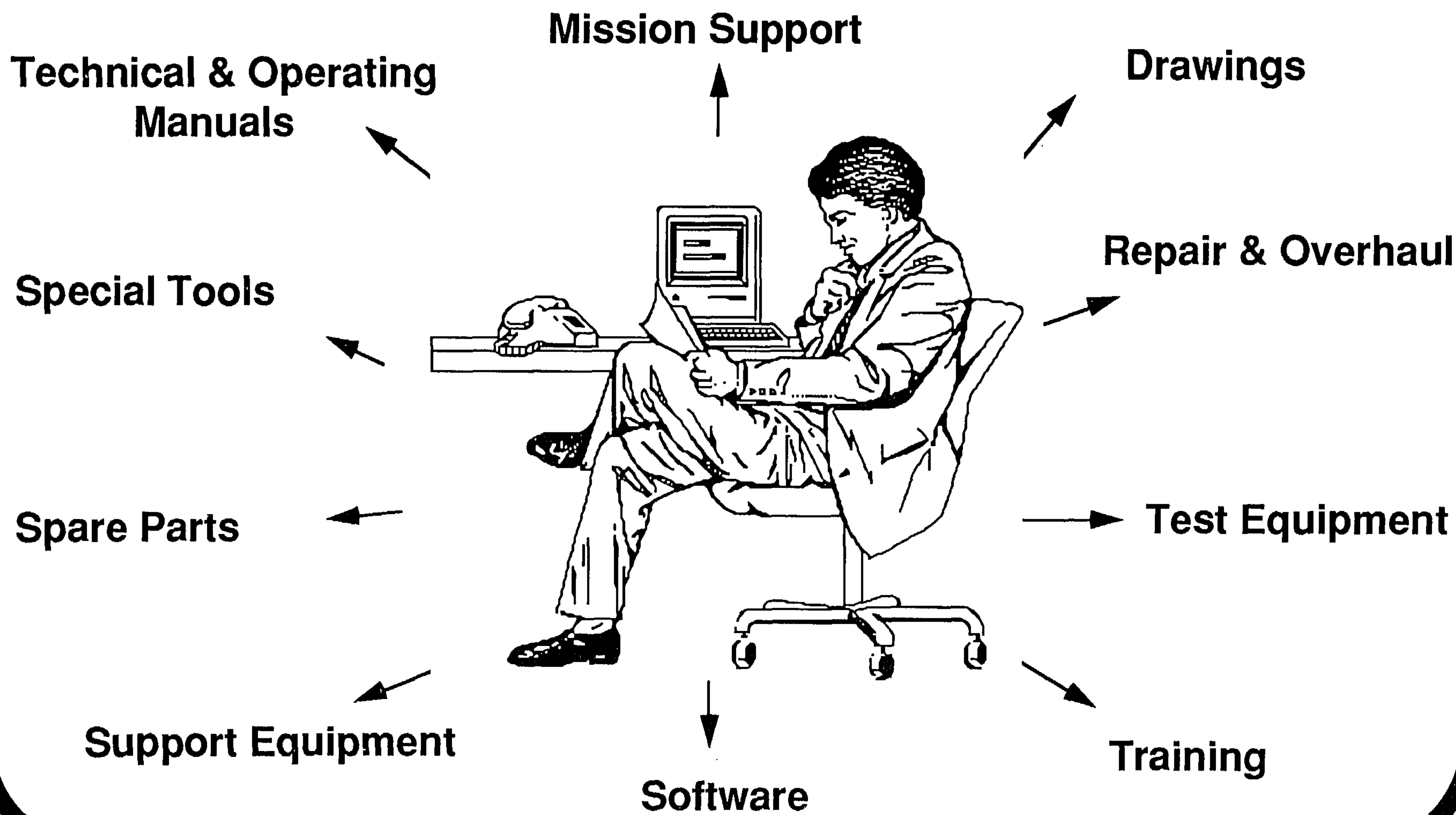
Captain N.D. Bell

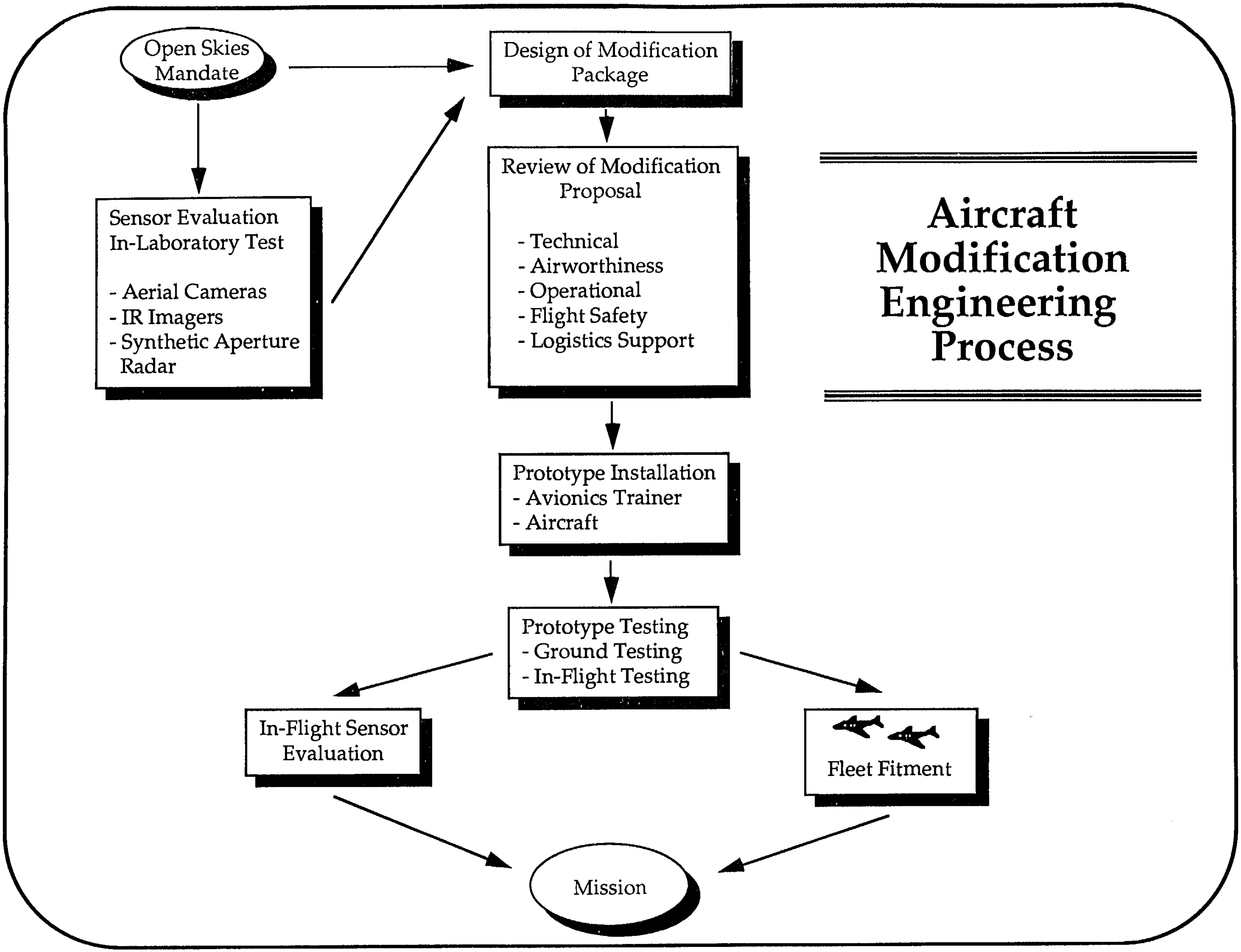
Ottawa, 15 January 1992

Engineering The Modification Package

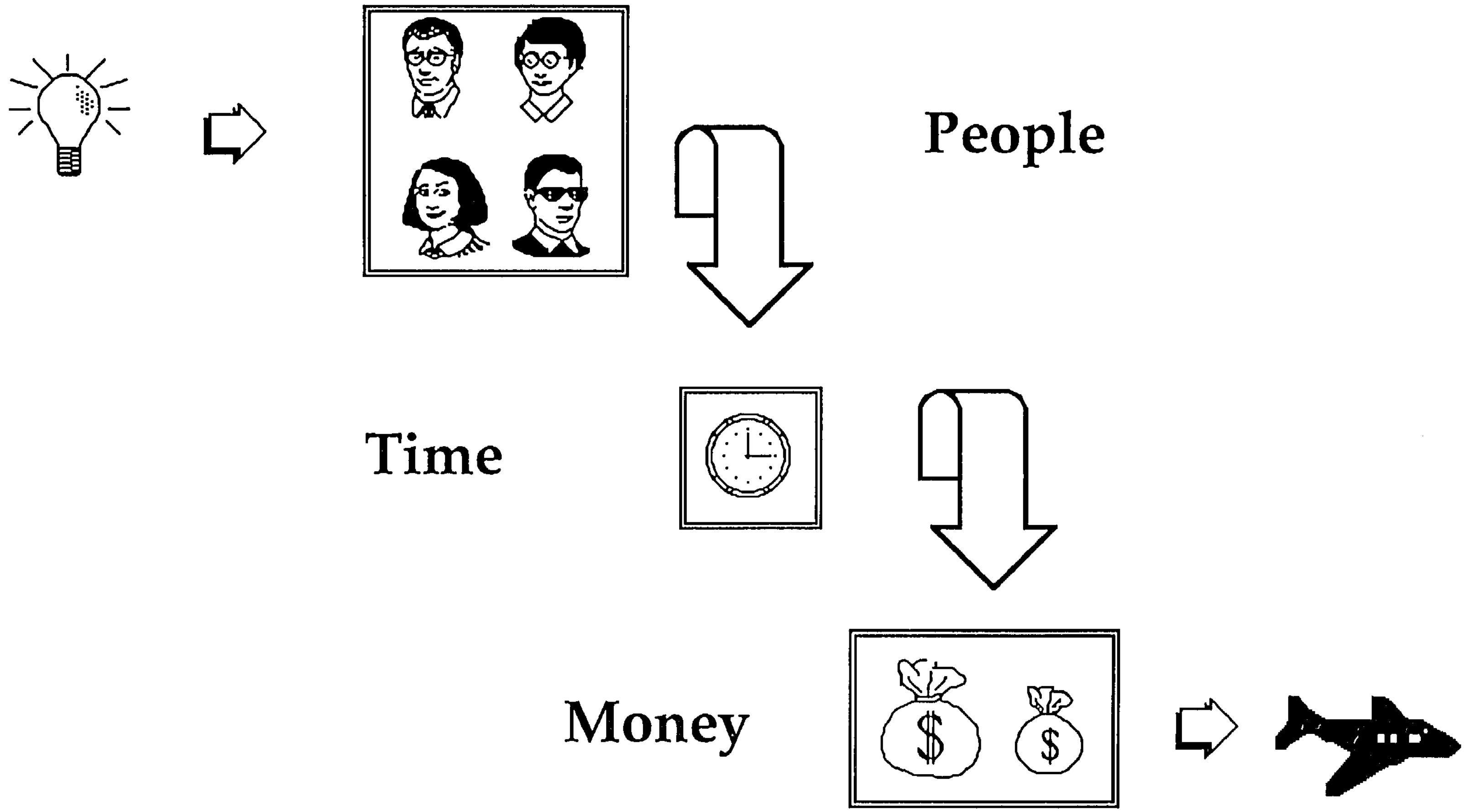


Logistics Support




Open Skies Mandate
Design of Modification Package
Sensor Evaluation In-Laboratory Test
- Aerial Cameras
- IR Imagers
- Synthetic Aperture Radar
Review of Modification Proposal
- Technical
- Airworthiness
- Operational
- Flight Safety
- Logistics Support
Aircraft Modification Engineering Process
Prototype Installation
- Avionics Trainer
- Aircraft
Prototype Testing
- Ground Testing
- In-Flight Testing
In-Flight Sensor Evaluation
Fleet Fitment
Mission

The Bottom Line



APPENDIX D

THE TRIAL OVERFLIGHT

Aircraft:	CCRS Convair 580
Duration of overflight:	3 hours, 05 minutes
Weather:	about 25 kilometres visibility cloud cover, in some places 6/8 overcast snow cover on the ground ground temperature of -25°C
Sensor types:	synthetic aperture radar (SAR) metric camera (Wild RC-10) low light level TV
SAR:	C band, two polarizations (HH, HV) data registration: HDDT, hard copy spatial resolution: 6 metres x 6 metres swath width: 16 kilometres, 8 kilometre half-swath recorded altitude: 20,800 feet AGL ground speed: 200 knots
	<u>AREAS</u>
	Trenton: Flight line 1, airport Pickering: Flight line 2, nuclear power plant Oshawa: Flight line 2, GM car factory Ottawa: Flight line 3, Rockcliffe airfield, Ottawa International Airport
Metric camera:	Wild RC-10, modified by CCRS (video operating, external navigation data recording on film) film type: AGFA 150 focal length: 152 millimetre frame size: 23 centimetre x 23 centimetre calibration according to Canadian National Standard

AREAS

Pickering: Flight line 4
exposures: 6529-6533
target: nuclear power plant

Oshawa: Flight line 5
exposures: 6549-6554
target: GM car factory

Trenton: Flight line 4
exposures: 6577-6582
target: CFB Trenton

Ottawa (north): Flight line 6
exposures: 6588-6591
target: Rockcliffe airfield

Ottawa (south): Flight line 6
exposures: 6600-6604
target: Ottawa International Airport

Low light level TV:

RCA Silicon Intensifier Target (SIT)
resolution: typical 600 lines
geometric distortion: maximum 1% of image height
light range: from bright sunlight to quarter moonlight

AREAS

Used in all areas mentioned above. LLLTV camera was switched on during SAR and optical camera operation.

35-mm photographs:

During the overflight, 35-mm colour photos were taken as required to record cloud/visibility conditions for each of the target sites.

APPENDIX E

ILLUSTRATIVE COST ESTIMATES FOR OPEN SKIES TRIAL OVERFLIGHT[1]

1.	**Flying time @ $2000.00 per hour**	
	estimated 3.0 hours	$6,000.00 (est'd)
2.	**Sensor time @ $1323.00 per hour**	
	estimated 1.5 hours	$2,000.00 (est'd)
3.	**Actual Fuel cost**	
	estimated 0.73 per litre	$2,700.00 (est'd)
4.	**Costs of consumables**	
	1. High density tape	
	2. VCR tape (3)	
	3. 8mm tape (1)	
	4. Floppy disk (1)	
	5. Dry silver paper	
	6. Chart paper	
	7. Log sheets	$350.00 (est'd)
5.	**Data Processing expenses**	
	1. HDDT system mount for film	$400.00
	2. HDDT system mount for CCT products	$400.00
	3. 6250 bpi CCT, est'd 3 @ $116.00 each	$350.00
	4. Film neg scene per frame, est'd 8 @ $79.00	$650.00
	TOTAL	**$12,850.00**

1. Estimates taken from contract with Canada Centre for Remote Sensing, not including crew costs.