Technical Trends in Aerial Imaging

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Part I - Introduction

(a) Very early types of airborne digital imagers date from the 1970s. Until the 1990s, these were almost all for military use.

(b) In the U.K., the RAF started to go over to digital imagers in a substantial manner in 1993; by 2003, no more use of film cameras.

(c) Development of the present types of medium- and large-format imagers that are available for civilian use dates from late 1990s.

(d) The first large-format airborne camera (DMC) and pushbroom scanner (ADS40) were shown in 2000; deliveries began in 2002.

(e) Over the **last five years** till 2007, over 150 large-format airborne digital imagers have been sold + several hundred small- and medium-format digital imagers.

(f) The manufacture of **airborne film cameras** has almost ceased and the use of film cameras is in sharp decline.

Outline & Structure of the Presentation

- **Part I – Introduction**
- **Part II – Sensor Technologies**
  - (a) Detector Types – CMOS & CCD Detectors
  - (b) Area Arrays
  - (c) Linear Arrays
- **Part III - Airborne Digital Frame Cameras**
- **(**a) Small-Format Frame Cameras
- (b) Medium-Format Frame Cameras
- (c) Large-Format Frame Cameras
- **Part IV – Airborne Pushbroom Line Scanners**
- (a) Monochrome Line Scanners
  (b) Thermal IR Line Scanners
- (continued)

Outline & Structure of the Presentation

Part IV (continued) – Airborne Pushbroom Line Scanners

(c) Colour Line Scanners
(d) Hyperspectral Line Scanners
(e) Three-Line Stereo Line Scanners
(f) Inertial Measuring Units (IMUs)
(g) Differential GPS

Part V – Airborne Radar Technologies

Part VI – Film versus Digital

Part VII - Summary & Conclusion

Part II - Sensor Technologies

(a) Detector Types – CMOS & CCD Arrays

(b) Area Arrays - used in frame cameras

(c) Linear Arrays – used in pushbroom scanners

Part II - Sensor Technologies

(a) Detector Types

(a) 2 Main Detector Types

CMOS – Lower quality – mainly used in document scanners, etc. Now being used in small-format aerial digital cameras

CCD – Better radiometric quality – as needed for airborne imaging in larger formats

(b) 2 Main Formats

Area Arrays – Up to 4k x 4k = 16 Megapixel (small-format); up to 7k x 7k = 50 Mpix (medium-format); up to 10k x 10k = 105 Mpix (large-format)

Linear CCD arrays – 4k to 14k detectors (pixels)

(c) 2 Main Types of Digital Imager

Digital Frame Cameras – based on area arrays

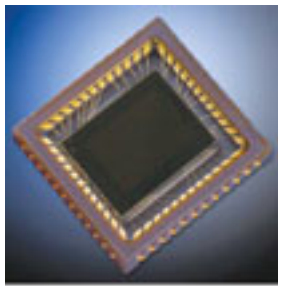
Pushbroom Line Scanners – based on linear arrays

Part II - Sensor Technologies

(b) Area Arrays

CMOS Detectors

- Originally CCD arrays used for small-format cameras – e.g. Kodak DCS 460 to 760 series - 6 Mpx images
- CMOS arrays used to have lower radiometric quality
- Now CMOS gives much better radiometric quality and larger formats, so much used for **small-format cameras**.
- First Kodak DCS Pro series (14 Mpx); now Canon EOS-1Ds Mk-II (16.7 Mpx) and Nikon D2X (12.4 Mpx) – all now used as **airborne small-format cameras**.



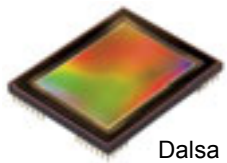
NatSemi
CMOS Array

Part II - Sensor Technologies

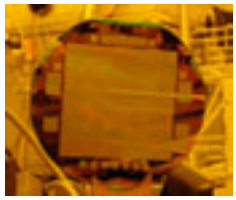
(b) Area Arrays

CCD Detectors

- Smaller pixels – now 6 to 7 µm instead of 9 to 12 µm
- Size of CCD arrays and digital backs has been doubled – were 16 Mpix; then 22 Mpix; now 30 to 40 Mpix using new CCD chips from Kodak & DALSA
- Used in **medium-format** airborne cameras
- Also in large-format airborne frame cameras – e.g. Vexcel UltraCam + Intergraph DMC use multiple medium-format CCD chips;
- Large-format CCD arrays now available from Fairchild (9k x 9k) and DALSA (10.5k x 10.5k)



Dalsa
22 Mpix Array



Dalsa 105 Mpix Array

Part II - Sensor Technologies

(b) Area Arrays

Colour Images

Generating colour images from area arrays is a complex matter –
CCD & CMOS area arrays are monochromatic (black and white)

Solutions

(a) ***Bayer interpolation***

- Employing a mosaic of colour filters placed over the detector array - used in small- and medium-format frame cameras

(b) ***Beam splitters*** - very small formats only

(c) ***Multiple cameras, each recording a single band***

- Much more expensive solution.
- Much more processing needed for image fusion – but no interpolation is required – very good colour image

Part II - Sensor Technologies

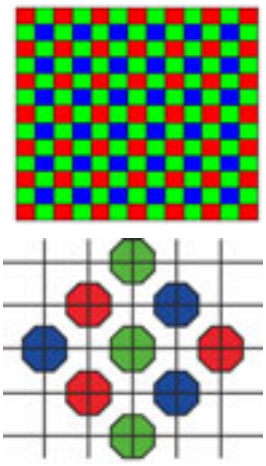
(b) Area Arrays

Solution (a) - Bayer Interpolation:-

(i) A mosaic of tiny filters is placed over the array of detectors.

(ii) Each pixel receives red or green or blue light in the pattern shown.

(iii) For each pixel in the output image, one of the three colour bands is received directly and the other two are interpolated from the neighbouring pixels.



Used very much in airborne small- and medium-format cameras – with some limitations in colour rendition!

Part II - Sensor Technologies

(b) Area Arrays

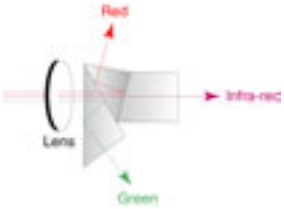
Solution (b) - Colour Using Beam Splitter

(a) Optical beam splitter, placed between the lens and the three separate image planes, each with its own filter and CCD area array.

(b) Good colour rendition

(c) Limited to very small formats – 1k x 1.5k

(d) Used in a very few digital frame cameras such as the Redlake MS3100 and MS4100



Part II - Sensor Technologies

(b) Area Arrays

Solution (c) – Colour Using Multiple Cameras

(a) Four cameras employed with parallel optical axes

(b) Each camera records a single spectral band – red, green, blue and infra-red (RGB + NIR) separately. So no interpolation of the colour

(c) Final colour image is produced by image fusion – each individual image is registered and superimposed on one another

(d) Excellent final colour image

(e) Multiple cameras – so limited to small formats

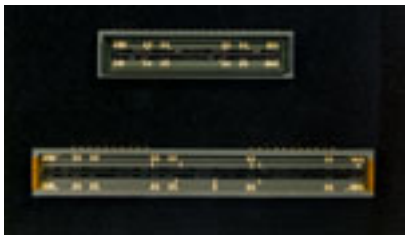
Part II - Sensor Technologies

(c) Linear Arrays

(a) Linear arrays are used in airborne pushbroom scanners employing CCD technology

(b) Longest arrays – 12,000 to 14,000 CCD detectors

- Atmel (France); e2v (U.K.); Kodak, Fairchild Imaging (U.S.A.)



CCD linear arrays from e2v
top – 4k pixel array;
bottom – 12k pixel array

Fairchild Imaging 6k pixel linear array

Part II - Sensor Technologies

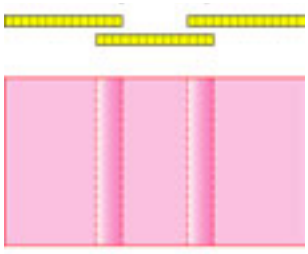
(c) Linear Arrays

(a) If a greater swath wide over the ground is required, then ***multiple linear arrays*** have to be used

(b) Cannot be butted together – stepped arrangement

(c) Then the three individual strip images need to be stitched together to form final image

(d) This arrangement is used in satellites (IRS-1C/D and QuickBird); but, so far, not in airborne scanners



Top (yellow part) – shows three linear arrays mounted in the focal plane of a digital line scanner;

Bottom (pink part) – the resulting image is formed by stitching the three sub-images together

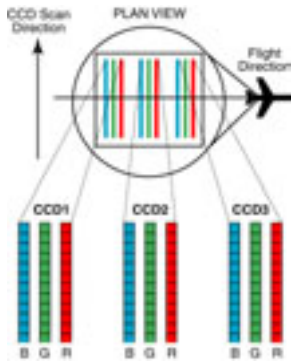
Part II - Sensor Technologies

(c) Linear Arrays

If **colour** is required, then multiple arrays have to be used

Solution (a) - Tri-linear Arrays

Colour using Kodak tri-linear arrays, as deployed in three-line airborne pushbroom scanners such as the Wehrli 3-DAS-1 and 3-OC models built by Geosystems in the Ukraine

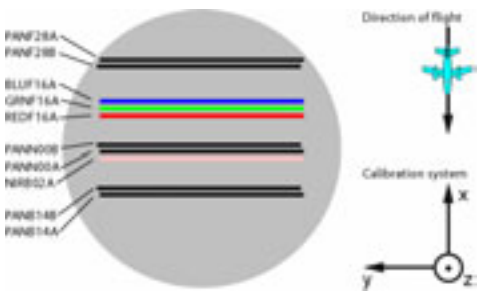


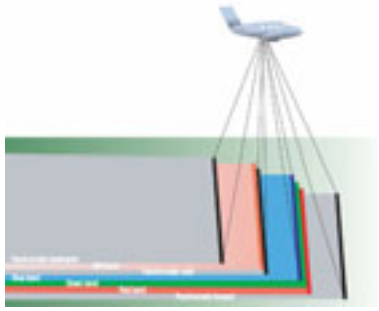
Offsets are created – different lines are being imaged on the ground at the same instant of time

Part II - Sensor Technologies

(c) Linear Arrays

Solution (b) – Three panchromatic (black and white) lines for stereo, supplemented by additional lines for colour



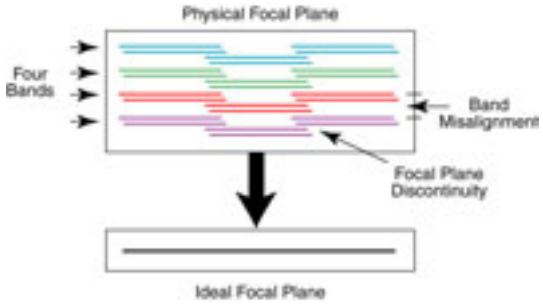


Again **offsets** are created – different lines are being imaged on the ground at the same instant of time

Part II - Sensor Technologies

(c) Linear Arrays

(a) When both greater swath and colour have to be provided in a line scanner based on linear arrays, the focal plane has a very complex layout and substantial photogrammetric processing is required to overcome discontinuities and misalignments



(b) Used in satellites – e.g. Quickbird; not yet in airborne scanners

Part III – Airborne Digital Frame Cameras

(a) Small-Format Frame Cameras
<16 Megapixels
(b) Medium-Format Frame Cameras
< 50 Megapixels
(c) Large-Format Frame Cameras
>50 Megapixels

Part III -Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

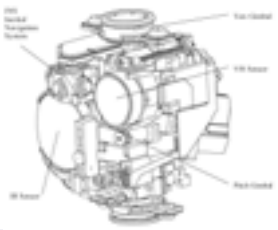
Monochrome Cameras

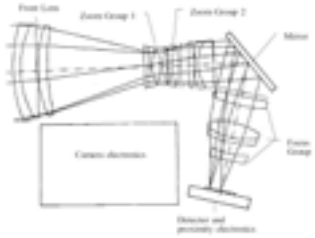
Purpose-built for reconnaissance purposes
Fast framing rates; small formats; zoom lenses; folded optics

- -

Example:-
Carl Zeiss VOS40 Series
2k x 2k = 4 Mpix images

(i) ***VOS40/270*** – f = 270mm lens; 15 frames per second
(ii) ***VOS40/500*** – f = 500mm lens; 3 frames per second





Part III -Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

Digital Video Cameras

Now very much used from airborne platforms

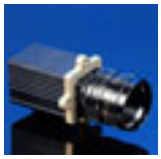
- -

(i) ***Standard Video Cameras***
Small Format – NTSC/PAL

(ii) ***HDTV Cameras***
Much larger formats – 1920 x 1020 pixels [2 Mpix] @ 50/60 Hz

(iii) ***Ultra HDTV Cameras***
Still larger formats – up to 4520 x 2540 pixels [11 Mpix] @ 50/60 Hz - are now in development

Sony Handycam



Adimec

Red One

Part III -Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

Digital Video Cameras

(a) In an airborne context, digital video cameras are usually operated on a gyro-stabilized mount.

(b) The cameras are mainly used for surveillance operations from helicopters, UAVs, blimps and STOL aircraft for continuous observation and monitoring purposes.

Predator UAV

av8pix Blimp

Diamond DA42 MPP

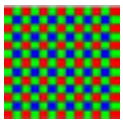
Part III - Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

Single Lens Cameras with Mosaic Filters & Bayer Interpolation – Colour Images

(a) Cameras built in large numbers for use in **professional photography**. Comparatively inexpensive.

(b) Formerly ***Kodak DCS 460/560/660/760*** series was much used – only 6 Mpix colour images.

(c) Now ***Nikon D2X*** -12.4 Mpix ; ***Canon EOS-1Ds-II*** - 16.7 Mpix); ***Mamiya ZD*** – 22 Mpix



Canon EOD-1DsII 16.7 Mpix image

Nikon D2X 12.4 Mpix image

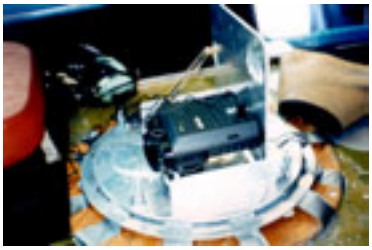
Mamiya ZD 22 Mpix image

Part III - Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

Adapted for use in ***airborne imaging*** – add mount; shock absorbers; control box; GPS (+IMU).

Fitted to small aircraft and helicopters

Widely used - excellent for local projects -
(i) repeated flights for monitoring;
(ii) quick response to disasters

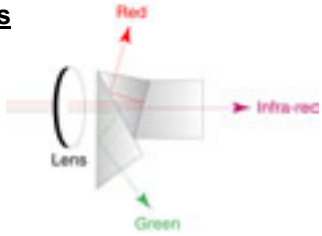


Part III - Airborne Digital Frame Cameras
(a) Small-Format Single Lens Cameras

Single Lens Cameras with Beam Splitters
These produce three multi-band images from which colour images can be produced – so no interpolation is needed

(a) Single Supplier – ***Redlake*** – only very small formats available –
(i) ***MS3100*** (1k x 1.4k) and (ii) ***MS4100*** (1k x 1.9k)

(b) Used as basis for airborne systems by various suppliers
(i) ***Airborne Data Systems*** (U.S.A.) – ***AgriView***
(ii) ***Integrated Spectronics*** (Australia) - ***ISAACS***



Part III - Airborne Digital Frame Cameras
(a) Small-Format Multiple Cameras

Multiple Cameras Generating Multi-Band Images

(a) Either 3 or 4 cameras with parallel optical axes, each camera recording one spectral band (RGB + NIR) only – so no interpolation!

(b) Placed on mount with **boresighting** – most are flown with GPS/IMU to provide rectification + geo-referencing data.

(c) Examples from ***Airborne Data Systems*** – SpectraView - and from ***John Deere*** – GeoVantage. Both systems built in large numbers.

Part III - Airborne Digital Frame Cameras
(a) Small-Format Multiple Cameras

Example:-

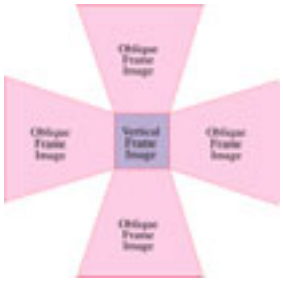
The SpectraView imager from ***Airborne Data Systems*** achieves colour and false colour images by means of four small-format digital frame cameras in a rigid mount, each camera having a different filter

Part III - Airborne Digital Frame Cameras

(a) Small-Format Multiple Cameras

Multiple Cameras Generating Oblique Images

Use of three (1 vertical + 2 oblique) or five (I vertical + 4 oblique) small-format cameras having mosaic filters. Specially built mounts



5-Camera Coverage

Oblique image of part of the Las Vegas Strip acquired by Pictometry International; the side views of the buildings indicate the information available from obliques, which are popular with emergency services, defense and homeland security agencies

Part III - Airborne Digital Frame Cameras

(a) Small-Format Multiple Cameras

MIDAS oblique 5-camera system built by Track'Air (Netherlands)

5 Canon small-format cameras give 5 x 16.7 Mpix = 83.5 Mpix per exposure – same as a large-format camera !!

Part III - Airborne Digital Frame Cameras

(b) Medium-Format Cameras

Single Cameras – Modified Film Cameras

(a) Based on well-known ***professional film cameras*** from Hasselblad, Rollei, Contax, Mamiya

(b) The film magazines are replaced by ***digital backs*** from MegaVision (USA); PhaseOne (DK); Imacon (Sweden)

(c) (i) Most first used the ***Kodak*** 4k x 4k = 16 Mpix CCD array;
(ii) later the ***Kodak*** 5.4k x 4k = 22 Mpix array;
(iii) now there are the newly introduced 31.6 and 39 Mpix arrays

(d) Examples:-
(i) *Applanix DSS* (Digital Sensor System) – uses Contax camera with MegaVision digital back + POS/AV (DGPS/IMU) unit
(ii) *Rollei AIC* uses Rolleimetric camera with Phase One back
(iii) *IGI DigiCAM* uses Hassleblad camera with Imacon back

Part III - Airborne Digital Frame Cameras

(b) Medium-Format Cameras

This H 25 digital back from **Phase One (Denmark)** is based on a Kodak CCD area array with 22 Megapixels.

The colour image is obtained using a mosaic filter and Bayer interpolation

It has been fitted, for example, to this Rollei camera as a replacement of the film magazine.

These digital backs generate colour images through the use of **mosaic filters** and **Bayer interpolation**

Part III - Airborne Digital Frame Cameras

(b) Medium-Format Cameras

Applanix DSS
camera & POS/DG
control box + screen

IGI DigiCAM
digital back,
body & lens

Rollei AIC camera
& digital back

Spectrum NexVue

GGS
AeroStab-2
stabilized mount

Part III - Airborne Digital Frame Cameras

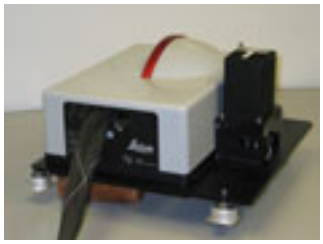
(b) Medium-Format Cameras – with Airborne Lidar

Rollei AIC
with Optech
ALTM Lidar

IGI DigiCAM
with
LiteMapper
5600
Lidar

Applanix
DSS with
Optech
ALTM Lidar

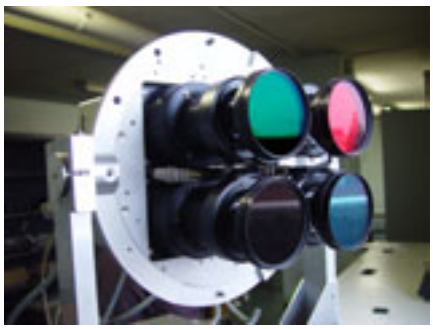
Spectrum
NexVue
with
Leica
ALS50
Lidar



Part III - Airborne Digital Frame Cameras
(b) Medium-Format Cameras

Multiple Cameras

IGN (France) uses four Kodak medium-format 4k x 4k = 16Mpix cameras + spectral filters to form the basis for its ***Quadricom*** multi-band camera system. No interpolation needed for colour images



Similar to small-format multi-camera / multi-band systems but with a much larger format.

Part III - Airborne Digital Frame Cameras
(c) Large-Format Cameras

There are two quite different lines of development:-

(a) Large-format cameras for military reconnaissance

- Use of **Single Camera** with single lens + single area array – monochrome image only
- The CCD area arrays have the largest size format available – difficult to manufacture – quite small yields – very expensive.

(b) Large-format cameras for civilian mapping use

- Use of **Multiple Cameras**; each camera is equipped with its own lens and shutter and its own medium-format CCD area array.
- Some of the cameras are equipped with **filters** to collect multi-band images from which **colour** images can be produced
- The final large-format image is produced using **image fusion** or merging techniques

Part III - Airborne Digital Frame Cameras

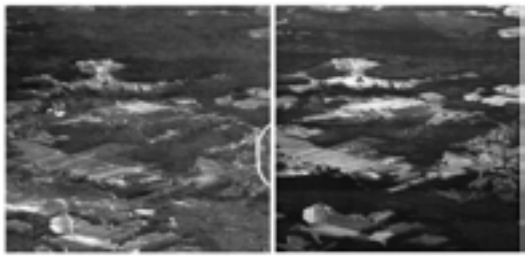
(c) Large-Format Cameras – Single Cameras

Large-Format Single Cameras

Camera with single lens + single area array producing **monochrome** images only.

(i) ***Recon Optical*** –

CA-260/270 series – 4 Mpx; 25 Mpix; and 50 Mpix models.



Part III - Airborne Digital Frame Cameras

(c) Large-Format Cameras – Single Cameras

(ii) ***BAE Systems*** –

F-979F & F-985F models – 9k x 9k = 85 Mpix

Clockwise from top left – camera; electronics unit; 9k x 9k CCD area array; & focal plane shutter

Part III -Airborne Digital Frame Cameras

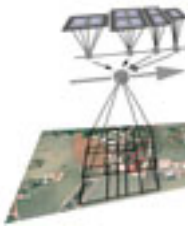
(c) Large-Format Cameras – Multiple Cameras

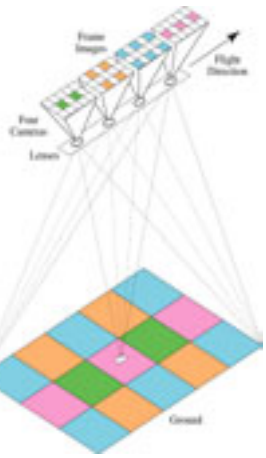
Vexcel UltraCam D –

(i) 4 medium-format vertical cameras - 86 Mpix pan image;

(ii) 4 small-format vertical multi-band cameras for colour, each 2.6k x 4k = 11Mpix

(iii) now ***UltraCam-X*** – (i) 133Mpix pan; and (ii) 5 x 3.3k = 16.5 Mpix for each colour





Vexcel patent – with 15 arrays!

Part III -Airborne Digital Frame Cameras

(c) Large-Format Cameras – Multiple Cameras

Vexcel UltraCam-D

The interior of an Antonov An-30 photographic aircraft being operated by the Russian Geokosmos mapping company – showing its Vexcel UltraCam D large-format digital camera, together with a pair of Rollei AIC medium-format digital cameras and an Optech ALTM laser scanner

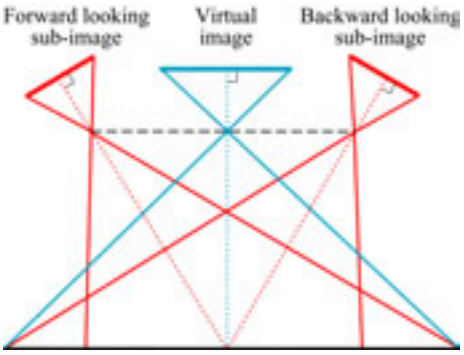
Part III - Airborne Digital Frame Cameras

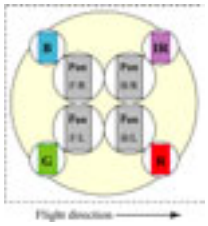
(c) Large-Format Cameras – Multiple Cameras

Intergraph DMC

(i) 4 oblique cameras with the tilted images rectified and merged to form 108 Mpix pan images;

(ii) 4 small-format vertical cameras for colour, each 2k x 3k = 6 Mpix covering a different spectral band





Part III - Airborne Digital Frame Cameras

(c) Large-Format Cameras – Multiple Cameras

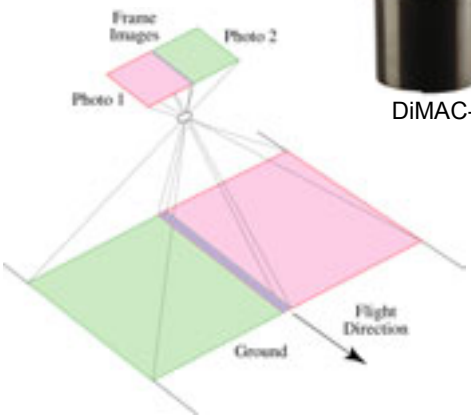
DiMAC Systems

(i) Originally 4 ***oblique*** cameras, each with 22 Mpix digital backs.

(ii) Now 2 ***vertical*** cameras, each with offset position of the digital backs to give images to left and right of the flight line.

(iii) Each camera has a 39 Mpix digital back from Phase One, giving 75.6 Mpix colour image when merged.

DiMAC-2



Part IV – Airborne Pushbroom Line Scanners

(a) Monochrome Line Scanners
(b) Thermal Line Scanners
- (c) Colour Line Scanners
(d) Hyperspectral Line Scanners
- (e) Three-Line Stereo Line Scanners
- (f) Inertial Measuring Units (IMUs)
(g) Differential GPS

Part IV -Airborne Pushbroom Line Scanners

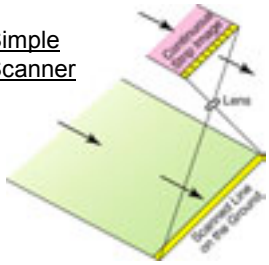
(a) All of these imagers use linear arrays with a pushbroom scan operation

(b) Each individual line in the image has a different **position** and **attitude** (tilt) value at its time of exposure

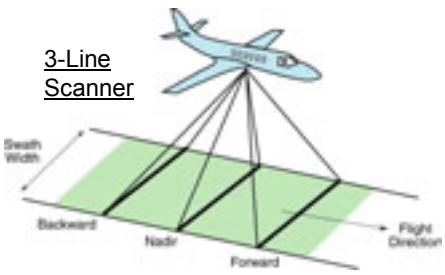
(i) These values need to be measured using a **DGPS/IMU system** – which adds considerably to the overall cost of the system;

(ii) Large changes in the aircraft heading or tilts result in **gaps** or **double imaging** – so a fast-acting **gyro-stabilized mount** is also obligatory.

Simple Scanner



3-Line Scanner



Part IV - Airborne Pushbroom Line Scanners

(a) Monochrome Pushbroom Line Scanners

Mainly used for military recce purposes – **monochrome** images only.

(a) ***Thales Optonics (Vinten)***
(i) ***Model 8010*** – 4k linear array Range of lenses for low-altitude operation. Roll-corrected, not fully stabilized.

(ii) ***Model 8042*** – 12k linear array + f = 45cm lens for high-altitude operations.
Scanner usually mounted in a pod under the aircraft.

(b) ***Global Scan (France)*** – 6k linear array + range of lenses. Low-altitude operation.

(i)

(ii)

Part IV - Airborne Pushbroom Line Scanners

(b) Thermal IR Pushbroom Line Scanners

(a) Lots of **military examples** from Honeywell (AN/AAD-5), now BAE Systems (D-500A); Sagem; Vinten; etc. – used for recce purposes

(b) In the **civilian domain**, the main use is for fire mapping; urban heat loss surveys; thermal pollution of water bodies; etc.

Examples of recent systems – **ITRES Research** (Canada)

(i) ***TABI*** - 320 pixel swath – single channel only

(ii) ***TASI*** – 600 pixel swath – 64 spectral channels (hyperspectral)

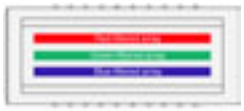
D-600A on TARPS

TABI

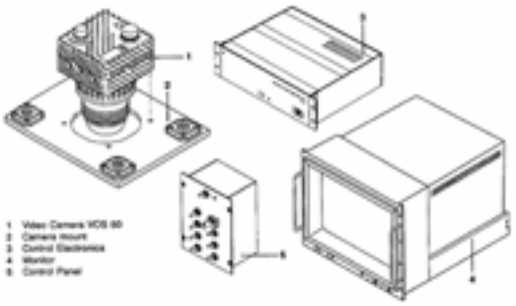
Part IV - Airborne Pushbroom Line Scanners

(c) Colour Pushbroom Line Scanners

These scanners produce continuous linescan images in colour (instead of monochrome) using a tri-linear array.



(i) Examples are the **Zeiss VOS-60 and VOS-80 scanners** with f = 60 and f=80 mm lenses.



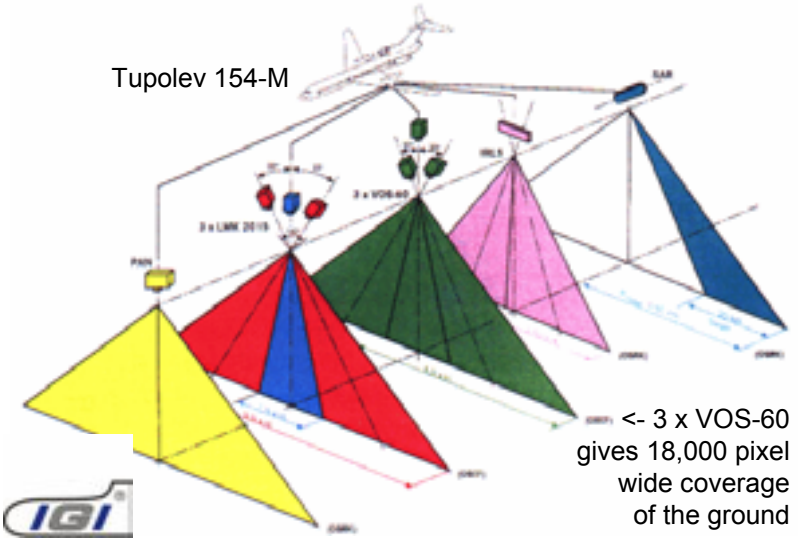
(ii) Both models use tri-linear arrays with 3 x 6,000 detectors.

(iii) The VOS-60 has already been approved for use in the German TU-154M Open Skies aircraft

Part IV - Airborne Pushbroom Line Scanners

(c) Colour Pushbroom Line Scanners

Tupolev 154-M



<- 3 x VOS-60 gives 18,000 pixel wide coverage of the ground

Part IV - Airborne Pushbroom Line Scanners
(c) Colour Pushbroom Line Scanners

German Tupolev 154-M 'Open Skies' aircraft

3x Carl Zeiss Jena LMK-2015 Cameras
3x Zeiss Oberkochen VOS-60 Scanners

Part IV - Airborne Pushbroom Line Scanners
(d) Hyperspectral Pushbroom Line Scanners

(i) ***Hyperspectral pushbroom line scanners*** use a CCD area array – which is however operated in a pushbroom mode as a a linear array.

(ii) The remaining detectors in the area array collect the spectral (colour) data for that line in hundreds of narrow spectral channels.

(iii) The spectral data is generated using a dispersive prism or grating – that acts as an imaging spectrometer.

(iv) The final result is an image "cube".

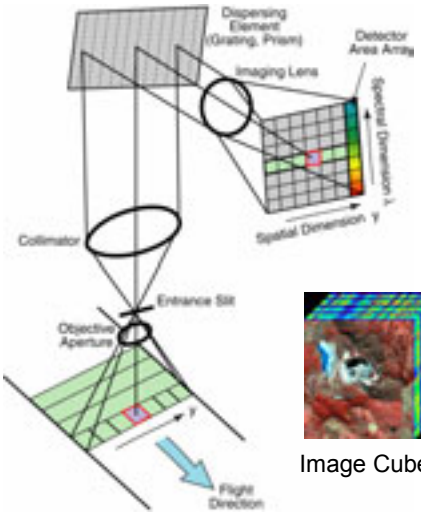


Image Cube

Part IV - Airborne Pushbroom Line Scanners

(d) Hyperspectral Pushbroom Line Scanners

Three main suppliers of hyperspectral pushbroom scanners:-

(1) ***ITRES Research (Canada)***

(i) CASI (VIS/NIR) – 1,500 pixel swath; 299 spectral channels

(ii) SASI (SWIR) – 640 pixel swath; 160 spectral channels

(2) ***SPECIM (Finland)***

(i) AISA+ (VIS/NIR) - 500 pixel swath: 244 spectral channels

(ii) AISA Eagle (VIS/NIR) – 1,000 pixel swath; 244 spectral channels

(iii) AISA Hawk (SWIR) – 320 pixel swath; 254 spectral channels

(3) ***Integrated Spectronics (Australia)***

HyMap (VIS/SWIR) – 128 spectral channels

CASI

AISA

HyMap

Part IV - Airborne Pushbroom Line Scanners

(e) Three-Line Stereo Line Scanners

The ***German Aerospace Agency*** (DLR) has been in the forefront of developing further the concept of the three-line stereo pushbroom scanner originally devised by Dr. Otto Hoffman. It has developed a number of these scanners –

(i) for ***spaceborne use*** – used in MOMS-02, Mars 96, Mars Express (HRSC)

(ii) for ***airborne use*** – WAAC;
HRSC-A – 5k linear arrays
HRSC-AX – 12k linear arrays
HRSC-AXW – 12k linear arrays

(i)

(ii)

Part IV - Airborne Pushbroom Line Scanners
(e) Three-Line Stereo Line Scanners

Leica Geosystems ADS40 scanner

Based partly on DLR WAAC pushbroom technology –

12k linear arrays - 3 for pan images, 4 for multi-spectral images; special telecentric lens; PAV30 gyro-stabilized mount; integrated DGPS/IMU

(i) The ADS40 has been adopted widely in **North America** by many major mapping companies.

(ii) A number have also been sold in **Europe** - including two in Russia operated by VISKHAGI for its LARIS cadastral project; and one in Estonia operated by its national mapping agency (MAA-AMET)

Russia

Estonia

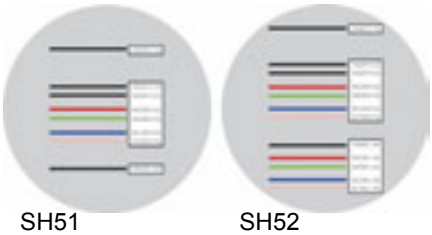
Italian ADS40 – CGR, Parma

Part IV - Airborne Pushbroom Line Scanners
(e) Three-Line Stereo Line Scanners

Leica ADS40 2nd Generation – two alternative "sensor heads" –

(i) ***SH51*** has a single tetrachroid prism giving 5 spectral bands (Pan + RGB + NIR) in nadir position + two Pan forward & backward pointing lines.

(ii) ***SH52*** has two tetrachroid prisms – 1st in nadir position as in SH51; 2nd in backward pointing position; each with 5 spectral bands + one Pan forward pointing line.



SH51 SH52

New IPAS10 DGPS/IMU unit developed in-house

Part IV - Airborne Pushbroom Line Scanners
(e) Three-Line Stereo Line Scanners

Wehrli Associates (U.S.A.) & Geosystems (Ukraine)

2 models, both built in the **Ukraine**. Each uses three Kodak Tri-linear arrays + three lenses

(i) ***3-DAS-1*** with 26° forward, nadir and 16° backward pointings; &

(ii) ***3-OC*** with nadir plus 45° forward/backward pointings – designed to produce continuous ***oblique linescan imagery*** of the terrain for use by emergency services (police, fire, ambulance).

(i)

3-DAS-1

(ii)

3-OC

Part IV - Airborne Pushbroom Line Scanners
(e) Three-Line Stereo Pushbroom Scanners

Jena Optronik - JAS 150
Similar to the DLR HRSC-AX scanner

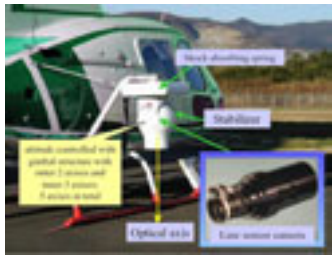
12k linear arrays – 5 for pan images; 4 for multi-spectral images.

Delayed due to problems with sub-contractor. Now about to be released.

Starlabo Starimager
Similar to Wehrli 3-DAS-1 scanner with three Kodak Tri-linear arrays.

Different models with different lenses.

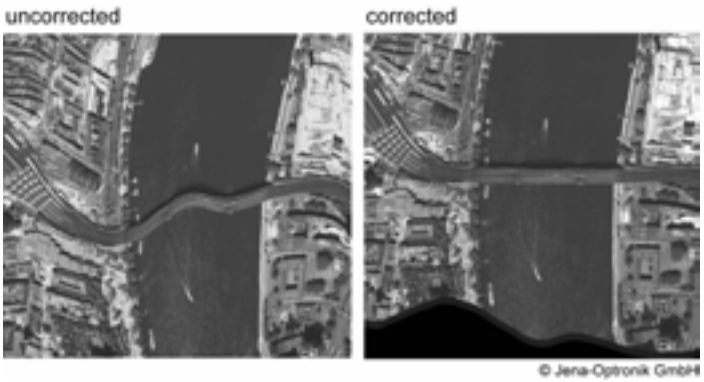
Now gone out of business.



Part IV - Airborne Pushbroom Line Scanners
(f) Inertial Measuring Units (IMUs)

(a) ***Airborne pushbroom line scanners*** cannot be operated without an **DGPS/IMU** unit giving position & attitude values for each image line.

(b) ***Airborne digital frame cameras*** can be operated without these **DGPS/IMU** units – although many are now operated in conjunction with them.



Uncorrected & Corrected Pushbroom Line Scanner Images

Part IV - Airborne Pushbroom Line Scanners
(f) Inertial Measuring Units (IMUs)

IMUs

(i) ***MEMS (Micro Electro-Mechanical Systems) Gyros*** that utilize tiny quartz tuning forks as sensors integrated on to silicon chips are coming into widespread use in the lower end systems employed on less demanding applications. ***Cost - $30,000***

(ii) ***Fibre-Optic Gyros (FOG)*** are somewhat less expensive and give a very acceptable performance that satisfies many applications.

(iii) ***Ring Laser Gyros (RLG)*** are the most accurate type, but they are the most expensive to produce – which limits their use to high-end imaging systems and the most demanding applications. ***Cost – $200,000***

Part IV - Airborne Pushbroom Line Scanners

(f) Inertial Measuring Units (IMUs)

Progressive increase in accuracy is directly linked to increased cost. See the range of **POS/AV** systems supplied by **Applanix.**

Table – POS/AV Absolute Accuracy Specifications – RMSE Values					
Model No.	210	310	410	510	610
Position (m)	0.05 – 0.3	0.05 – 0.3	0.05 – 0.3	0.05 – 0.3	0.05 – 0.3
Velocity (m/s)	0.01	0.075	0.005	0.005	0.005
Roll & Pitch (d)	0.04	0.015	0.008	0.005	0.025
True Heading (d)	0.08	0.035	0.015	0.008	0.005

(i) The lower-end ***POS/AV 210, 310 and 410*** systems all use ***MEMS*** quartz gyros
(ii) The ***POS/AV 510*** system uses higher-performance ***FOG*** gyros
(iii) The top-end ***POS/AV 610*** uses highest-performance ***RLG*** gyros

Part IV - Airborne Pushbroom Line Scanners

(g) Differential GPS

(a) Besides the attitude (tilt and heading) values generated by the IMU, differential GPS values are also required to carry out the corrections to the continuous linescan imagery.

(b) These values can be provided either from ground stations or from one of the commercial differential GPS services – such as Fugro OmniSTAR or C & C Technologies C-NAV – which operate world-wide and send the corrections using the Inmarsat satellites. **N.B**. C-NAV has 5 Russian base stations.

Part IV - Airborne Pushbroom Line Scanners

(g) Differential GPS

Russian Mil-8 helicopter used as the platform for an airborne lidar and digital camera combination – operated by the Geokosmos company. In the foreground are the tripod-mounted antennas of the Trimble GPS base stations.

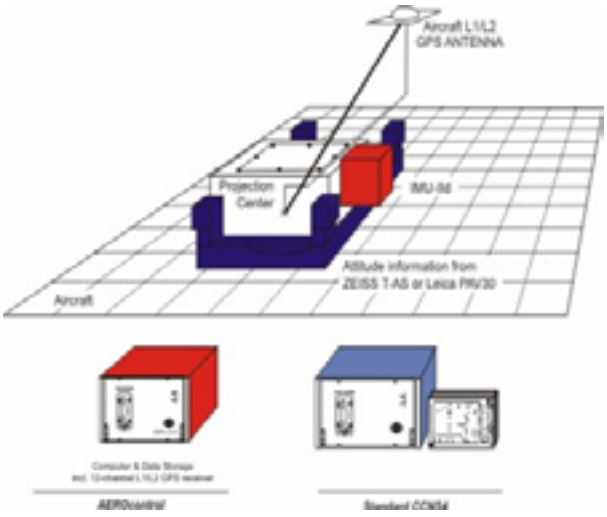
Optech ALTM lidar and Rollei digital camera on their mount

Control electronics and GPS receiver

Part IV - Airborne Pushbroom Line Scanners

Inertial Measuring Units (IMUs) + Differential GPS

The IMU is attached rigidly to the camera. The offset between the GPS antenna and the IMU with respect to the camera projection centre needs to be determined by a prior calibration



Part V – Airborne Radar Technologies

Part V - Airborne Radar Technologies
Synthetic Aperture Radar (SAR)

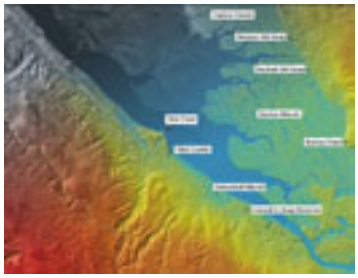
Civilian SAR systems are operated by 2 main groups:-

(i) ***Commercial Service Providers***

(a) **Intermap Technologies** operate four aircraft (2 jet; 2 turbo-prop) world-wide, each equipped with its Star X-band SAR.

Main business is DEM production using interferometric SAR (IfSAR) methods – NEXTmap Britain/ Germany/ USA. Now NEXTMap Europe. 1 m ground resolution + 1m RMSE vertical accuracy

Intermap also operate a turbo-prop aircraft equipped with a P-band SAR for penetration of vegetation in thick tropical forest.

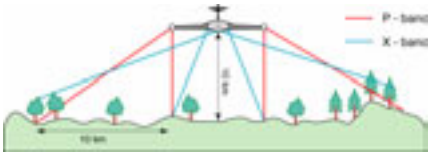


Part V - Airborne Radar Technologies
Synthetic Aperture Radar (SAR)

(b) **EarthData Corporation**

This company operates a single jet aircraft equipped with the GeoSAR system using two X-band and two P-band SARs.

Again the main emphasis is on DEM production – mainly in North & South America.



(ii) ***Govt. Research Agencies***

One-off SAR systems are also operated by NASA (AirSAR); DLR (E-SAR); TNO (MIniSAR); Danish Center for Remote Sensing (EMISAR); etc.

Part VI - Film versus Digital

Part VI - Film versus Digital

(a) Acquisition of Airborne Image Data

Film Camera – Needs expensive rolls of stable wide-format film + Darkroom lab, processing machines and chemicals + Metric film scanner

Digital Camera – No film; No Lab; No Chemicals; No Scanner
Superior radiometric resolution – 12-bit v. 8-bit values

(b) Exploitation of Data

Film **–** Needs specialist optical-mechanical devices – light tables with motorized drives; stereoscopes; stereo-plotters; enlarging projectors.
Very expensive; inconvenient; inefficient - No longer produced! Film images now scanned and converted into digital form.

Digital – With the image data in digital form, even a small PC can carry out all the functions of the previous specialist exploitation devices very much more quickly and efficiently.
In particular, the display, manipulation and visualization of the image data is so much quicker and easier to achieve.

Part VI - Film versus Digital

(c) System Availability

Film Cameras – (i) Intergraph RMK & Leica RC30 film cameras no longer being manufactured
(ii) Availability of replacement parts and lack of technical knowledge and expertize re ageing equipment is now becoming a problem
(iii) Choice and availability of film, paper, chemicals is now much more limited

Digital Imagers – (i) Over last 5 years, more than **150** large-format airborne digital imagers have been sold - > 60 Vexcel; > 40 Intergraph; > 50 Leica;
(ii) More than **200** medium-format airborne digital cameras sold
(iii) **Several hundred** small-format digital cameras now operational

Part VI – Film versus Digital - Costs

(a) **Small-Format Frame Cameras**

(i) ***Kodak Pro SLRn*** (= Nikon) ***SLRc*** (= Canon) – Street Price:- <$5,000

(ii) ***Geotechnologies (U.K.)*** - Pro SLRn or SLRc + lens + mount + control unit - $17,000

(iii) ***IGI (Germany)*** – DigiCAM14K + lens + mount + interface - $32,500

(b) **Medium-Format Frame Cameras**

(i) ***IGI (Germany)*** – DIgiCAM-22R (= Rollei); 22H (= Hasselblad) - Camera + Storage Unit + 2 Lens Cones (VIS &NIR) + Interface - $78,000
If Aerocontrol DGPS/IMU unit is required, then additional $190,000

(ii) ***Spectrum (U.S.A.)*** – NexVue - Camera only - $249,000
If DGPS/IMU is required, the C-MIGITS @ $35,000 + Software $12,500 or Applanix POS/AV 410 @ $190,000

(iii) ***Applanix (Canada)*** – Digital Sensor System (DSS) – Camera + mount + control computer + POS/AV 410 + flight management software - $350,000 to $400,000

Part VI – Film versus Digital - Costs

(c) **Large-Format Frame Cameras**

(i) ***DiMAC Digital Modular Camera (DMC)*** – Core Module – $279,000
Additional camera modules @ $84,000 per module
2 cameras - $363,000; 3 cameras - $448,000; 4 cameras - $532,000

(ii) ***Vexcel UltraCam D*** – Camera + storage unit + control - $650,000

(iii) ***Intergraph/ Z/I Digital Mapping Camera (DMC)*** - $940,000

N.B. In each case, the DGPS/IMU is additional cost – circa $200,000
Stabilized mount – Leica PAV30 or Zeiss T-AS or Somag GSM3000 - $75,000

- -

3-Line Pushbroom Scanners

(i) ***Wehrli 3-DAS-1*** – Scanner + ASP-1 stabilized platform - $230,000
The required DGPS/IMU is additional – Novatel ($90,000); IGI ($190,000)

(ii) ***Leica ADS40*** - Scanner + PAV30 stabilized mount + Applanix POS/AV DGPS/IMU 510 unit + flight planning software + training - $1,300,000

- -

Many suppliers of software – inexpensive packages from Eastern Europe!

Part VII – Summary & Conclusion

(a) A rich variety and large number of airborne digital imagers are now available as **COTS (Commercial-off-the-Shelf)** items

(b) They include both frame cameras & pushbroom scanners in many **different formats** and generating either **monochrome or colour images** as required.

(c) Larger CMOS and CCD area arrays are being developed – so still **larger-format** digital frame cameras can be expected soon.

(d) Airborne pushbroom scanners cannot function well without **gyro-controlled mounts** and **DGPS/IMU systems** – the linescan images also need much more processing – which can be quite challenging!

(e) The use of airborne digital imagers is now well established in both the **military** and **civilian** domains.

(f) The use of film cameras and photographic materials is in steep decline.