## Earth Observation from Space & the Air

# Jena-Optronik's Imaging Scanners

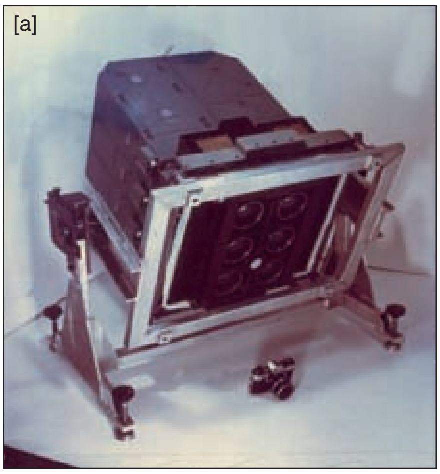





*Fig. 1 (a) - The Carl Zeiss Jena MFK-6 multi-spectral film camera that was used on various Soviet spacecraft had six lenses and six separate film magazines. (Source: Deutsche Museum)*
*(b) - The Carl Zeiss Jena MSK-4 four channel airborne multi-spectral film camera on its mount with its viewfinder and navigation/tracking device at the right. (Source: MGGP Aero)*
*(c) - A Carl Zeiss Jena LMK-1000 photogrammetric film camera mounted in a Piper Navajo aerial photographic aircraft. (Source: MGGP Aero)*

*The Jena-Optronik company has come to the fore in recent years as a supplier of a wide range of imaging scanners that can be mounted on spaceborne and airborne platforms for Earth observation purposes. In many ways, this development marks the revival of a traditional name that, for a long time, was revered in the area of aerial photographic, photogrammetric and surveying instrumentation. However there is nothing too traditional in its range of new scanner products that make use of the latest opto-electronic imaging technologies.*

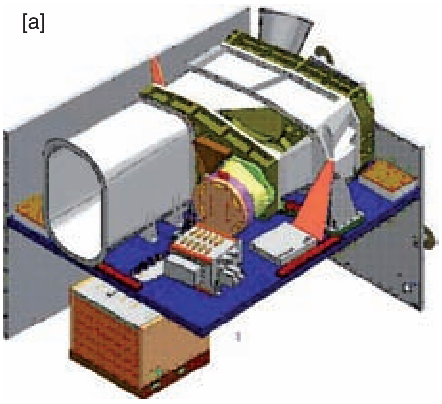
By Gordon Petrie

### Background

The area around Jena is, by tradition, Germany's “Optical Valley”. Its famous optical industrial companies include ***Carl Zeiss Jena*** - renowned for its range of precision optical instruments - and ***Schott***, the famous glass-maker. During the period of communist rule of East Germany, these companies became government-controlled “people's enterprises”. After the collapse of the communist government in 1989, followed by German re-unification in 1990, these companies were gradually returned to private ownership. However, with the loss of their main captive markets in Eastern Europe, including Russia, these large state enterprises had to be much reduced in size in order to be competitive in the global market. Out of the traumatic period of downsizing and re-organization that followed, a number of new companies have arisen.

### Jena-Optronik

One of these companies is ***Jena-Optronik GmbH***, founded in 1991 jointly by DASA (now part of EADS) and Jenoptik - the latter company having taken over a substantial part of the former VEB Carl Zeiss Jena “people's enterprise”. Since 2005, Jena-Optronik has been wholly owned by ***Jenoptik AG***. When it was first established, the core of the then new Jena-Optronik company came from the space engineering department of the former VEB Carl Zeiss Jena enterprise. This had supplied many components, instruments and systems for use in the Soviet space programme. These included the MFK-6 multi-spectral film cameras that were used to acquire imagery from the Soyuz-22, Salyut-6 and -7 and MIR spacecraft [Fig. 1 (a)]. A somewhat similar MSK-4 multi-spectral film camera was also produced for airborne use [Fig. 1 (b)]. Besides which, the photogrammetric department of Carl Zeiss Jena had produced its range of LMK metric film cameras that has been used widely for aerial mapping purposes in many parts of the world [Fig. 1 (c)]. So there is a lot of tradition, knowledge and experience lying behind these newest developments in spaceborne and airborne imagers that are coming from the Jena area. As well as the new imaging devices that are being produced by Jena-Optronik, it is worth noting that the company is also a major supplier to Boeing, ESA and DLR of rendezvous and docking sensors, as well as the star and Sun sensors that are used for attitude determination and orbit control purposes on satellites and spacecraft.



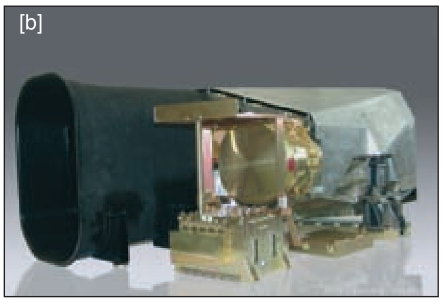
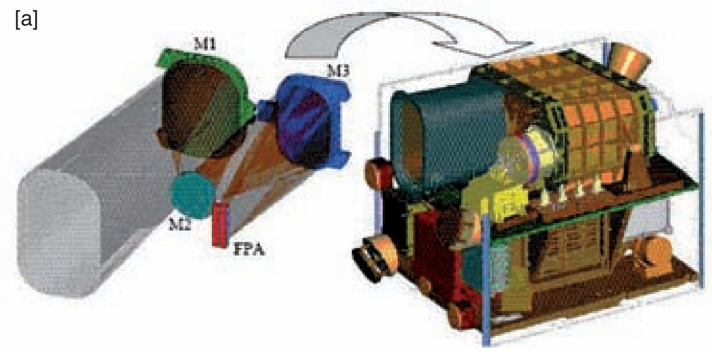




*Fig. 2 (a) - A CAD drawing showing the main components of the JSS56 spaceborne scanner.*
*(b) - A photograph of a JSS56 spaceborne scanner.*



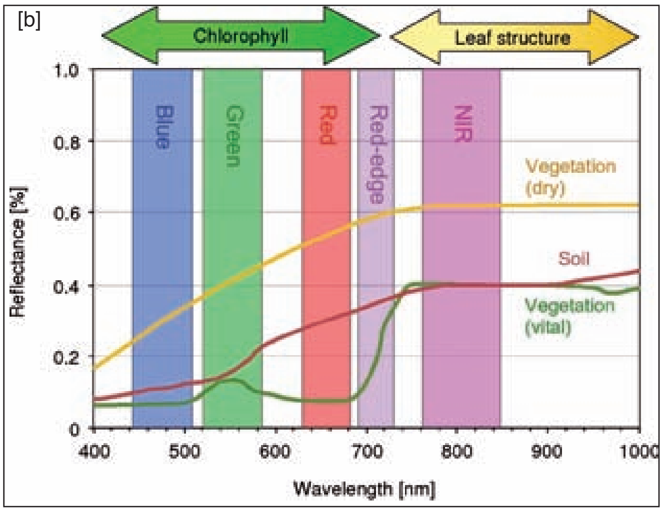




*Fig. 3* ***(a)*** *- The three-mirror anastigmatic (TMA) telescope showing the mirrors (M1, M2 & M3) and the focal plane array (FPA) and their relationship to the overall construction of the JSS-56 spaceborne scanner on which it is mounted.*
***(b)*** *- The five spectral bands or channels that are imaged by the JSS56 spaceborne scanner.*

## I - Spaceborne Scanners

### *Jena Spaceborne Scanners (JSS)*

Currently the ***Jena Spaceborne Scanners (JSS)*** line of pushbroom line scanners comprises four different models, each designed for a different application. The number given after the abbreviation (JSS) indicates firstly the number of spectral channels and secondly the magnitude of the ground sampling distance (GSD) in metres.

**(a)** The *JSS-54* has been designed to produce images from space in five different spectral channels in the visible and near infra-red (VIS/NIR) parts of the spectrum. It will feature five CCD linear arrays, each containing 5,000 detectors, and will use a Mangin-type optical system combining both reflective (mirror) and refractive (lens) optical elements with a focal length of 980 mm and an aperture of f/5. The JSS-54 will provide multi-spectral linescan images of the Earth's land surface having a ground sampled distance (GSD) of 4.2 m and a swath width of 21 km from an orbital altitude of 600 km.

**(b)** The *JSS-56* is the model of which five examples have already been built for installation in the forthcoming RapidEye constellation of satellites. Like the JSS-54, it is a very lightweight and compact five channel VIS/NIR design intended for use on small satellites or micro-satellites [Fig. 2 (a)]. However it is designed to cover a much wider swath over the ground than the JSS-54, using five CCD linear arrays, each with 12,000 detectors, in combination with a three-mirror anastigmatic (TMA) telescope having a focal length of 633 mm and an aperture of f/4.3 [Fig. 2 (b)]. Using this combination of components, the JSS-56 scanners will produce multi-spectral linescan images with a ground sampled distance (GSD) of 6.5 m and a swath width of 78 km from the operating altitude of 600 to 620 km that will be used by the RapidEye satellites.

**(c)** The *JSS-61* model features six channels, comprising (i) a single high-resolution panchromatic channel producing linescan images with a 1.5 m GSD from an orbital altitude of 600 km, and (ii) five medium-resolution channels providing multi-spectral linescan images with a 4.5 m GSD and a swath width of 18 km from an orbital altitude of 600 km. To obtain the high-resolution pan image, the optical telescope is of a Richey-Chretien design with a long focal length of 2.58 m and an aperture of f/4.6.

**(d)** The *JSS-95* design will provide an extension to the spectral range into the short-wave infra-red (SWIR) part of the spectrum employing a total of nine channels - comprising six VIS/NIR channels and three SWIR channels.

## JSS-56 Scanner Construction

The three-mirror anastigmatic (TMA) telescope used in the ***JSS-56*** model is of especial interest in that it has an all-aluminium construction with a reflective silver coating instead of utilizing optical glass [Fig. 3 (a)]. The required optical quality of the aluminium surface has been achieved using novel ultra high-precision metal milling and polishing techniques devised and implemented by the Fraunhofer Institute of Applied Optics & Precision Engineering (IOF) - which is also based in Jena. The 12,000 pixel linear arrays that are being used in the JSS-56 scanners have been supplied by Atmel in France. Each of the five linear arrays is equipped with the appropriate spectral filter to produce continuous strip images in the blue (μ= 440 to 510 nm); green (520 to 590 nm); red (630 to 685 nm); red edge (690 to 730 nm) and near infra-red (760 to 850 nm) parts of the spectrum [Fig. 3 (b)]. Off-nadir pointing of the scanner at angles of up to 25° from the vertical can be achieved through the rotation of the actual satellite itself.

## JSS-56 on RapidEye

As noted above, Jena-Optronik is supplying the JSS-56 multi-spectral pushbroom line scanners that will be used to acquire continuous strip images of the Earth from each of the five polar-orbiting satellites in the constellation that will be operated by the ***RapidEye AG*** company based in Brandenburg, Germany. All five satellites are scheduled to be launched together early in 2008 using a Russian Dnepr rocket. The RapidEye concept was developed originally by the Kayser-Threde company based in Munich, supported by the German Aerospace Center (DLR). The RapidEye company that resulted from this development is now being financed by a group of German and Canadian financial institutions supported by the German state of Brandenburg and by DLR. Jena-Optronik has just completed the supply of the five JSS-56 scanners to ***Surrey Satellite Technology Ltd. (SSTL)*** in the U.K. which has built the five satellite busses (platforms) for the RapidEye project. Once SSTL has completed the mounting and integration of each of the JSS-56 scanners on to their respective platforms [Fig. 4], they will be taken over by ***MacDonald Dettwiler & Associates Ltd. (MDA)*** from Canada - which is

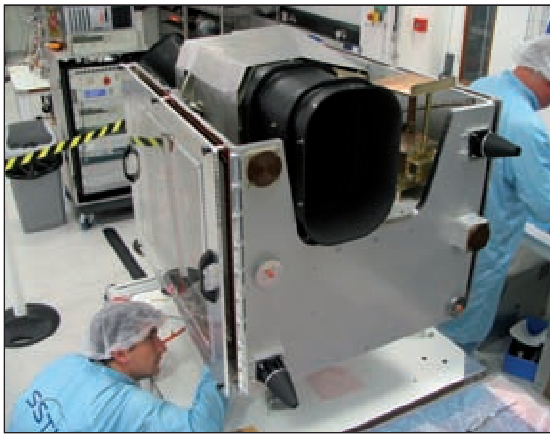
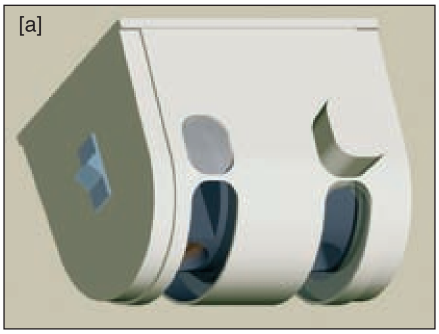


*Fig. 4 - A JSS56 scanner being mounted on and integrated with a RapidEye spacecraft at Surrey Satellite Technology Ltd. (SSTL) in the U.K. (Source: SSTL)*



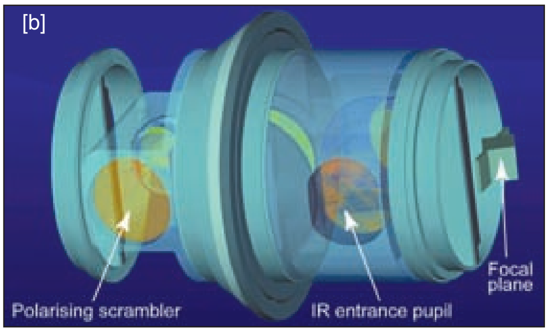



*Fig. 5 (a) - The METimage scanning radiometer that is being developed by Jena-Optronik for future use on European polar-orbiting meteorological satellites.*
*(b) - The optics and focal plane of the METimage scanning radiometer. The two telescopes are used to acquire images in the VIS/NIR and LWIR/TIR parts of the spectrum respectively.*

the prime contractor for the overall RapidEye project, including the provision of its ground segment.

## METimage

Another spaceborne scanner that is being developed as a future meteorological imager by Jena-Optronik is ***METimage***. This is a multi-spectral (indeed super-spectral) scanning radiometer that is being developed as a replacement for the AVHRR scanning radiometers that are currently in use in the American NOAA and European METOP polar-orbiting weather satellites that operate at an orbital height of ~800 km. The METimage scanner will utilize a rotating TMA telescope equipped with two cross-track scanning units to image the Earth's land and ocean surfaces (and its cloud patterns!) with a swath width of 2,300 km at a basic GSD of 250 m [Fig. 5 (a)]. The instrument will also cover all the main spectral channels from the visible (VIS) to the long-wave or thermal infra-red (LWIR/TIR) [Fig. 5 (b)]- i.e. over the wavelength range 400 nm to 13.4 µm - using a number of separate focal plane arrays (FPAs) to generate the required images in the different parts of the spectrum. The scanner will also have a built-in flexibility regarding the number of spectral channels (up to 30) and the GSD of individual channels. The pre-development of METimage is being financed by DLR. The later phases B, C and D are in the scope of the German Federal Ministry of Transport, Building & Urban Affairs.

## Sentinel-2

At present, Jena-Optronik also has a strong involvement in the definition and development of the design of the super-spectral imager intended for deployment in the ESA Sentinel-2 space imaging mission. This is the second of the five Sentinel missions that are being developed for the EU and ESA under their joint ***Global Monitoring of the Environment & Security (GMES)*** programme. The Sentinel-2 polar-orbiting satellite is intended to carry out the optical imaging of the land surfaces of the Earth at medium resolution values. This would provide enhanced continuity of the image data that have been provided by the SPOT and Landsat programmes. Various possible scenarios are being explored - especially with regard to the number of spectral channels and the GSD values of the resulting imagery. The outcome seems likely to be a pushbroom scanner with ten VIS/NIR bands and three SWIR bands producing images with GSD values in the range 10 to 30 metres.

## II - Airborne Scanners

### *Heritage*

The Jena Airborne Scanner (JAS) was first announced in July 2005. As with the spaceborne scanners, there is a certain amount of previous heritage in the form of the ***High Resolution Stereo Camera (HRSC)*** [Fig. 6 (a)]. Originally the HRSC pushbroom line scanner was built by a team from the DLR Institute of Space Sensor Technology & Planetary Exploration in Berlin under Prof. Gerhard Neukum for use on the Russian Mars 96 mission - which failed during its launch in November 1996. Since then, a second HRSC scanner has been used very successfully in the ESA Mars Express mission that was launched in June 2003 and went into operation early in 2004. In the context of the present account, one notes that the optical lens systems for the HRSC scanners were developed and manufactured by Jena-Optronik, as was the optical test equipment (OGSE) for the scanner. During the seven year time period between these two Mars missions, development of airborne versions of the HRSC was undertaken by DLR. This resulted first of all in the HRSC-A (= Airborne) model equipped with a 5,000 pixel CCD linear array as used in the HRSC. This was followed by two wider angled versions using 12,000 pixel CCD linear arrays and wider-angled lenses - called the HRSC-AX (with an f = 151 mm lens) and the HRSC-AXW (with an f = 47 mm lens) [Fig. 6 (b)]. These various airborne models were used extensively by DLR for scientific research flights and by the French ISTAR company (now part of Infoterra) for commercial aerial mapping operations.

## JAS 150 Specification

Several recent presentations by Jena-Optronik have mentioned that, in many ways, the HRSC-AX has served as a template for the new JAS 150 airborne pushbroom line scanner. Indeed it shares a very similar specification – having an f = 151 mm lens; 12,000 pixel CCD linear arrays using a 6.5 µm pixel size; 12-bit radiometric resolution; etc. Furthermore, the JAS 150 has a similar number (nine) and geometric arrangement of its linear arrays to those used in the

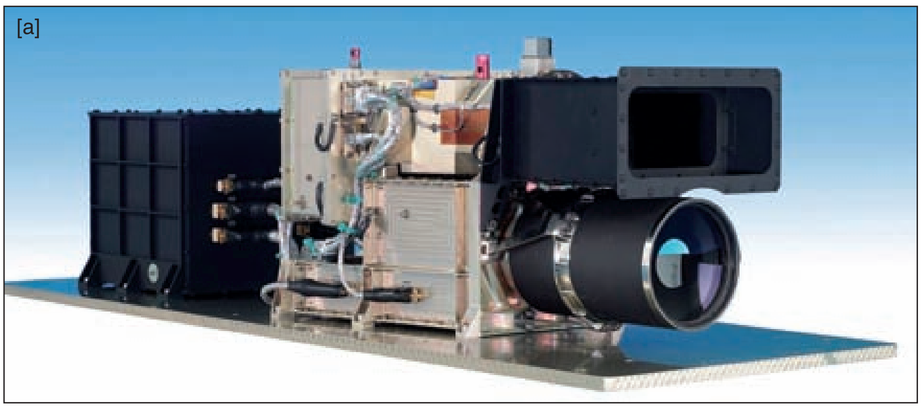



*Fig. 6 (a) - The HRSC pushbroom line scanner that has been used on the ESA Mars Express mission. (Source: DLR)*
*(b) - An HRSC-AX airborne pushbroom line scanner. (Source: DLR)*

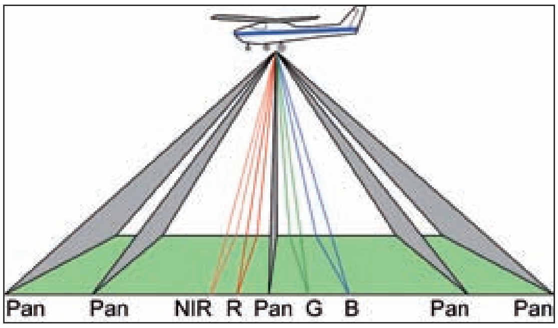



*Fig. 7* - *The geometry of the nine-line arrangement of the linear arrays used in the HRSC-AX and JAS 150 pushbroom line scanners showing their angular positions and ground coverage. [Pan = Panchromatic; B = Blue; G = Green; R = Red; NIR = Near Infra-red] (Drawn by M. Shand)*

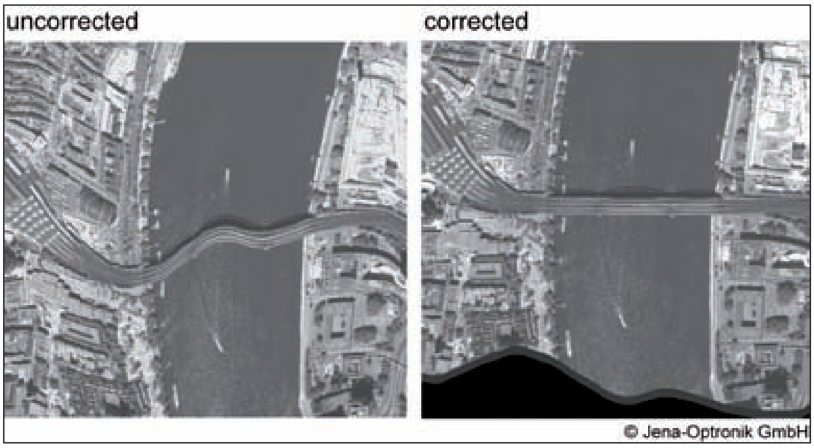



*Fig. 9* - *The uncorrected and corrected versions of a JAS 150 pushbroom line scanner image of the area around the railway bridge crossing the River Rhine in the city of Cologne.*

HRSC-AX. Five of these linear arrays provide stereo panchromatic channels with two forward and two backward pointing arrays at ±20° and ±12° from the vertical, together with a fifth array being nadir pointing [Fig. 7]. The remaining four (of the nine) linear arrays provide multi-spectral coverage of the ground in the red, green, blue (RGB) and near infra-red (NIR) spectral channels around the nadir position using the appropriate filters placed in front of each of the linear arrays. The cross-track angular coverage of all nine lines is 29.1°.

## JAS 150 Construction

Although there are these basic similarities between the overall system specifications of the two pushbroom scanners, the actual construction of the new JAS 150 is of course substantially different [Fig. 8 (a)]. Internally the JAS 150 has a specially designed Jenoptik Aenar achromatic lens; new electronics; a ruggedized lightweight carbon-fibre housing; a high-speed Firewire interface to the camera control unit; etc. [Fig. 8 (b)] Externally the scanner has a mass memory capability comprising either (i) a RAID disk unit with a capacity of 1 to 2 Terabytes, or (ii) a unit with hot swappable disks with a capacity of 2 to 5 Terabytes that can be changed in-flight [Fig. 8 (c)]. Besides which, a quick look capability to view the stored image data can also be provided for off-line operation during the flight - e.g. during the turns at the end of each flight line. The inertial measurement unit (IMU) coupled to the JAS 150 can either be the IGI AEROcontrol system or the POS/AV 510 system from Applanix. At the present time, flight management and the control and operation of the scanner in-flight can be carried out using either Jena-Optronik's own scanner control unit or an IGI CCNS-4 system. In the future, the Applanix POSTrack system will also be offered. Any one of the standard gyro-stabilized mounts for aerial cameras - the GSM 3000 (from Somag in Jena); Leica Geosystems PAV30; or Intergraph T-AS - can be used with the JAS 150 scanner.

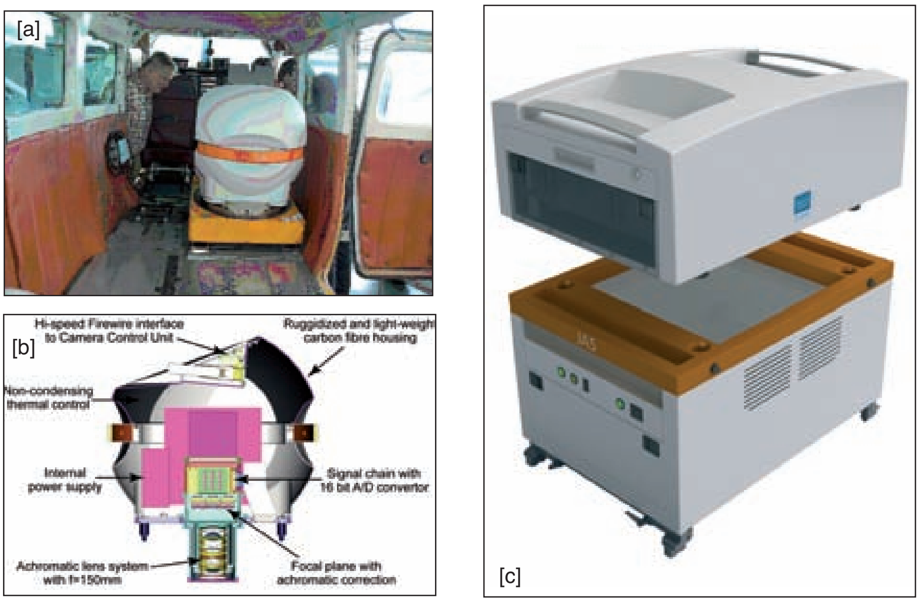



*Fig. 8 (a)* - *A JAS 150 pushbroom line scanner mounted in an aircraft operated by the ILV aerial imaging company.*
*(b)* - *The internal design of the JAS 150 pushbroom line scanner, showing the main components.*
*(c)* - *The two-piece system rack of the JAS 150, including the control electronics and the mass memory used for the storage of the image data acquired in-flight.*

## JenaStereo

Closely associated with the JAS 150 scanner is the ***JenaStereo*** photogrammetric software suite. This runs on PCs under the Windows or Linux operating systems. The software is a modular system comprising a core module (CORE) and a so-called JAS 150 'sensor' module (JSM). The JSM/ASM module is also available as a stand-alone piece of software that carries out the preliminary processing of the raw JAS 150 image data [Fig. 9] and has an interface to allow the processed data to be passed to a BAE Systems SOCET SET or an Inpho digital photogrammetric workstation (DPW). This allows the image data that is generated by a JAS 150 scanner to be used by the numerous commercial companies and government mapping organizations who utilize SOCET SET or Inpho's software to generate their map and GIS data. For triangulation purposes, the BINGO software from Dr. Erwin Kruck can also be used with JAS 150 linescan image data.

## Conclusion

From the above account, it can be seen that Jena-Optronik has become solidly established as a developer and supplier of spaceborne imaging scanners. However the airborne imaging market is very much larger. Furthermore it is experiencing a boom as commercial companies and government mapping organizations change from aerial photographic film cameras to the equivalent large-format airborne digital imaging systems. It will be very interesting to follow the progress of the new JAS 150 airborne pushbroom scanner within this market.

*Gordon Petrie (Gordon.Petrie@ges.gla.ac.uk) is Emeritus Professor of Topographic Science in the Dept. of Geographical & Earth Sciences of the University of Glasgow, Scotland, U.K.*