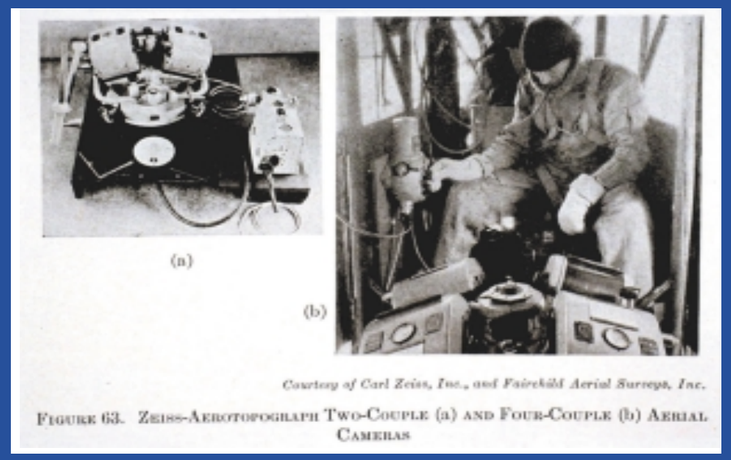
The Configurations of the New Airborne Digital Imagers Are All Rooted in the Distant Past!

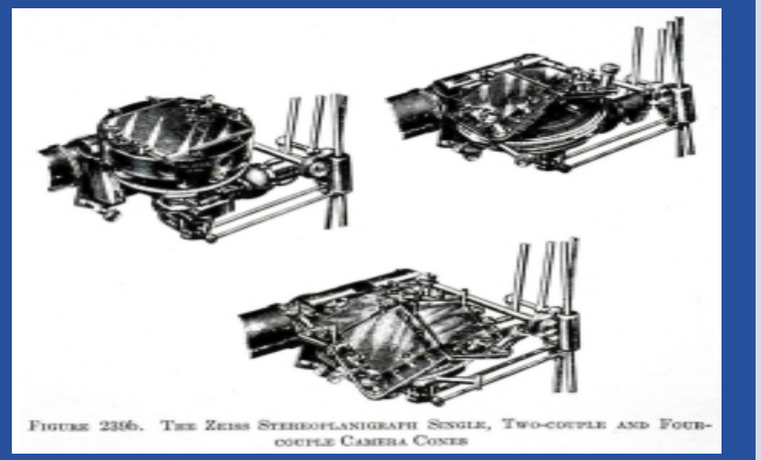
"Déjà Vu"

At the forthcoming ISPRS Congress at Amsterdam, we will see the entrance of airborne digital imaging sensors into the mainstream of mapping. Of course, very small-format digital cameras such as the Kodak DCS series have already been used to acquire images from airborne platforms. Furthermore linear array scanners have already been used to capture multi-spectral image data from aircraft and helicopters - besides those other well known examples that have been deployed in space, mounted on-board the MOMS, SPOT and IRS satellites. But the entry of the two major suppliers of aerial photogrammetric cameras - Z/I Imaging (Zeiss) and LH Systems (Wild) - into the digital imaging field puts a quite different complexion on this matter. With their world-wide sales and support network and their large core of existing users, the entry of these two companies into this field sends out a clear message that airborne imaging is eventually going digital - albeit that this will not happen overnight. While the actual digital sensor technology is new, it has been most interesting to observe that the configurations that are being adopted with these new imagers bear a close resemblance to those adopted with the film-based imagers of the 1930s and 1940s.

By Professor Gordon Petrie



The Zeiss two-coupled (2 x RMK-13.5) and four-coupled (4 x RMK-13.5) cameras from the 1930s.



The single, two-coupled and four-coupled plotting cones used with the Stereoplanigraph. (Source: Talley - "Engineering Applications of Aerial & Terrestrial Photogrammetry", 1938)

Digital Cameras

One of the major limitations in the introduction of the new digital cameras has been the small size of the areal arrays of CCDs that have been available for incorporation in these new cameras. In this respect, 4k x 4k = 16 Megapixel arrays are the largest sizes that have been used to date in the experimental airborne digital cameras such as that developed by IGN, France. Now Philips have produced a 7k x 9k = 63 Megapixel array and Lockheed Martin an 8k x 8k = 64 Megapixel array. Even using these larger arrays, this still falls a long way short of competing with the 25k x 25k = 625 Megapixels that can be produced by digitizing the film image produced by a standard 23 x 23cm aerial film camera at the same pixel size. The result of this restriction to small array sizes is that Z/I Imaging has had to resort to the use of multiple cameras in order to achieve a reasonably useful ground coverage with their Digital Modular Camera (DMC) that is promised for introduction at the ISPRS Congress in Amsterdam.

• Film Cameras

All of which gives rise to a feeling of "Déjà" in the minds of some older photogrammetrists. This arises from their knowledge of the solutions that were adopted in the 1930s when the aerial film cameras of the time were restricted both in terms of the format sizes and the limited angular coverages that were then possible with the lenses that were available at that time. Typical cameras from that period were the Zeiss RMK-13.5 with its format size of 12 x 12cm and its f = 13.5 Orthometar lens and the British Williamson F24 camera with its 5 x 5 inch (12.5 x 12.5cm) format and f = 5 inch (12.5cm) lens.

Not only was the format size small but, at that time, it was difficult to produce a wide-angle lens that did not have a large lens distortion and a marked fall-off in illumination towards the edges and corners of the image.

Thus the solution to these difficulties that was adopted in several countries was to utilize a multiple camera system.

Each of the cameras in such a system had its optical axis deliberately tilted to produce oblique photography in order to increase the ground cove rage that was possible during a single flight - as is being done with the Z/I Imaging DMC digital camera system.

• Multiple Cameras

Typical of these 1930s solutions were the two-coupled and four-coupled camera configurations adopted by Zeiss. The two-coupled arrangement with each of the two individual cameras tilted in opposite directions on a single mount could be used in one of two ways. Either it could be utilized to produce twin convergent photography with 100% overlap and a good base:height ratio in the along-track or flight direction - as was often done with the Zeiss cameras. Alternatively it could be used to give a wider ground coverage in the cross-track direction - as was often done with the British cameras to produce what were called (somewhat misleadingly!!) "split verticals" - when they were, in fact, low obliques. The four-coupled arrangement, as developed by Zeiss, comprised four of the 12 x 12cm format RMK cameras, each equipped with the f = 13m lens. This was used for example by Fairchild Aerial Surveys in the United States. Each camera was tilted outwards in a star-type configuration to provide in total an 83° angular coverage of the ground. By contrast, in the U.K., the four-coupled arrangement was mainly used in a fan configuration to give an even wider coverage cross-track. Even when larger format cameras came into use, these different configurations continued to be used right up till the 1960s when they were finally killed off with the advent of cameras equipped with high quality, low distortion, wide-angle and super-wide-angle lenses.

• Photogrammetric Solutions

In view of the advent of an airborne imager comprising multiple digital cameras, it is also interesting to note some of the photogrammetric solutions that were adopted during the period of time (i.e. in the 1930s) when multiple film cameras were in vogue. Thus Fairchild built a special optical rectifier with four tilted stages to remove the tilts from each of the component photographs and allow the production of a single rectified composite photographic image. To allow stereo-plotting to be carried out in its Stereoplanigraph analogue stereo-plotting instrument, Zeiss also produced a special plotting cone equipped with four tilted projectors. The four individ-

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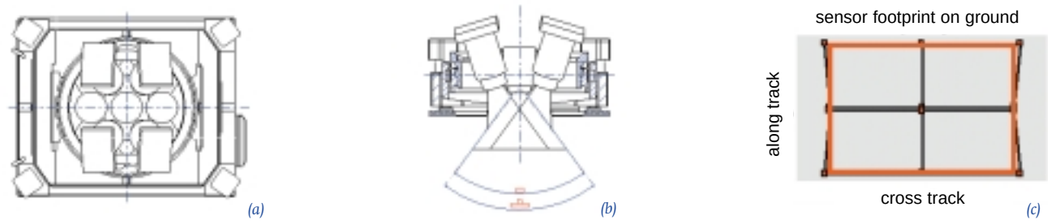

(a) Plan and (b) cross-section drawings showing the configuration of the Z/I Imaging DMC (Digital Modular Camera) comprising four tilted digital cameras that produce pan images. The other three vertically-pointing cameras produce multi-spectral images. (c) The ground coverage of the four-coupled pan images produced by the DMC digital camera. (Source: Z/I Imaging)

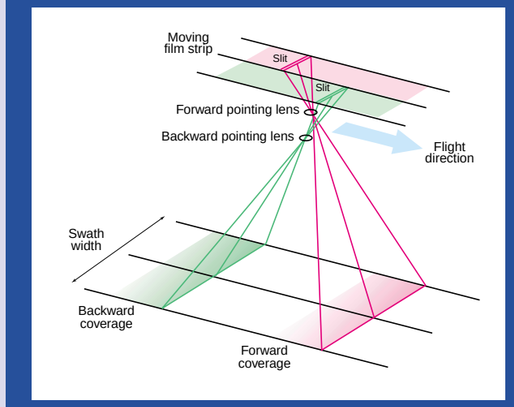

Diagram showing the concept of the shutterless airborne film strip camera providing stereo-coverage of the ground. (Drawn by M. Shand)

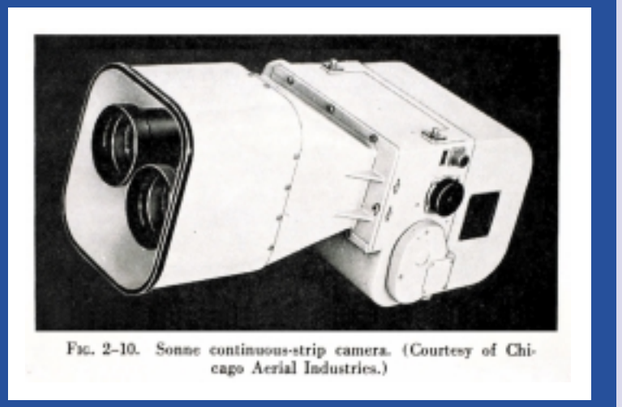

FIG. 2–10. Sonne continuous-strip camera. (Courtesy of Chicago Aerial Industries.)

An early example of the Sonne stereo-strip camera.

ual projectors were placed in the appropriate tilted positions within a single mount that allowed them to be rotated as a unit. Each projector had its own individual image plane and lens to accommodate the four photographs taken by the multiple camera system. In total, this set-up replicated exactly in the stereo-plotting instrument the four-coupled camera arrangement used in the aircraft. The use of a pair of these four-coupled plotting cones allowed the overlapping multiple photos to be oriented and a stereo-model to be formed. The feature extraction and contouring needed for map compilation could then be carried out from these stereo-models.
A similar configuration could also be employed in the stereo-plotting instrument with the two-coupled camera photography - as the author remembers only too well while he was a student at the ITC in the late 1950s!

• Multi-Lens Cameras

It is also worth mentioning in this context that the alternatives to these multiple camera arrangements in the 1930s were the multi-lens cameras. These consisted of a single camera body with a wide-format film and magazine, but equipped with multiple lenses to give a wide ground coverage. This comprised an array of tilted lenses and mirrors arranged around a single central lens. This gave a similar configuration to that of the multiple cameras, but without the need for a series of separate film magazines. Typical of these were (i) the Aschenbrenner 9-lens camera built by Steinheil in Germany; (ii) the Reading 9-lens camera used by the U.S. Coast & Geodetic Survey; and (iii) the Barr & Stroud 7-lens camera built in the U.K. Again special rectifiers were developed for use with each of these cameras to produce a single rectified composite image from the multiple tilted exposures.

Pushbroom Scanners

The alternative approach of using linear arrays of CCDs deployed in a pushbroom scanner configuration to create an airborne digital imager has been adopted by LH Systems. The basic technology has been developed slowly over a long period by the German Space Agency (DLR). This has

As with the new digital camera, so does the new pushbroom scanner have a film-based ancestor in the form of the strip camera. This was also developed originally in the 1930s under the aegis of the American Air Force General George Goddard.

employed three linear arrays in conjunction with suitably positioned lenses that are arranged to give forward-, nadir- and backward-pointing images respectively. This use of this so-called three-line imaging principle allows stereo-coverage to be collected along-track in a single flight. Previously this arrangement was confined largely to space imagers such as MOMS-02, since atmospheric turbulence caused serious gaps and double imaging when linear array pushbroom scanners were used from aircraft. The use of modern fast-acting gyro-controlled mounts limits these effects. Furthermore the development of integrated DGPS/INS systems provides the position and attitude information needed to correct the images geometrically and provide a photogrammetric solution on a line-by-line basis. As implemented by LH Systems, the new imager has been developed further than the DLR prototypes in having much longer linear arrays; a new lens; an internal inertial measurement unit; etc.

• Strip Camera

But, as with the new digital camera, so does the new pushbroom scanner have a film-based ancestor in the form of the strip camera. This was also developed originally in the 1930s under the aegis of the American Air Force General George Goddard. As recounted in his autobiography entitled "Overview", the original idea for this imager came from the high-speed film-based strip cameras used to record the position of horses passing the finish line at racetracks in the U.S.A.! This was developed into a shutterless airborne strip camera by Frank Sonne of the Chicago Aerial Surveys (CAS) company. Thus later, it became known as the Sonne camera. With this device, the photographic film was passed continuously in front of a narrow open slit with its axis located cross-track in the focal plane of the lens. This movement of the film was carried out at an appropriate rate that was related to the speed of the aircraft over the ground. This allowed the camera to record the ground passing below to form a continuous strip image of the terrain. Later a stereo version of the strip camera was developed through the use of two lenses. Each lens was offset forward and backward with respect to the exposure slit in the direction of flight. Thus one lens produced a forward-looking image, while the other produced the corresponding backward-looking image. A rather crude type of gyro-controlled mount was used to stabilize the images and cut down the occurrence of large tilts so that good results could be obtained when the images were used for measurement or mapping purposes.

Panoramic Cameras

To complete this series of parallel developments involving both film-based and digital cameras - albeit separated by several tens of years - yet another new digital imager -

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the Digital Direct Panoramic (DDP) imaging system - has just been introduced (in January 2000) by ImageAmerica of St.Louis, Illinois in the U.S.A. The DDP is a digital panoramic camera that has been mounted in a Beech aircraft equipped with twin pusher engines. The resulting imagery is marketed by the ImageAmerica company under the TerraSource label. As its title suggests, the imager is based on a direct-scanning panoramic camera design. This employs a rotating lens swinging across a cylindrical imaging surface that images the ground in the cross-track direction.
In the case of the digital implementation of this imaging principle, a linear CCD array replaces the film with its narrow exposure slit. Essentially this is a modern day development of the Hyac (High Acuity) type of film-based panoramic camera.
These cameras were first developed for reconnaissance purposes in the late 1940s.
However, since then, they have also been used extensively in pairs to produce very high-resolution stereo-coverage both from high flying aircraft (e.g. the Lockheed U2 and SR-71) and satellites (e.g. the Corona spy satellites). Now we have the digital equivalent.

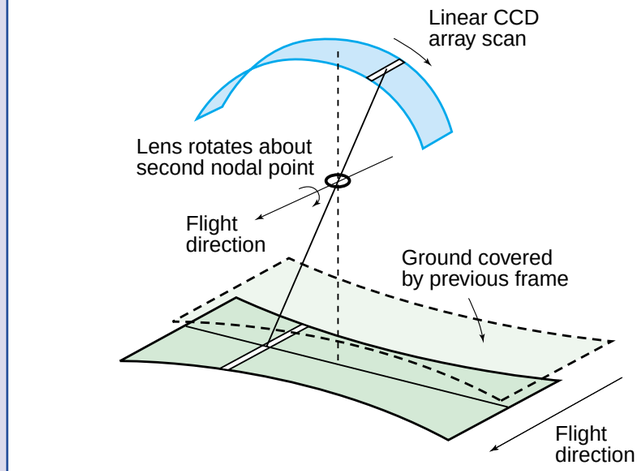

Diagram showing the operating principle of the new ImageAmerica digital panoramic camera which follows that of the Hyac film-based panoramic camera. (Drawn by M. Shand)

Conclusion

As can be seen from the discussion above, some close parallels exist regarding the configurations that are being used with the new airborne digital imagers that are now being introduced and their film-based equivalents from 60 to 70 years ago.

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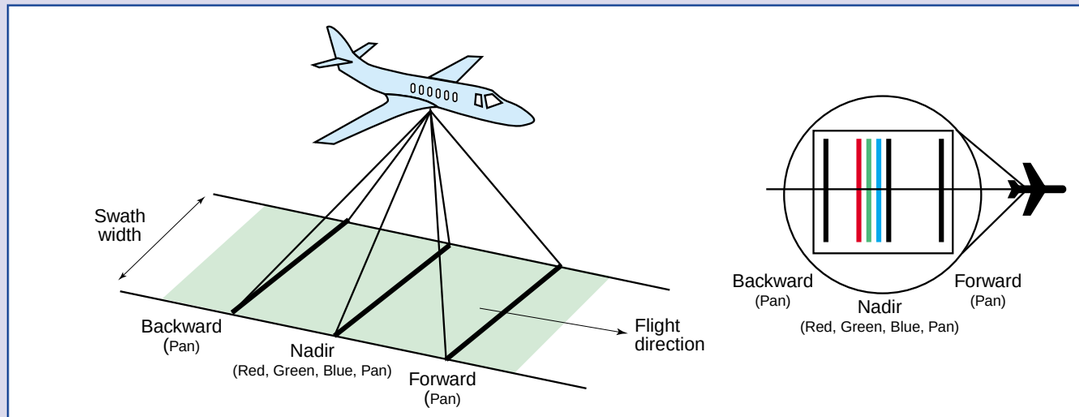

The basic concept of the 3-line airborne digital pushbroom scanner. (Drawn by M. Shand)