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Military Cartography

EDITED BY MIRELA ALTIĆ

Società Italiana di Storia Militare

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3-foot ramsden theodolite from 1791 used during the principal Triangulation of Great Britain. Noe in the Science Museum, London.
Photo by User.geni, December 2008. CC-BY-SA GDFL

Evolution of Military Aerial Imagery 1859-2015: From Balloons to Drones

by Marco Belogi (Italian Army) - Elena Leoni (Italian Army - Reserve)

Abstract. Aerial photography for military purposes started around 1880, when all major European armies used balloons as observation platforms. Starting from the first shot in 1911, the airplane gradually became the main photographic platform through all WWI to take both oblique and vertical aerial shots of front lines. The years 1919-1939 saw the development of topographic mapping from aerial photos, which led all colonial powers to map their areas of influence and to carry out "secret" aero-photographic missions. During WWII, all nations created specific air photographic planes for detecting targets, preparing attack missions and assessing damage, solving huge problems of altitude and autonomy and organizing dedicated photographic units. The Cold War led to the development of recce jet planes, where panchromatic, infrared and radar imagery sensors were installed on the nose of the aircraft. USA also developed strategic air photo collection systems including the U-2 and SR-71 "Blackbird".

The years 1959-1970 saw also the development of satellite photography: CIA's Corona Project laid the foundation for intelligence satellite imagery. Between the 1970s and 2000s, new digital electro-optical or radar sensors for satellites with increasing resolution were developed both for military and civilian use. In parallel, unmanned Aerial Vehicles can take and send oblique motion video, while others can carry out systematic vertical footage of the terrain, such as the Buckeye system in Iraq and Afghanistan. From old balloon photographs to recent Buckeye imagery, an important secondary use of this military technology has been the opportunity to better study archaeological and monumental sites.

Keywords: Military, Aerial Imagery, Air Photography, WWI, WWII, Cold War

Early Aerial Imagery

Military aerial imagery is covered or mentioned in many articles or publications, but usually this topic is approached from limited perspectives (strictly military, technical, survey, mapping, urbanistic, archaeological, etc.). This study is an attempt to present a comprehensive histor-

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ical evolution of aims, methodologies, observation platforms, remote sensors, organizations, and possible civilian use of this truly military activity, as well as giving a glimpse about its main leading actors.

In military related operations, remote sensing of an adversary entity (persons, place, thing, or activity) can be divided into reconnaissance (periodic observation) or surveillance (continuous observation) and needs both observation platforms and remote sensors. While the first remote sensing was made by human terrestrial observation with the later help of magnification lenses, the first observation platforms other that elevated terrain were observation towers, which had the limit to extend only a short distance upward.

After the first balloon flight in 1783, the French were the first to observe the adversary from the air and to form a military Aerostatic Corps in 1794, but this was soon disbanded after its two different companies were captured or lost their equipment. The American Civil War (1861-1865) finally tested the effectiveness of balloons in battlefield reconnaissance with balloon operator Thaddeus Lowe, who reported movements of Confederate armies. On the same battlefields, the official military observer Count Ferdinand Von Zeppelin had the idea to overcome the limited area of view of the tethered balloon, thus creating the first dirigible in 1874. This rigid airship, despite always relegated to a secondary role as military observation platform, would be periodically revitalized until recent years under the name of Aerostat due to the advantage of its persistence in air.

In parallel, the idea of using aerial photography as sensor for military purposes was developed between years 1859 and 1880. In fact, together with observation from balloons to observe the movements of troops and to guide the firing of artillery, terrestrial stereo photographic images were popular since the mid-1850s. The famous French photographer Nadar (real name Gaspard-Félix Tournachon, 1820-1910)[1], who was a pioneer of balloon photography, is credited with having proposed balloon photography to the French army in 1859 in support of its operations in Italy.

Unfortunately, until the end of 19th century the use of aerial photography was still hampered by the problem of impression and development of the plates coated with collodion, which had to remain moist during the flight. It was only in

1 Adam BEGLEY, *The Great Nadar: The Man Behind the Camera*, Tim Duggan Books, New York, 2017.

1880, on the idea of the English physicist Richard Maddox[2], that the photographic plates were coated with dry gelatin, allowing for subsequent development after landing. Thanks to this invention, the period from 1880 to 1910 saw the development of military balloon photography.

Following the example of the major armies, in November 1884 First Lieutenant Alessandro Pecori Giraldi (1858-1948) promoted the establishment of a "Sezione Aerostatica" (Aerostatic Section) embedded in the Mixed Brigade of the Military Engineers of the Italian Army. This section, later named "Compagnia Specialisti del Genio" (Engineer Specialists Company), participated in the Eritrea Military Campaign between 1887 and 1888. In that occasion, Pecori Giraldi and his company were deployed in Saati, the Eritrean village recently reconquered by the Italian troops on 1 February 1888. His small photographic album shows the panoramic views of the forts, glimpses of the landscape, the encampments and the ascents of the three balloons (named Serrati, Volta and Lana) anchored to the ground by ropes and cables[3].

In 1896 Captain Maurizio Moris promoted the establishment in Rome of a "Photographic Section" embedded in the Aerostatic Section of 3rd Military Engineer Regiment. This section, which in 1887 came under the newly developed Aerostatic Specialist Company and in 1894 under the more complex Aerostatic Specialist Brigade, in June 1899 carried out the first ascension for archaeological purposes in Rome[4].

In Russia, in May 1886 military engineer and commander of an aeronautical unit Alexander Matveyevich Kovanko (1856-1919), together with Dmitry Mendeleev (the same scientist who created the periodic table), became the first in Russia to take a photograph from the balloon during a flight over St. Petersburg with a special camera constructed by Professor Vyacheslav Ivan Sreznevsky.[5]

2 Helmut GERNSHEIM, *The Rise of Photography 1850-1880*, Thames and Hudson, London 1988.

3 5 Reparto–Ufficio Storico (SMA), Raccolta Capitano Alessandro Pecori Giraldi, Archivio dell'Ufficio Storico dell'Aeronautica Militare.

4 Patrizia FORTINI, Veronica ROMOLI, « La collaborazione tra il Genio Militare e Giacomo Boni per la nascita della fotografia aerea archeologica », In *100 anni di Archeologia aerea in Italia. Atti del Convegno Internazionale, Roma, 15-17 aprile 2009*, pp. 23–32.

5 Ivan T. ANTIPOV, « The Development of Photogrammetry in Russia », http://www.close-*range.com/docs/The_Development_of_Photogrammetry_in_Russia--Antipov.pdf*.

During the Russo-Japanese War of 1904-1905, three Russian specialized aerial battalions (one of them was the 1st East Siberian under Colonel Kovanko) used tethered balloons and kites created by Russian engineer and balloonist Sergei Ulyanin. Before the advent of the aircraft, these kites were big enough to lift an observer two hundred meters off the ground, high enough for reconnaissance and photographic survey of terrain as far as four to seven kilometers away without being noticed.[6]

The first experiment on topographic planimetric survey was performed in Rome in the winter of 1902-03 by Italian Army Lieutenant Attilio Ranza, who photographed a section of the course of the Tiber River. In 1908 Captain Cesare Tardivo, director of the Photographic Section for two years, took photographs at a scale of 1: 3.500 on an area of fifty kilometers along the Tiber River. Tardivo basically started the aerophotogrammetry, which is a three-dimensional measurement, drawing or model of some real-world features on the ground captured from air photographs. He presented this new topography technique from the balloon in 1910 at the International Conference of Photography in Brussels and in 1913 at the 1st International Conference of Photogrammetry in Vienna, creating great admiration both for the concepts and accuracy results. His manual from 1911 recommended truncated pyramidal cameras for shooting, with telephoto lenses ranging from 4 to 10 magnifications. The movements of the balloon were compensated by the use of mechanical release shutters with exposure times of less than 1/1000 of a second. The plates were in 13x18 or 18x24 cm format.[7]

The years around 1910 also marked the start of development of aerial photography by airplane. The first aerial photography motion picture from an airplane was taken on 19 April 1909 by Major Maurizio Moris as Wilbur Wright's passenger on the Centocelle airfield, during a series of demonstration flights.[8] The first credited use of aerial war photography occurred during a reconnaissance flight carried out on 24 January 1912 by Captain Carlo Maria Piazza in a Blériot XI during the Italian-Turkish war in Tripolitania. Piazza had a Newman & Guardia

6 Nikolay DANILEVSKY, *The Aerial Kites of Captain Ulyanin*, Vozdukhoplavatel' Magazine, St. Petersburg, Usmanov Publishing, 1910.

7 Francesco GUERRA, Luca PILOT, *Historic Photoplanes*, Laboratorio di Fotogrammetria, CIRCE, Istituto Universitario di Architettura di Venezia, Italy, 2008.

8 Video: Wilbur Wright und seine Flugmaschine (Wilbur Wright e la sua Macchina Volante), Société Générale des Cinématographes Eclipse, 1909.

Fig. 1 Postcard showing Italian Aerostieri (Balloonmen) over Rome.
(Author's collection)

Baby Sibyl camera with Zeiss lens supplied from the Engineer Corps in Tripoli and mounted vertically downwards on his plane, which allowed only one slide per flight.[9] In the following months, an automatic plate change system was developed to increase the number of photos per mission.[10]

9 Alberto GRAMPA, *Carlo Maria Piazza Cavaliere del cielo*, Busto Arsizio, 2007.

10 Manlio MOLFESE, *L'aviazione da ricognizione italiana durante la grande guerra europea (maggio 1915-novembre 1918)*, Provveditorato generale dello Stato, Roma, 1925.

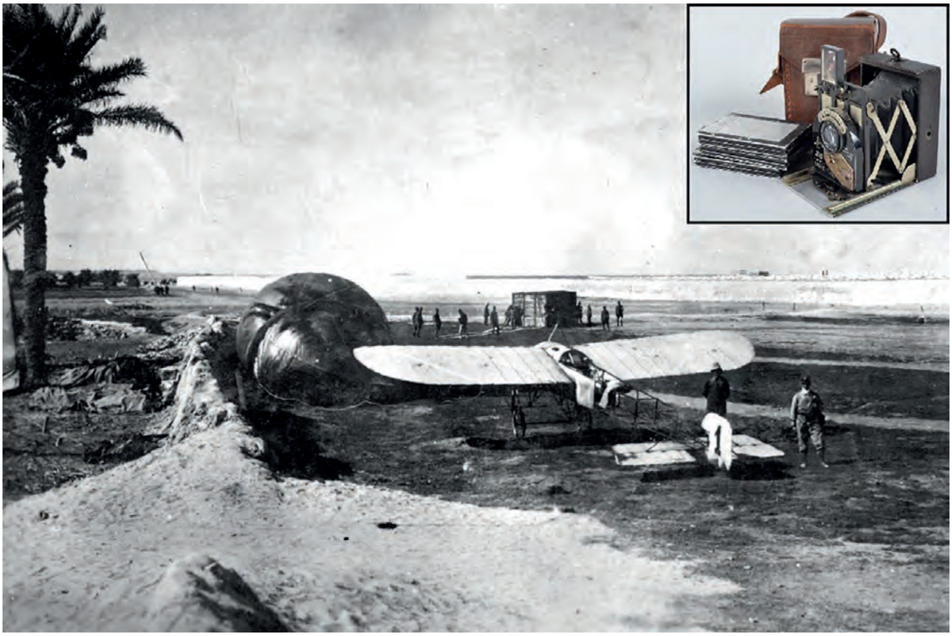


Fig. 2 Blériot XI of Captain Carlo Maria Piazza, who carried out the first reconnaissance flight on 24 January 1912 during the Italian-Turkish war in Tripolitania. Also note the photographic reconnaissance balloon. In the smaller image, Newman & Guardia Baby Sibyl camera with Zeiss lens used for this mission.
(https://www.modellismopiu.it/modules/newbb_plus/print.php?forum=160&topic_id=131586, modified by authors)

Aerial Photography in WWI

Despite this first interesting experiment, in 1914 all main armies entered the First World War with an institutionalized tethered balloon observation system. The balloons could climb up to two kilometers high, but they were easy to shoot down and were unstable observation platforms in any wind, despite attempts of stabilization. Furthermore, they could not navigate from place to place in such a way as to allow rapid and continuous photography of large areas. Finally, the camera had to be operated through elaborate mechanisms for pointing and manipulating the imaging and plate-changing devices.

All these issues led to the gradual affirmation of the aircraft as photographic platform, with the major countries involved (France, Britain, Russia, Austro-Hungary, Italy and Germany) developing their own reconnaissance aircraft. In August

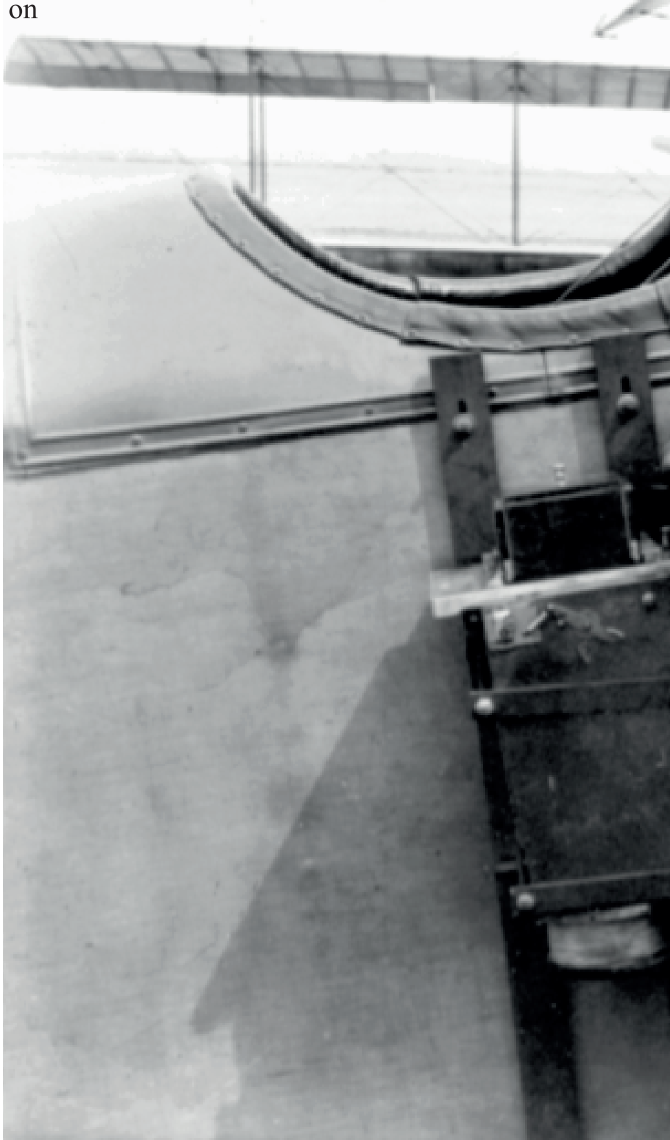
1914 most of the fighting countries had only few propeller aircraft, which flew 2-4,000 meters above the ground and were exclusively dedicated to "ethically correct" reconnaissance and artillery fire of the enemy. Only in the following months they were increasingly used to take vertical aerial photos of entrenchments near the front lines. If at the beginning priority was to make the aircraft a stable platform, soon it was realized that priority was its survivability, achieved mainly with fast and high flight.

The first aim of aerial photography from a military propeller aircraft was the "spotting" of a definite individual target, which included particular trenches or pivotal points in a trench system before an attack, roads or bridges along avenues of approach, batteries or big guns both before and after their bombardment. The technique of spotting consisted in getting properly over the target and then securing the exposure at just the right moment. If cameras were completely hand operated, this needed an auxiliary operator other than pilot, who due to his limited view perspective could otherwise entirely miss a large or elongated objective.

The task of spotting was mainly fulfilled through oblique aerial photography. In comparison with vertical views, oblique views are much easier to be interpreted especially with reference to elevations and depressions of land: obstacles like moats, walls and embankments would hardly be noticed on vertical views, at least without special training. Oblique views taken from low altitudes of the territory to be attacked remained crucial for the infantry in the later stages of the war. Aerial oblique photographs could be either high angle (proper oblique) or low angle views (panoramic), "bird's-eye views" (if taken from different sides) and even stereo oblique, in this last case needing special instrumental equipment and techniques.

The task to obtain aerial oblique photographs with a camera fixed in the fuselage in a vertical position was simply fulfilled by banking the plane steeply, but this technique was not recommended for taking a consecutive series of exposures. The most satisfactory arrangements were to mount the camera obliquely in the plane or to use a mirror or prism, in front or behind the lens of a vertically mounted camera. While the first method has been employed mainly by the French, the English had to use the second method because their cameras were fed by gravity. The oblique, longitudinal or lateral mounting was mainly depending on the aircraft characteristics. In the longitudinal mounting it was necessary to fly directly toward the objective, with the small advantage of less motion in the image, but with the big disadvantage of shooting only a single cross section of the target, not to mention the high risk involved in the maneuver. However, longitudinal mounting was necessary with the bulky 120-centimeter cameras, which simply could not be slung athwart the plane. In addition, mosaics of oblique photographs could be made only by complex systems of conical mounting. In any case, oblique photographs remained necessary to observe enemy positions staying at safe distance during fighting.[11]

The second task for aerial photography was the aid for artillery and the need to reach the so-called situational awareness on the ground, which led to the photography of continuous strips on the ground. At the same time, it was clear that this effect was possible only width almost-vertical photographs. In this way aerial photography, in a continuous crescendo, passed from single lenses shooting to the creation of photographic mosaics that allowed HQs to have a clear view of the front. However, the intelligence value of aerial reconnaissance in World War I was always considered secondary to that of leading artillery fire. Already during the bloody Battle of the Somme in 1915, the British Royal Flying Corps took 19,000 aerial images of German trench positions and reprinted them 430,000 times.[12]



11 James Warren BAGLEY, *The Use of the Panoramic Camera in Topographic Surveying*, US Geological Survey, 1917.

12 Terrence J. FINNEGAN, *Shooting the Front, Allied Air Reconnaissance in the First World War*, The History Press, Spellmount, 2011.

Fig. 3 This British "Type C" aerial camera is externally mounted on an American Curtiss JN-4 aircraft. (U.S. National Archives and Records Administration)

An interesting application of aerial photography to achieve situational awareness was the creation of the so-called trench maps. In order to be able to trace the trenches and the enemy artillery positions, near-vertical aerial photographs were superimposed with various methods to the existing mapping, which had been produced in previous decades starting from angular measurements on the ground. In order to print and mount mosaics, the first step was to determine if each overlapping negative had to be scaled by comparing it with an illuminated glass map sketch. The second step was to print negatives by simple contact or, in case they needed to be scaled, through an enlarging camera. An alternative method, mainly used by Germans, was to trim successive film negatives so that the trimmed sections will exactly juxtapose, instead of overlap. The sections were then mounted at their edges by stickers on a large sheet of glass and finally printed together. All these methods assumed the previous existence of an accurate map, so they were not usable in unmapped regions. In addition, photographic distortions due to lens, shutter, film warping, and paper shrinkage did not allow to produce any kind of precision mapping.

Due to the increasing number of reconnaissance flights, the infantry and artillery started to camouflage their structures from aerial observation by building fake or dummy constructions, and by covering buildings and camps with vegetation, painted canvas and earth. This led to the exploitation between 1916 and 1918 of the aerial stereoscopy.[13] Stereoscopic views or stereograms, made either by photography consist of pairs of pictures made of the same object from two different points. With a minimum overlap of 60% between each frame, the pairs of images could be viewed through a stereoscope to produce a 3D effect. In this way, the two aerial photos could show an elevation and concreteness otherwise not possible in the ordinary flat aerial vista.[14] Often, indeed, these attributes are essential for detecting and recognizing the nature of objects seen from above. Stereoscopic aerial photography has been justly termed "the worst foe of camouflage." The first techniques of interpretation of vertical aerial photographs were

13 Herbert E. IVES, *Airplane Photography*, Philadelphia and London J. B. Lippincott Company, 1920.

14 The ability to see objects in relief is possible when both eyes see the same objects in their fields of vision. Due to the separation of the eyes, the real appearance of all objects not too far away is different, and it is from the interpretation of these differences that the brain gets the feeling of relief.

very much relying on the correct exploitation of the shadows made by terrain and human features. Furthermore, simple mechanical devices, called stereo-plotters, were introduced to orient two photographs relative to each other and relative to the ground.

The whole practical problem of making a photographic map from the air consisted in taking a large number of slightly overlapping negatives, all from the same altitude, with the plane flying uniformly level. It was the observer's duty to time the intervals between exposures so that they overlap enough, but not so much as to be wasteful of plates or film. He must also change magazines or films so quickly as to miss no territory, or if some be missed, his is the task of directing

Fig. 4 An Italian Officer drawing a "trench map" from an aerial photo image through a graphic method. MUSE Museo delle Scienze di Trento. (http://www.archividellascienza.org/it/storia/item/montagne-guerra-1915-1918.html).

the pilot back to the point of the last exposure, where they begin a new series. The most usual overlap was 20%, except for stereos, which call for 50 to 75%. An alternative method of securing parallel strips, which in wartime was highly recommended if enough airplanes equipped for photography were available, was for several aircraft to fly side by side, maintaining their proper separation. The most suitable cameras for mapping were unquestionably those of the entirely automatic type, whose use always demanded knowledge of the ground speed. Cameras of each nation were different in sizes and shapes, but all shared the same limits in the operation process: there were no viewing screens and most of them were plate cameras. In addition, many times the photos taken were blurry due to the slow shutter speed of the cameras compared to the speed of the plane. These issues were improved only towards the end of the war.

When war broke out in August 1914, the French paved the way for aerial reconnaissance. In October, each Army Corps included an aerial photographic section made up of specialized personnel, with pioneering camera development and the gathering of intelligence information from aerial photographs. A school was established in Paris attended by observers and pilots from all other nations, thus creating the famous "French School". Field exercises for pilot and observer training were conducted at several additional sites in France. French pilots mainly used DeMaria cameras, with a focal length of 50 or 120 cm.

On the other hand, Germany had a scientific advantage in the lenses field with the adoption in 1913 of the first aerial camera, the Görz, equipped with Carl Zeiss optics[15]. This optics included the F25, F50 and F70, with focal lengths from 25 to 70 cm and photographic plates 13 × 18 cm. Austria-Hungary followed their lead: at the end of 1917 the Austrian air force took about 4,000 photographs a day, updating the entire Italian front every 2 weeks. The Central Powers used many different aircrafts, but mostly the Rumpler and Albatros types which fitted Görz and ICA cameras. The radio-equipped unarmed reconnaissance aircraft Rumpler C. VII Rubild (short for photographic airplane) stood out for its long range and high altitude, reaching 6,500 m.

In Great Britain, in March 1913 a unit of the newly formed Royal Flying Corps (RFC) was created specializing in aerial photography, on three squadrons with

15 Robert M. CLARK, *Geospatial Intelligence: Origins and Evolution*, Georgetown University Press, Washington DC, 2020.

Fig. 5 A British Royal Flying Corps laboratory unit showing all different aero-camera types. (USAFA McDermott Library Special Collections)

Pan-Ross circumstance cameras. In 1915 the "A" type camera was developed which, being a portable device, was risky to handle during flight. In the summer of 1915, the "C" type was developed, with the same body as the "A" type, but with a semi-automatic plate refilling system consisting of two magazines placed on top of the camera. Thanks to this magazine, the images could be taken in rapid succession. Towards the end of the war came into service the L-type camera, which could be placed inside the aircraft. In the meantime, British photography specialist invented a method for developing the glass plate negatives during flight, so that printed copies would be soon available just after landing.

While Great Britain invented a semi-automatic plate refill system, Italy was not inferior. The first aerial cameras used were mounted by Italians on the sides of aircraft to obtain vertical views, but as vibration of the aircraft was a serious problem, Italy was the first country to have an anti-vibration camera, the Lamperti & Garbagnati with 24 plates, generally mounted sideways on the excellent Ansaldo SVA 5 aircraft, which reached 200 km/h of speed.

In August 1917, First Lieutenant Ermenegildo Santoni was assigned first to the 44th and then to the 42nd Italian airplane squadron as an aerial observer. In order to solve the need to take photographs in sequence to map the terrain, he created an automatic intervalometer, the first sample of which was already produced in the second half of 1917. The device was based on a small variable pitch propeller which operated the photographic advance lever and on a sight notch for the check of the apparent sliding of the ground underneath. Santoni patented his invention on August 1918, the first of a series of over forty licenses.

The United States, while entering at the end of the conflict without much experience, aligned itself with the British and the French and assigned to each Army Corps of the American Expeditionary Forces (AEF) an observation group, each consisting of two or more observation squadrons and one photographic section for the processing and printing of the frames. However, Americans introduced a crucial improvement for aerial cameras, that was to provide more ground coverage. In fact, a single photograph from a single-lens cameras could cover only a relatively small area, while recconnaissance aircraft could not afford to loiter for an extended period of time over the adversary lines to take more photographs. This issue was partially solved by topographic engineer James W. Bagley and Captain Fred Moffit, who developed the T-1 tri-lens camera from a French model to produce one vertical image and two oblique images. In addition, United States were the first to introduce the camera roll. In fact, the Eastman Kodak Company designed the K-1 camera which, with a 6-inch (15.24 cm) film and integrated film roll, was the primary American camera used in the final days of the war.

All World War I cameras were still depicting only the visible part of the electromagnetic spectrum to produce black and white panchromatic images. Their photographs had a variable number of formats (for example 13×18 cm camera with a focal length of 26 cm; 18×24 cm camera with focal lengths of 52 and 120 cm) and had different markings and numbers to identify not only the air force unit, but also the north direction.

In fact, during WWI airplane photography was mainly used for focused battlefield reconnaissance rather than for mapping. For example, between 1915 and 1918 British RFC carried out air photographic survey in Palestine and in Mesopotamia, but they used the simple method to build up mosaics in order to redraw existing maps with the addition of more details.

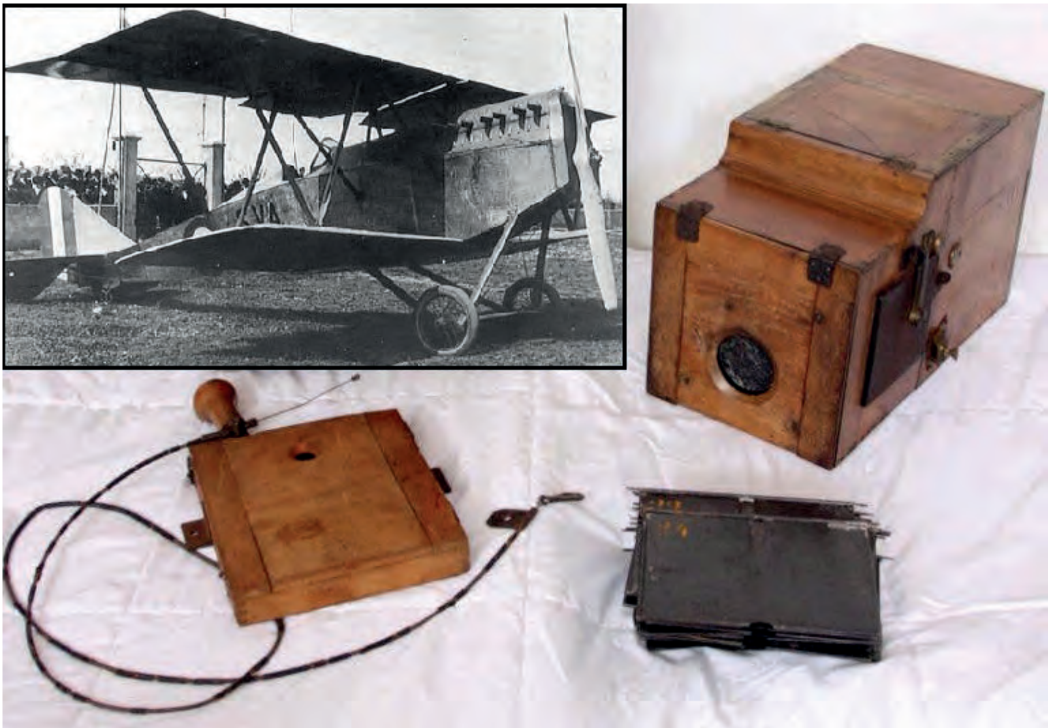


Fig. 6 Lamperti & Garbagnati with 24 plates, generally mounted sideways on the excellent Ansaldo SVA 5 aircraft, which reached 200 km/h of speed. (http://www.papermodeldownloads.com/aircraft/Ansaldo-SVA/SVA.html, modified by authors)

The Interwar Period

The building up of a map from scratch was possible only soon after the war, when the development of cameras and photographic techniques allowed extensive aerial mapping, which turned out to be much faster than ground surveys.[16] For example, in Great Britain in 1920 the British War Office created the Air Survey Committee in order to investigate the exclusive use of photogrammetric air survey to draw maps. This required the definition of specifications for specific aerial photogrammetry cameras. This meant that surveyed ground control points were needed at both ends of every strip of photography. With this new method, it was necessary to carry out ground geometrical triangulation to determine the

16 Peter COLLIER, « The Work of the British Government's Air Survey Committee and its Impact on Mapping in the Second World War », *Photogrammetric Record* 21 (2006), pp. 100–109.

exact coordinates of a certain number of terrain features which were at the same time recognizable on an air photograph (the so-called control points). These control points would later allow the drawing of an outline map, whose details were to be supplied by aerial photographs. But this operation needed to operate on a non-hostile territory. The first military photogrammetric mapping to integrate ground survey was carried out in Palestine in 1919, but the mapping in Mesopotamia when it came into British hands on the same year can be considered the first example of mapping for military purposes using exclusively aerial photogrammetry.[17]

Another issue evaluated by Air Survey Committee was to find simple, low-cost map plotting methods. But still in that year the air survey instruments were essentially terrestrial plotters adapted to deal with differently inclined air photographs through different graphic methods. Only the competitive development of optical-mechanical projection instruments by inventors and producers from different nations solved the problem. Already in 1919 Umberto Nistri, as Commander of Aerial Observation School in Centocelle (Rome) patented the "Photocartograph" optical projection instrument. Around the same years the French Georges Poivilliers designed the "Stereotopograph" for the Service géographique de l'armée, followed by more developed models. Between 1921 and 1926 Reinhard Hugershoff created an optical-mechanical table instrument called "Aerokartograph". In 1922 Walther Bauersfeld's Carl Zeiss Company in Jena developed the "Stereoplanigraph" C-1 optical projection instrument, followed in 1930 by the C-4, which was also adopted in the United States. In 1925 the Wild Company manufactured the first Universal "Autograph" and Officine Galileo with Professor Santoni manufactured the "Autoriduttore" (1920) and the "Stereocartograph" (1925) mechanical projection instruments. All of these photogrammetric stereo plotters allowed the topographic map to be drawn with a pantograph starting from two successive partially overlapping images. In order to orient these stereo pair, a feature of topographical cameras was the presence of markers imprinted on the frame, which made it possible to identify the perspective center of the aerial view through references on the edge of the frame itself.[18]

17 Caren KAPLAN, « Mapping "Mesopotamia": The Emergence of Aerial Photography in Early Twentieth-Century Iraq», in Caren KAPLAN, *Aerial Aftermaths: Wartime from Above*, Duke University Press, Durham, USA, 2018, pp. 138–179.

18 Peter COLLIER, « The Impact on Topographic Mapping of Developments in Land and Air

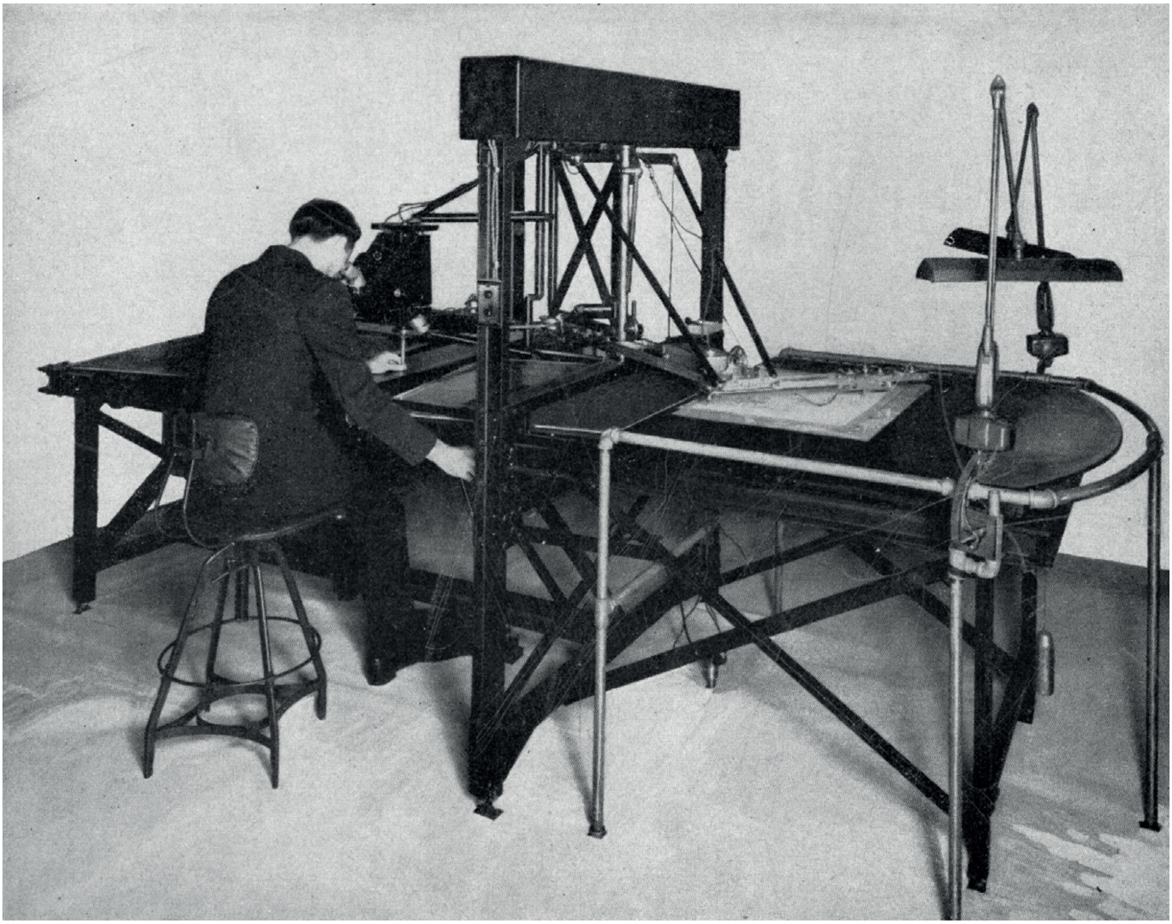


Fig. 7 US Model A stereoplotter (1939).
(https://celebrating200years.noaa.gov/foundations/mapping/image11.html)

Due to these achievements, the years until 1930 saw an international race for the development of photogrammetric instrumentation. German (Zeiss), French (Poivilliers) and Swiss (Wild) firms engineered different plotter designs, while the British and American ones lagged behind for a while.[19] Also in Italy, under the impulse of the General Staff of the Italian Army who made plans for the map-

Survey: 1900–1939 », *Cartography and Geographic Information Science* 29/3 (2002), pp. 155–174.

19 Heinz GRUNER, *Reinhard Hugershoff*, XI1 International Congress of Photogrammetry 23 July to 5 August, 1972.

ping of Eritrea, Somalia, Ethiopia and Libya, Ermenegildo Santoni created the Stereosimplex photogrammetric stereo plotter at the Officine Galileo in Florence. Among the many people involved in military aerial photography at that time was Thomas Edward Lawrence, also known as Lawrence of Arabia (1888-1935). Lawrence joined the recently formed Royal Air Force (RAF) on August 30, 1922 under the name of John Hume Ross. After basic training he was assigned to the RAF Farnborough School of Photography on 7 November 1922 to begin training as an aerial photographer. He chose this position because his father, who was a pioneer of photography, had taught him the technique of matter. During that period Lawrence was assigned photographic work for several British Museum expeditions, but his true identity was soon discovered and in January 1923 he was forced to leave the RAF.

Once the opportunity to map vast territories through this instrumental method became efficient enough, all major national powers tried to achieve a potential military advantage over the others. In fact, the years between 1930 and 1939 saw the increasing use of the aerial photography to map vast territories, with all colonial powers engaged in the creation of the cartography of their respective areas of influence. This stimulated the development of increasingly improved cameras for vertical shooting, virtually free from vibrations and with great autonomy of shots.

Among all, Germany was at the vanguard of private photogrammetry with its numerous companies, including the Hansa-Luftbild in Berlin, the Photogrammetrie in Munich, the Aerokartographisches Institut in Breslau (now Wroclaw) and the Bildflug in Bonn. At the beginning of 1934, all these organizations were brought together to form the Deutsches Einheitsluftbildinstitut (German Unified Aerial Photograph Institute) of the Berlin-based Hansa-Luftbild with autonomous branches, each with: Aerial Photography Section, Photomosaic Section and Stereoplotting Section.

The years after World War I saw also a further development in camera technology. One field to improve in camera configuration was to optimize the ratio between focal length, roll dimensions and body weight. In 1919, British Captain Victor Laws designed the excellent F8 camera, which used a 17.78x17.78 cm roll film and could be used with lenses of various focal lengths. In 1925 was produced the F24 which, with a size of only 12.7x12.7 cm, had less definition but was lighter, stronger and more reliable. The F24, in various configurations, would become the British standard camera of the Second World War.

In the aftermath of WWI, the USA strengthened the organization for the creation and study of aerial photographs, relying on the British experience. As stability and shutter speed remained a problem with aerial cameras, Sherman Fairchild (1896-1971) took charge of building a camera with the shutter located inside the lens, finally completing it in 1920. This design significantly improved image quality, becoming the standard for aerial cameras systems in the following decades. After founding the Fairchild Aerial Camera Corporation, he improved the previous T-1 tri-lens camera in cooperation with its original developer James W. Bagley, building the four-lens T-2 (1928) and five-lens T-3 models, the latter giving one vertical and 3 or 4 oblique images in one film exposure. Fairchild also made the F-1 series airplanes in 1926, with top wings and closed cabins to provide a more secure and stable platform from which to perform aerial photogrammetry.

On the Italian side, in 1924 Ermenegildo Santoni, as reserve officer and expert within Istituto Geografico Militare (Geographical Military Institute), engineered two 210 mm focal length cameras reciprocally mounted at 30° and fed by two magazines of 60 13x18 cm plates, covering about 350 km^2. A solar periscope connected to the system defined the inclination of the machines at the moment of shooting. Also, his 1938 camera model adopted for the first time in Italy the film (60 m for a total of 300 frames), which during the exposure was made to adhere by compression.[20]

Despite the various technical developments achieved at the end of the First World War, the exclusive attention to photogrammetric aerial mapping distracted from the formation of a real military operational capacity through the adequate synergy between organization, means and procedures. As already mentioned, the only military aerial photographic activity which was really improved by nations was about carrying out "secret" aero photographic missions.

Regarding Great Britain, in 1939 Frederick Sidney Cotton, a former pilot in the photographic sector of the Royal Naval Air Service, was enlisted in the Air Information Service and equipped a Lockheed 12A with one vertical and two oblique cameras. Cotton, flying at about 7,000 meters, could photograph an area

20 Enzo SANTORO, *La Fotogrammetria presso l'Istituto Geografico Militare*, in Lo Sguardo di Icaro – Le collezioni dell'Aerofototeca Nazionale per la conoscenza del territorio, Roma 2003.

Fig. 8 Oblique air photo of Pantelleria Island taken by a British aircraft in 1936. (From Marco BELOGI, Pantelleria 1943 - D-Day nel mediterraneo, Liberedizioni, Gavardo, 2001)

ten kilometers long and 16 km wide and flew 15 secret missions to targets in Germany, Italy and the Mediterranean.[21] It is also of particular interest the series of oblique aerial photos which were taken from 1936 onwards to verify the secret fortification works in Pantelleria Island. The photos were by Supermarine Scapa seaplanes from the 201st Squadron at Kalafrana (Malta) at a distance of six miles in order to not infringe the prohibition of flying over the island.[22]

From German side, between 1934 and 1939 Lieutenant Theodore Rowehl of

21 Roy CONYERS NESBIT, *Eyes of the RAF: A History of Photo-Reconnaissance*, Sutton Pub Ltd, London, 1996.

22 Marco BELOGI, *Pantelleria 1943 - D-Day nel mediterraneo*, Liberedizioni, Gavardo, 2001.

the Luftwaffe, who was an aerial reconnaissance pilot during the First World War, under the cover of Lufthansa flights took aerial photographs with a He-111V2 over the Soviet Union, the English Channel, the North Sea and the Baltic Sea through heavy paired vertical cameras.

Aerial Photography in WWII

The World War II period (1939-1945) brought tremendous growth and recognition to the field of aerial photography, transforming it into a real weapon. In addition, there was a surge in government interest in photogrammetry in order to support the map making efforts. During WWII, uses of aerial photography were further differentiated. Primarily, photographic reconnaissance examined potential targets, thus allowing the analysts to determine the opponent's vital infrastructure, to trace the attack routes and to prepare the target list for the aircraft crews. Additionally, post-attack sorties provided the bombing damage assessment needed to assess success. While vertical shots remained crucial to build maps, oblique shots were more descriptive and often more useful for detecting targets and preparing attack missions.

During the conflict the Germans, which had an initial technical-organizational advantage, were gradually overtaken by the British and then by the Americans. In fact, when the United States entered the war in 1941, they practically had no military photointerpretation experience, but through massive training programs they achieved the best photographic interpretation skills of any nation in the world. On the other side, the Germans continued to use photography as a tactical support and never came to the strategic use of American photographic reconnaissance. As for Great Britain, in 1939 the RAF still did not have a specialized photographic reconnaissance aircraft.

Due to the high death rate among early reconnaissance flights, some Supermarine Spitfire fighter planes were depleted of machine guns and radios, sealed to improve aerodynamics, and their engines were modified to optimize performance at altitudes up to 12,000 meters. To improve visibility, a drop-shaped bubble canopy was fitted. Two F24 cameras were mounted vertically and synchronized to provide two slightly overlapping photos. Eventually, the aircraft were equipped with additional fuel tanks and were painted a pale shade of blue to make the aircraft less visible. Operation at high altitudes led to cameras being frozen, to fogged lenses, or to film being cracked, but RAF engineers solved the problem by channeling hot air from the engine through the camera housings. After these changes, this special purpose aircraft was nicknamed "Cottoned" Spitfire also with reference to his developer, Sidney Cotton, who at that time was heading up the RAF 1 Photographic Development Unit (PDU) at Heston Aerodrome. Additional photography units were also created: No.2 in the Middle East (later in Heliopolis in Egypt), Unit No. 3 on the seas and No. 4 in Gibraltar.

The main merit of Great Britain was to maximize the synergy between the available cameras and aircraft. In fact, the poor resolution of the F24 camera, which provided poor detail from 10,000 meters, was resolved with the adoption of the Swiss photogrammetric stereo plotter Wild A5 which magnified up to 8 times. In 1942 the F52 camera was introduced with 21.59x17.78 cm frames, with 35.56, 50.8 and 91.44 mm lenses and with 250 or 500 exposure magazines. In order to be able to take pictures at low altitudes an unarmed version of the Spitfire Mk VII was developed, with a pale pink color to hide in the low banks of clouds. Another very efficient reconnaissance aircraft was the twin-engine Mosquito, which had the advantage of a second operator able to adjust the cameras during the flight and which was also able to flight at altitudes up to 12,000 meters.

Through the year 1943 British Bomber Command managed to have all its aircraft engaged in night bombing equipped with a camera and able to shoot at least one photograph in synchronization with a photo-flash cylinder released together with the first bomb, or together with the target indicator in case of Pathfinder aircraft. Yet, this technical solution remained very unpopular among the aircrews mainly because of the risk of premature explosion of the flash cylinder and because, due to the long film exposure necessary (at least ten seconds) to not miss the brief illumination of the flash, it was not possible to perform any evasion maneuver.

In the early years of the conflict RAF secretly enlisted civilian photo-interpreters from the Aircraft Operating Company and its associate Aerofilms: between them the aristocratic figure of Constance Babington Smith (1912-2000) stands out as "Queen of Photo Interpreters". Being passionate about aviation, in the 1930s she wrote articles in Airplane magazine. When the war broke out, she joined the RAF Women's Auxiliary Service. In April 1941 she was a Section Officer of an air interpretation section embedded in the RAF's Central Photo Interpretation Unit in Medmenham, which later became an Allied unit. She coordinated geolo-

Fig. 9 This image shows a RAF photographer fitting two F24 cameras into a Mk Ic Photo-Reconnaissance Spitfire in 1939-1940. (https://www.militaryimages.net/media/spitfire-cameras.7515/)

gists, geographers, archaeologists, mathematicians, botanists, and cartographers for the preparations for the landing in Normandy. In November 1943 she first identified the prototype of the German V1 "flying bomb" in Peenemünde.

When the US Army Air Force (USAAF) entered the war in Europe, they lacked an aircraft designed specifically for aerial reconnaissance with adequate speed, altitude and range. The famous Lockheed P-38 "Lightning" fighter-bomber was modified into the F-4 and then the F-5 version by replacing the guns with four cameras. Models of 200 F-4s and F-5s were produced, while other series P-38s were modified for photographic function. In mid-1943 the P-38 began to be replaced by the longer-range P-51 "Mustang" in its F6 reconnaissance variant.

In the Pacific, vast distances and poor infrastructures were a huge obstacle. The Royal Australian Air Force (RAAF) and Royal New Zealand Air Force (RNZAF) had some air reconnaissance capability in the South Pacific, but the first true U.S. strategic reconnaissance capability in the Pacific began in April 1942, when Captain Karl Lewis Polifka formed the 8th Photographic Squadron in Port Moresby (New Guinea) with five P-38 in the F-4 photographic version equipped with additional fuel tanks. The USAAF later introduced the F-13, a Boeing B-29 Superfortress modified to conduct long-range aerial reconnaissance. On November 1, 1944, an F-13 flew a 14-hour mission from Saipan to Tokyo at an altitude of 10,000 meters and since then 118 F-13s have flown hundreds of missions over Japan mapping each significant target.[23] USAAF developed a vast range of cameras depending on their focal lengths varying from 6 (15.24 cm) to 24 (60.96 cm) inches. Each camera station type (Trimetrogon, Vertical, Split-Vertical, Oblique, Photo-Navigator and Radar Observer), in combination with a specific focal lens, was suited for each kind of military purpose (Charting and Mapping, Reconnaissance, Intelligence, Night Photography, Opportunity, Radar Scope Photography, Motion Picture).

The main role in this development was taken by the Fairchild Company. The Fairchild Graflex K-20 handling camera was the primary reconnaissance camera used by the Allied forces. It could shoot 100 9"x9" (22.6x22.6 cm) negative frames in a single roll, although 50 was the most common figure. The K-17 camera was designed for both vertical and oblique photography. It was also fed by

23 William M. CAHILL, « Imaging the Empire: the 3rd Photographic Reconnaissance Squadron in World War », *Air Power History* 59/1 (2012), 12–19.

Fig. 10 Constance Babington-Smith, who worked at the Allied Aerial Central Interpretation Unit, is considered as the “Queen of Photo Interpreters”. (https://www.walpersberg.de/history/)

a 200 “9x9” negative roll magazine. In 1943, at the request of the USAAF, Professor Harold Edgerton of the Massachusetts Institute of Technology built a flash unit for nighttime aerial reconnaissance photography. The aerial camera was just 60 cm longer than a 35mm camera, but the flash tube was made of tough quartz glass coiled into a spiral positioned in an 80 cm reflector pointing down from the plane’s belly or tail. Banks of capacitors, weighing up to 240 kg each, were slung on the plane’s bomb racks. The flash unit was tested on 5 June 1944 over the D-Day target areas, where the nighttime landscape showed that the Normandy invasion was not expected in the designated landing areas.

A further photographic device was Sonne stereoscopic strip camera, which being shutterless photographed a continuous strip of terrain on a sensitized film that was moving continuously across a fixed slit, thus allowing low altitude photography at extremely high plane speeds. The large photo scales produced (up to

1/300) were very helpful in reducing distortion and improving detail in dangerous low-altitude photography from aircraft like the Lockheed P 38. The camera used black-and-white or color film and a single or stereo lens. This device had been developed by the air imagery pioneer Colonel George W. Goddard, who in February 1944 was sent to England to assist in setting up the reconnaissance program for the 325th Reconnaissance Wing. Goddard helped in modifying F-8 Mosquitos for radar photography, and assisted in the development of night photography using the Edgerton D-2 skyflash.

At the same time, Luftwaffe's most used camera was the Rb 30 series, introduced in 1938. It was a large format camera designed primarily for carrying out cartography work. At the start of World War II, the Rb 20/30 was widespread throughout the Luftwaffe; however, as allied aircraft slowly forced the Luftwaffe to fly at higher altitudes, the focal length of the lenses had to increase and was replaced by the Rb 75/30. These cameras, with diaphragm shutter inside the lens, were mounted vertically, single or in pairs, with a 64 m roller, to give 32x32 cm frames. An assortment of Junkers Ju 88, Dornier Do 17 and Messerschmitt Bf 110 were used for pre-raid tactical collection and post-raid missions for damage assessment. Unlike the RAF, the Luftwaffe made very few modifications to their reconnaissance aircraft, which remained armed. As the war progressed, the Allies intercepted Luftwaffe reconnaissance flights until September 1944, when the new Arado Ar 234 with its speed and altitude managed to penetrate the British airspace. Specialized aircraft such as the curious Blohm & Voss BV 141 were produced only towards the end of the war.

In 1943 the office of the chief of aerial photography was reorganized as Department 7 of the General Staff, under the leadership of Rowehl, with six operational groups. The Hansa-Luftbild, although still outside Department 7, was militarized and renamed Sonderluftbildabteilung (Sobia). As the equipment to carry out a systematic mapping was insufficient and trained technicians were scarce, mosaics and anaglyphs printouts[24] often replaced topographic maps. In particular anaglyphs printouts were used by German Commands to plan the defense of Gothic Line. In the absence of adequate cartography of their areas of operations, the Germans also used many photomaps, made through rapid geometrical correc-

24 Anaglyph is the stereoscopic 3D effect achieved by means of encoding each eye's image using filters of usually chromatically opposite colours, typically red and cyan.

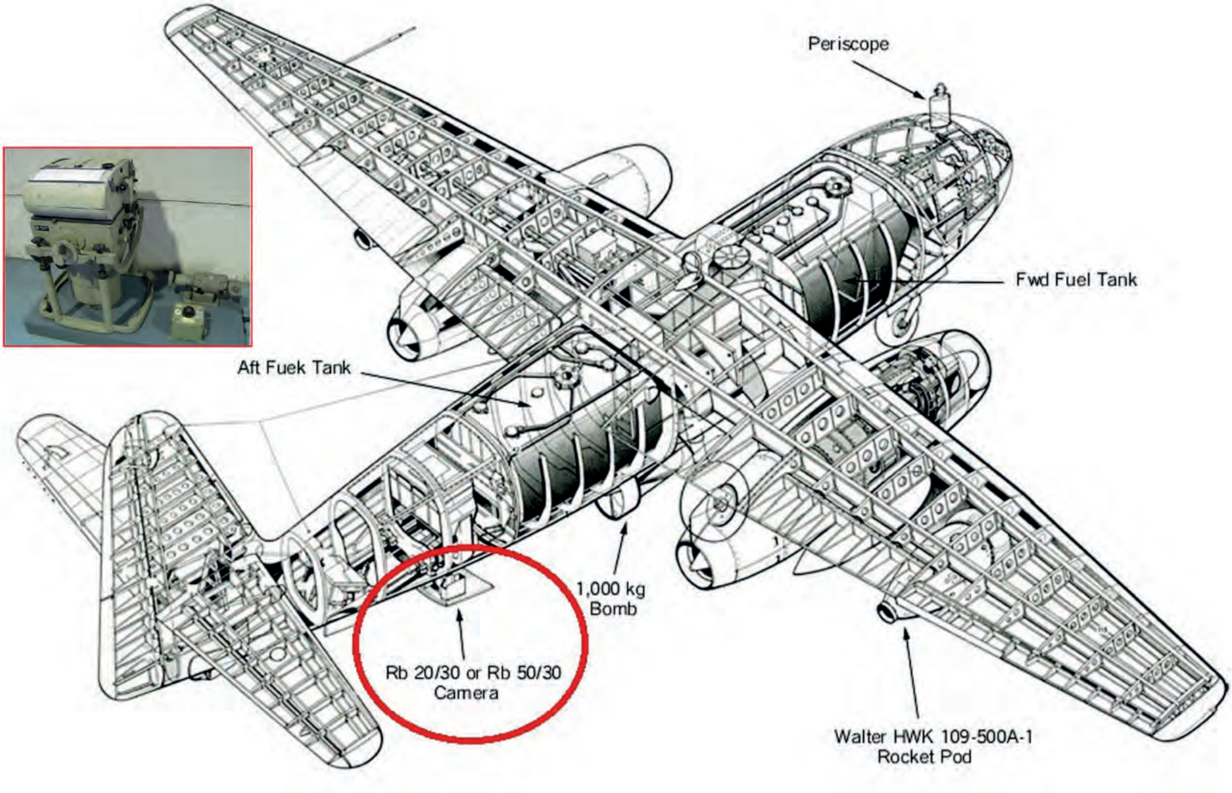


Fig. 11 Arado Ar 234 B was the world's first operational jet bomber and reconnaissance aircraft. The first Ar 234 combat mission was a reconnaissance flight over the Allied beachhead in Normandy, 1944. In the smaller image, a Rb 50/30 aerial camera which could equip the aircraft. (http://www.aviation-history.com/arado/234.html, modified by authors).

tion and mosaicking of aerial photos and the addition of marginal information. The Allies troops widely used photomaps, for example to plan the crossing of Po River in northern Italy.

At the same time, Japanese Forces appreciated the value of aerial reconnaissance developing very high-quality reconnaissance airplanes. Japan boasted a well-developed aviation industry and produced high-quality specialized reconnaissance aircraft such as the Kawanishi H8K "Emily" and the Mitsubishi Ki-46 "Dinah". Prior to the war, the Japanese had performed meticulous aerial mapping of Malaysia and the Philippines, but bitter rivalry between their militaries

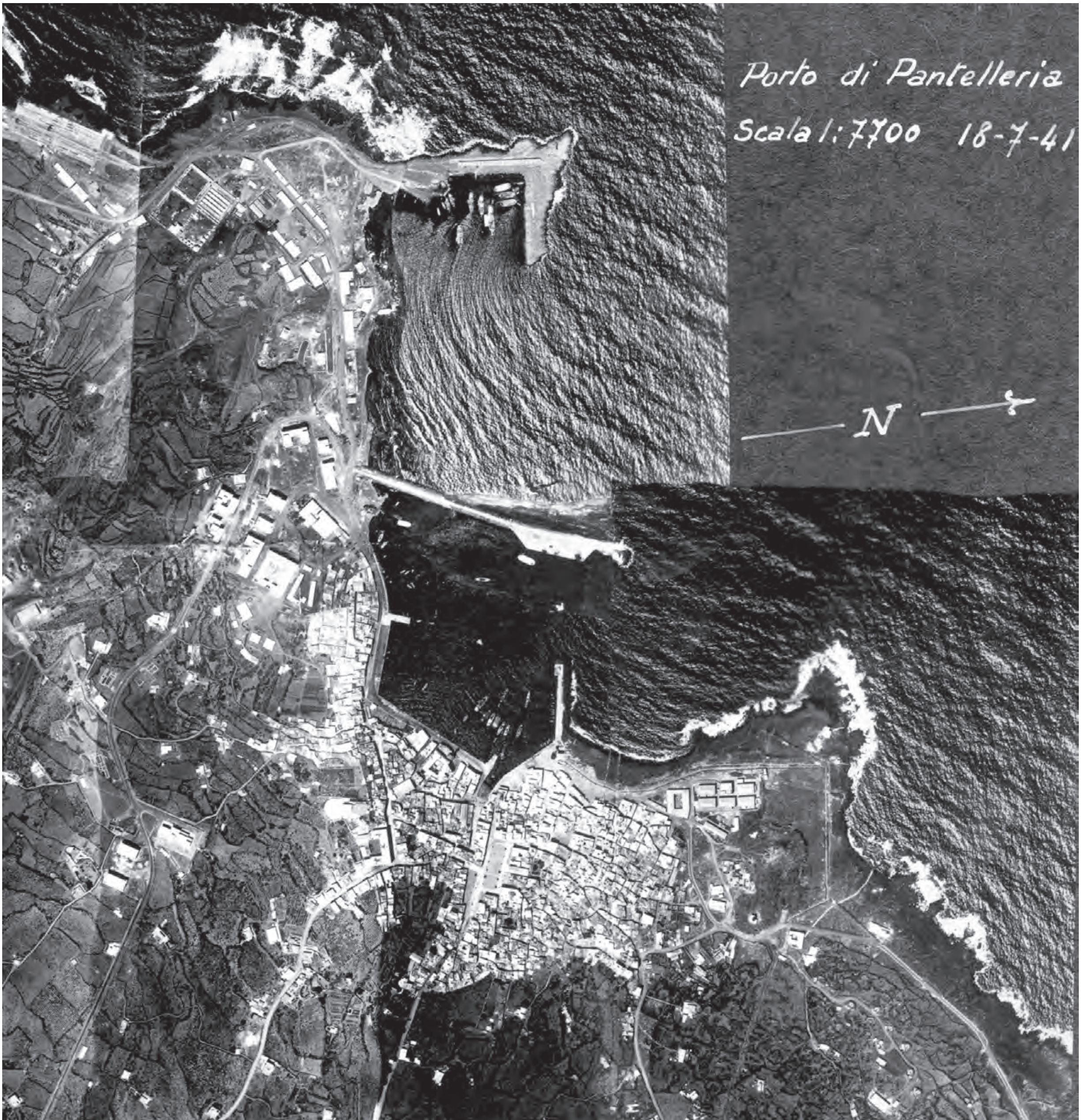


Fig. 12 A 1941 Italian air photo plan of Pantelleria Island harbour (From Marco BELOGI, Pantelleria 1943 - D-Day nel mediterraneo, Liberedizioni, Gavardo, 2001)

Fig. 13 General Dwight Eisenhower (first on left), Head Commander of the Allied Forces of North Africa and future commander of the operations in Normandy, portrayed in the air photo depot at La Marsa (Tunisia). On the right, Lieutenant Colonel Elliot Roosevelt, commander of the North African Allied Photographic Reconnaissance Wing. (From Marco BELOGI, Pantelleria 1943 - D-Day nel mediterraneo, Liberedizioni, Gavardo, 2001)

prevented the Japanese from realizing their full aerial reconnaissance potential. Eventually, once the Japanese lost air superiority, their reconnaissance aircraft were too vulnerable to be effective.

A separate analysis is necessary about the Allied photo-reconnaissance organization between 1943 and 1945. With the landing in Morocco in November 1942, the Americans took over the leadership of the aerial photography organization. The son of the President of the United States, Lieutenant Colonel Elliot Roosevelt, became the commander of the North African Allied Photographic Reconnaissance Wing first based at La Marsa in Tunisia. This unit coordinated both American and British aerial photography flying groups.

The first systematic use of aerial photography for operational purposes by the Allies happened during the seizing of Pantelleria Island in Sicily. From 18 May to 11 June 1943, on the premise of the invasion of Sicily, the Allies subjected the island of Pantelleria to a massive aerial bombardment with 6,200 tons of explosives in order to force the Italian garrison to surrender. To calculate the scale of the offensive effort, a special study group was created led by Professor Solly Zuckerman, who suggested using the "Corkscrew" operation as a test to evaluate the potential of an air force against permanent fortifications similar to those in Normandy. Based on statistical procedures Zuckerman theorized a high-density bombing in order to cause at least indirect damage to the batteries. Using zenith and oblique photographs, Zuckerman's team made an accurate and systematic analysis of the island's defenses, carried out a rigorous recording of the number of sorties and bombs destined for each target and finally evaluated the damage to the batteries using graphs.[25]

In November 1943 the North African Allied Photographic Reconnaissance Wing was renamed Mediterranean Allied Photographic Reconnaissance Wing (MAPRW) and was based in San Severo in Puglia, with a subsequent detachment in Naples. A notable Royal Intelligence Corps photographic interpreter serving within the MAPRW was John Bradford (1918-1975), who noted the remains of many archaeological sites while analyzing aerial photographs.[26] At the same time, in order to prevent the bombing of cultural property he worked closely with Monuments Man Lt. Col. John Bryan Ward-Perkins, Director of the Monuments, Fine Arts and Archives (MFAA) section in Italy. Just after the war, along with Ward-Perkins, Bradford also helped in establishing air photograph collections in the American, British, and Swedish Academies in Rome, as well as at Oxford University.[27] The Free France Groupe de Reconnaissance 2/33 also operated under the MAPRW, that of the famous poet and writer Major Antoine de Sant'Exupery, who died at the controls of his Lookeed F-5B reconnaissance plane on 30 July 1944.

The organization was dissolved in October 1944 in favor of the 106th Group, formed in May for the invasion of France. Lieutenant Colonel Roosvelt was sent for some months to cooperate with the Soviets in Ukraine, noting the primitive photographic survey carried out by the Russians.

25 BELOGI, 2001.

26 Giuseppe CERAUDO e Fabio PICCARRETA, *Archeologia Aerea*, Studi di Aerotopografia Archeologica I, Istituto Poligrafico e Zecca Dello Stato, 2004.

27 Monuments Men Foundation. https://www.monumentsmenfoundation.org/bradford-capt-john-s-p

Fig. 14 Antoine de Saint-Exupéry with the P-38 Photo Reconnaissance planes used by the Free France Groupe de Reconnaissance 2/33. (Credit plus.randomania.fr).

Cold War and Beyond: From Aerial Photography to Imagery Intelligence

After the Second World War, the emphasis in aerial photography returned to that of pre-war days, with camera manufactures' mostly focusing in crafting better devices for more detail and accuracy. The development of aerial photography for military purposes was also boosted by the Cold War (1946-1989). The Korean War (1950-53) led to the development of US jet planes, in which cameras initially coming from the previous decade were this time generally installed on the nose of the aircraft. A small improvement was the automatic recording of shooting data (date, flight ID, altitude, compass, etc.) in order to facilitate the archiving and reconstruction of the map.

Another achievement by USA was the exploitation for war use of infrared photography, which was sensitive to infrared light reflecting from green chloroplast rich trees and leaves. While panchromatic black and white film consists of a negative material with a sensitivity range comparable to that of the human eye, infrared black and white film is sensitive to the spectral region ranging from 0.7 micrometers to 0.9 micrometers (i.e. near infrared band). This technique, first developed in 1910, needed long exposures and special glass filters and initially was used only for landscape photography. Infrared ground photography was reportedly used to attempt to see though smoke and fog during First Word War and became popular in the 1930s when many manufacturers (Ilford, Kodak, Agfa, Leica) produced infrared-sensitive films. But the exposure time needed by films was still not suitable for military air operations, so it was only in 1942 that Kodak developed Aerochrome 1443 false-color slide reversal film in the form of Aero Kodacolor Reversal Film for camouflage detection.[28] The special feature of this film was that it could be processed anywhere without elaborate equipment.[29] A faster version of this color film (Ektachrome) was standardized only in 1945, mainly for operational use in the Pacific. Since then, infrared films had a steady life of around 50 years for military air photography until being replaced by digital imaging.

Camouflage detection film was depicting natural broad-leaf foliage in a reddish color, while infrared absorbing materials, such as paints that were used to simulate foliage, appeared purplish or bluish in color. Unlike the color infrared film for camouflage detection, the black and white infrared photography was produced with a conventional camera system by using a black and white infrared-sensitive film. The result was a thermal difference image which looked like a low-grade photograph, where hot vehicle motors, fires, and other heated objects were visible as hot spots. Black and white infrared photographs were also showing the difference between wet and dry surfaces and also had excellent haze penetration capabilities. The standard color photography was particularly useful in the identification of industrial stockpiles, vegetations, soil types and rock outcrops. In addition, it had good water penetration capabilities and was useful in the recognition of water depth determination.

28 Raife G. TARKINGTON, *An aspect of colour photography and interpretation*, Research Laboratories, Eastman Kodak Company, Rochester, N. Y, 1953.

29 A typical exposure for this film was approximately 1⁄300 second at f⁄5.6. This exposure is based on a solar altitude of 40 degrees, a clear day, and an aircraft altitude of 10,000 feet.

A further development was the Side-Looking Airborne Radar (SLAR) imagery, which allowed the production of a map-like presentation of the terrain by recording the radar reflectance on aerial film. Due to the low resolution of the resulting imagery, special interpretation techniques were required to extract information.[30] Due to the different nature of products to manage (photography, infrared and radar) the US Army in 1964 changed the name of Photographic Intelligence into Imagery Intelligence. In 1950 the British introduced in service a jet-powered replacement for Mosquito. The result was the English Electric Canberra which, together with its American version B-57, served for more than 50 years. It was the best long-range aircraft of the second half of last century, being able to reach an altitude of 21,000 meters, even if not for a long time.

During the Cold War, the United States also developed strategic photo collection platforms and sensors. The K-42 Camera, nicknamed "Pie Face", or the "Boston Camera" from Boston University, was engineered in 1951 and was the largest aerial camera ever made in the world. It weighed up to 3 tons and was mounted on the huge RB-36 Peacemaker strategic bomber airplane. This camera could take oblique or vertical photos at a shutter speed of 1/400 of a second through a hidden aperture and had a focal length of no less than 6 meters, made possible by two mirrors. The fact that it could photograph a golf ball from an altitude of 14,000 m became proverbial for the following years.

In 1953, under the auspices of the Central Intelligence Agency, photographic scientist Dr. Edwin Land, optics scientist Dr. James Baker and project engineer William McFadden tested a panoramic automatic camera, with a lens barrel capable of rotating from side to side and filming from horizon to horizon. This camera had an image-movement compensation that could compensate for the motion of the aircraft and the vibration of the engine and the movement of the highly sensitive, fast, and ultra-thin Kodak film especially designed for the project. This camera, which was finally engineered by Hycon Corporation under the name of 73B[31], was mounted on the new Lockheed U-2 reconnaissance aircraft, codenamed Aquatone, developed by engineer Clarence Leonard "Kelly" John-

30 Robert BOLIN, *Field Manual FM 5-30, Engineer Intelligence*, Headquarters, Department of The Army, September 1967.

31 https://airandspace.si.edu/collection-objects/camera-aerial-hycon-73b/nasm_A19771125000.

Fig. 15 The first strategic reconnaissance aircraft was the RB-36D specialized photo-reconnaissance version of the B-36D. In the smaller image, a K-42 Camera, nicknamed “Pie Face” or the “Boston Camera”. (Image modified by authors).


The "Boston Camera"

son. The U-2 was able to fly above the safer altitude of 18,000 m travelling for 5,500 km and gliding for 1,500 km.[32] Hycon 73B panoramic camera could shoot from U-2 under fuselage through seven glass encased windows, recording 200 km wide views along a 3,500 km path and it could provide up to 4000 pairs of stereoscopic photographs. Its 36-inch focal length lens could resolve features as small as 75 centimeters from an altitude of 20 kilometers. The film was loaded onto two counter-rotating film spools, one located forward and the other aft in the camera body to maintain the center of gravity within in the aircraft.

In 1956, after his Open Skies proposal (authorized bilateral surveillance flights over declared military facilities) was rejected by the Soviets the year before, President Eisenhower authorized the first Lockheed U-2 secret reconnaissance missions over Soviet Block (Poland and East Germany). The loss of one of these aircraft in the Soviet Union in 1960 created an international accident with the capture of the pilot, Francis Gary Powers. The U-2 aircraft also played a leading role in the Cuban missile crisis in 1962 and flew over China and Vietnam.

The last strategic aircraft before the advent of satellites was the Lockheed SR-71 "Blackbird", which thanks also to a largely titanium structure could operate at high speeds (Mach 3.2) and altitudes (25,900 meters) and was also protected by sensors and by a stealth technology. The "Blackbird" was equipped with different optical cameras.[33] The forward oblique Terrain Objective Camera (TOC), manufactured by Fairchild, had a 6 inch (15.24 cm) focal length lens with 9 inch (22.86 cm) wide film, achieved a medium ground resolution (8 meters) and was designed for tracking flight. Two side Operational Objective Cameras (OOCs), initially manufactured by the Italian ITEK, were panoramic cameras with a focal length of 13 inches (33 cm) that used 70mm-wide film. Both OOC cameras were able to scan horizontally from -5 degrees below the plane's nadir to +45 degrees on their respective sides and were able to adjust their framing speeds to the momentary ground speed. Each photo overlapped the area covered by the previous photo by 55%, so that stereo views could be obtained. The OOC's were discontinued in the early 1970's in favor of two lateral Optical Bar Cameras (OBCs),

32 Thomas FENSCH, *The CIA and the U-2 Program: 1954–1974*, New Century Books, Chula Vista, California USA, 2001.

33 Richard GRAHAM, *SR-71: The Complete Illustrated History of the Blackbird*, *The World's Highest, Fastest Plane*, Zenith Press, Minneapolis, 2013.

Fig. 16 Technicians load a Hycon 73B camera into a U-2's equipment bay.
(U.S. Air Force photo).

also previously manufactured by ITEK, were high resolution panoramic cameras with an initial 24-inch (60.96 cm) focal length, later extended to 30 inches (76.2 cm). They could photograph 100,000 square miles of the Earth's surface per hour. Finally, two lateral computer-aided Hycon HR-308B Technical Objective Camera (TEOC) allowed very high-resolution photography of designated areas with an average ground resolution of 15 cm thanks to their 48-inch (121.92 cm) focal length.

Fig. 17 On the foreground of Lockheed SR-71 “Blackbird”, there are its main photographic sensors: the Technical Objective Camera TEOC and the Optical Bar Camera (OBC). (Photo Courtesy Dave Nolte, Boeing).

The Cold War marked also a big way forward for tactical aerial photography. During the Vietnam War, the United States had the possibility to employ no less than 112 different combinations of aircraft, sensors and services, but due to the increased demand for close air support, it was necessary to create a Combat Operations Center to control and coordinate photographic and visual reconnaissance and electronic intelligence carried out by the 460th Tactical Reconnaissance Wing of the 7th Air Force.[34] The US Air Force used photographic versions of the RF-101 and the Phantom RF-4C airplanes, through elongating their noses to accommodate the cameras.

The Navy used the RA-3B Skywarrior, which with its ability to fly at 650 km/h at a height of 500 m, could approach the objectives with a surprise effect. In addition to the pilots, it housed a photo-navigator and a photo technician and up to 12 oblique and vertical cameras. The Army was instead using the twin engine Mohawk OV1 aircraft equipped either with high a performance camera, with a newly developed infrared equipment or with a side-looking airborne radar (SLAR) to be used at night, often in conjunction with C-130 flareships from Air Force.

From 1965 to 1972, the 1st Military Intelligence Battalion (Air Reconnaissance Support), also known as the 1st MIBARS was placed at Tan Son Nuth airbase near Saigon and played a unique role in the Vietnam War to produce tactical military information.[35] As photointerpretation was limited by the triple level of jungle vegetation, during night operations, thermal infrared sensors were used.

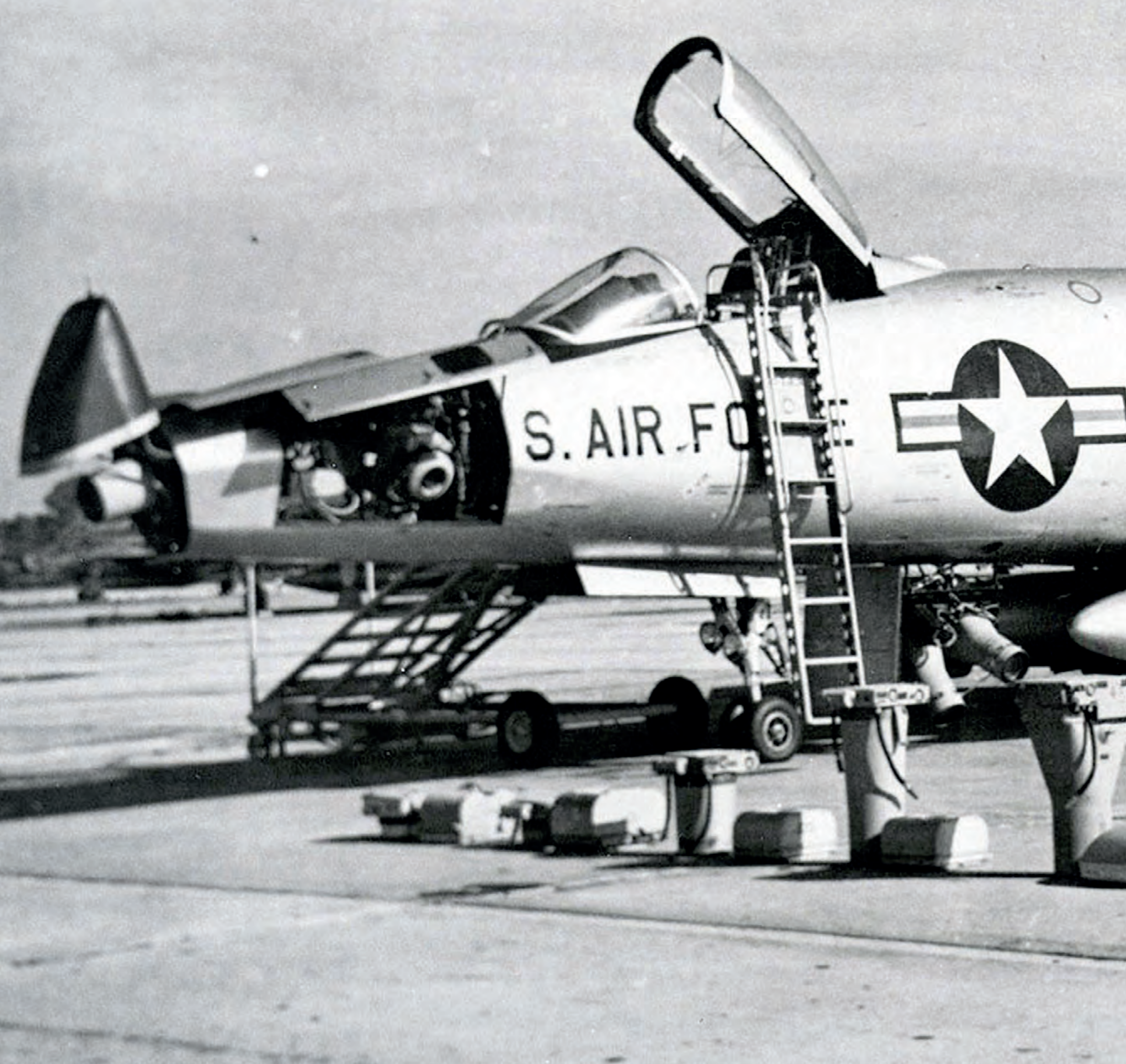
Analogic aerial photography exploitation was at that time completely mature and led to different Intelligence products. Together with the traditional mosaics of aerial photographs (two or more photographs arranged to give a continuous picture of an entire area) and photomaps (a photo image base with the addition of grid lines, marginal data, and place names) there were also composite photomaps (printed from three or more vertical and oblique photographs negatives which were exposed simultaneously by a multi-lens camera), Sonne photoprints (depicting a continuous strip of terrain photographed at low altitude) and pictomaps (a photo image base with the addition of cultural, planimetric, and topographic

34 Joseph MCCHRISTIAN, *Vietnam Studies, The role of Military Intelligence 1965-1967*, Department of the Army, Washington DC, 1974.

35 http://1stmibarsinvietnam.org/

information improved by adding shadows caused by relief and color tones to accentuate vegetation, open areas).

Panoramic photography was also still crucial, as the resulting image was a "sweep" presentation of the terrain, usually from horizon to horizon and perpendicular to the line of flight. This had the appearance of a left and right oblique separated by vertical exposure with no lines of demarcation. Panoramic cameras were also used in the forward oblique position and give a forward panoramic view of the terrain which is useful in briefing pilots on the approach into an area.



The shift from mechanical and analogue electronic technology to digital electronics in the late 1960s and early 1970s allowed cartographers to quickly and accurately orient photographs in producing maps beyond the mechanical approximation of stereo-plotters and lead to the transition between paper-based maps to digital maps. Moreover, the fact that aerial photography no longer was exactly describing the many forms of imagery collected using radiation outside the visible region of spectrum led to coin the new term of remote sensing.

Fig. 18 USAF RF-101C aircraft camera configuration during Vietnam War: four KA-45 cameras with one lens pointed forward, one pointed straight down, and two angled to the side. Optical cameras were at that time also used at night with photoflash cartridges, while infrared cameras were used both at night and in bad weather. (U.S. Air Force photo).

In parallel, the years between 1959 and 1970 saw the development of satellite photography from satellite. The US was the first to use space satellites for reconnaissance, soon followed by the Soviets. But just before that, a launch test of the thirteenth V-2 missile confiscated to Germany contained a motion picture camera, protected by the landing crash, delivered the first picture from 100 kilometers up, followed by a thousand of them between 1946 and 1950 reaching 160 km.

The launch of Sputnik satellite in 1957 created a crucial precedent in international law, because for the first time a camera platform an aircraft was able to overfly the theoretical national sovereignty airspace above all other countries, including US. President Dwight David Eisenhower took official advantage of this situation and approved the CIA's Corona Project (1959-1972) in February 1958, which laid the foundation for satellite imagery by taking photographs of, among other areas, China and the Soviet Union.[36] In addition, the US created in 1961 the National Reconnaissance Office (NRO), whose existence remained secret until 1992. It is interesting to underline that the use of reciprocal surveillance by space satellites was never a matter of legal dispute over the Cold War (then under the euphemisms of "National Technical Means" or "Overhead Collection") and it is still accepted today.

The first four versions of the Corona were designated RX-1 to KH-4 (KH denoted Keyhole); KH-4 went through three versions. The KH-1's camera (code-named Discoverer) had a nominal ground resolution of 12m. In 1963 the KH-2 and KH-3 reached resolutions of 3 m. The KH-4 mission launched in 1962, took a major breakthrough in technology by using the Mural camera to deliver stereoscopic images. In 1967, the KH-4B's J-3 camera had entered service with a resolution of 1.5m. This final version of Corona continued to fly over until 1972. Despite many technical failures, a total of 145 Corona missions produced over 800,000 images. In order to obtain a good resolution, the satellite orbit was lowered from 160 to 120 kilometers, but the drag from the higher atmosphere was quickly shortening the time to remain in space. Nevertheless, each one-day mission collected ground images as much as 24 U-2 missions. Today, declassified images of the Middle East and Central Asia are used for archaeological research. It is curious to note that the exposed films returned to the Earth in capsules, which military C-119 aircraft recovered in mid-air over the Pacific Ocean.

36 Curtis PEEBLES, *The Corona Project: America's First Spy Satellites*, Annapolis, Maryland, Naval Institute Press, 1997.

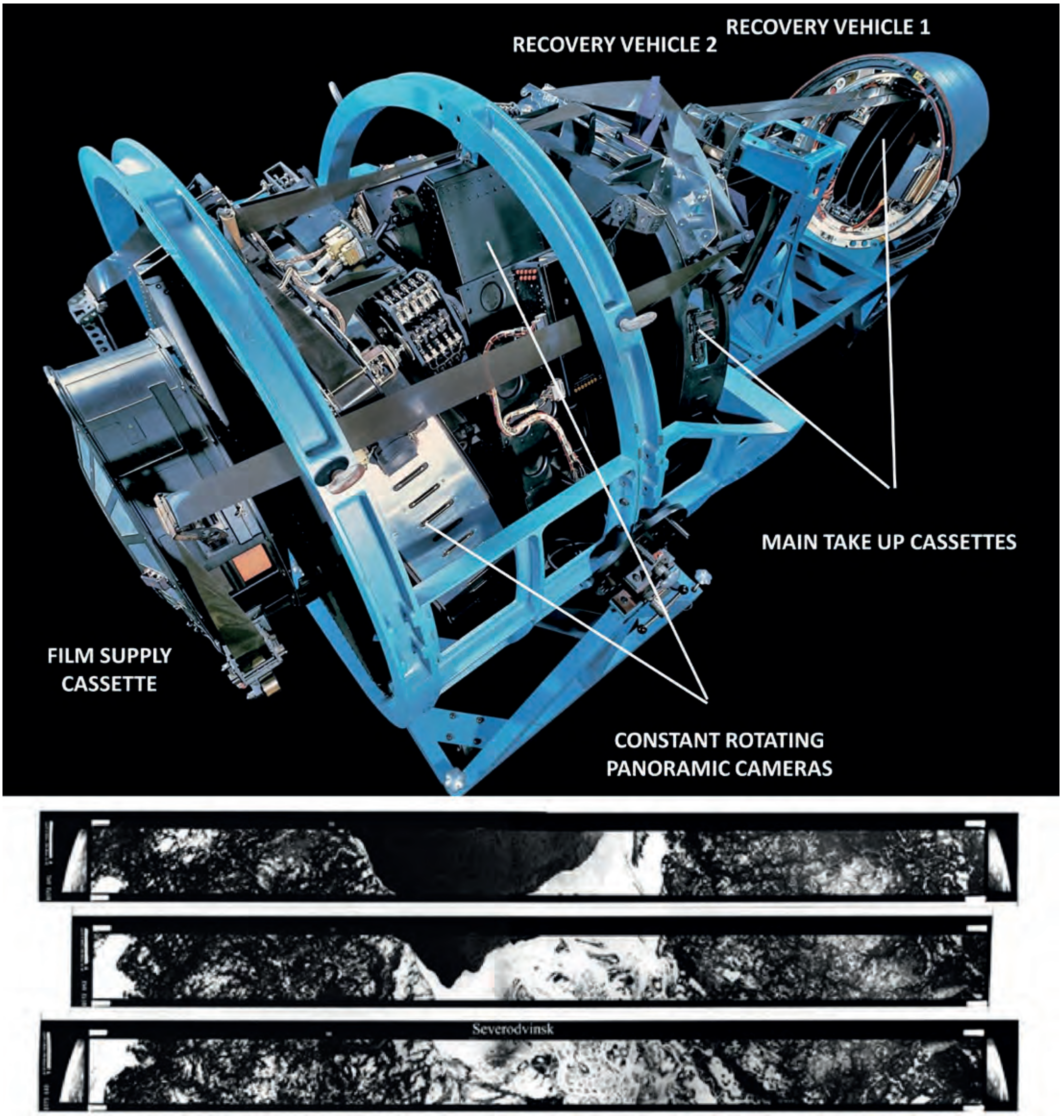


Fig. 19 The KH-4B was the last and most advanced camera system used in Corona Project. Two optical lenses in black barrel-shaped housings; two film supply canisters at aft end; camera has cylindrical shape with film return bucket at front end. Film return capsules containing the exposed film separated from the spacecraft in orbit, re-entered the atmosphere, and were recovered in mid-air. Image strips below: when the satellite's main camera shot a picture of the ground, two small cameras took an image of the Earth's horizon at the same time on the same piece of film. The horizon cameras helped to know the position of the spacecraft relative to the Earth and verify the geographical area covered in the photo (see the ends of the film strips).

The last satellite using photographic technology was the KH-9 Hexagon, which had an elliptical orbit (160 km at perigee and 275 at apogee) designed to occur around the regions of most intelligence interest (at that time URRS and China). Between March 1973 and October 1980, twelve KH-9 missions were flown. It is interesting to note that satellite was equipped with stereoscopic cameras, which allowed the mapping of vast areas, as well as the creation of terrain elevation data.

On the Soviet Union side, it must be mentioned the Zenit series of military photoreconnaissance satellites launched between 1961 and 1994, whose public name was Kosmos in order to hide their scope. Zenit satellite was similar to a Vostok spacecraft, with return and service modules, the last one consisting into a spherical re-entry capsule of 2.3 meters. This capsule contained the camera system, its film, recovery beacons, parachutes and a destruct charge. The mission duration was 13-15 days.[37] Differently from the American Corona, the return capsule carried both the film and the cameras, thus simplifying the design and engineering of the camera system and allowing reuse of cameras. The first operational satellite was Zenit 2 launched in 1961, which had four cameras of 1000 mm focal length and one of 200 mm in order to give a context to the high-resolution pictures. Each camera from Krasnogorsk Optical-Mechanical Factory had 1500 frames, each holding an image covering a square of 60x60 km, while ground resolution was 10 m or probably more.

The Zenit 4 (1963) was intended for high-resolution photography and carried one camera of 3000 mm focal length as well as a 200 mm camera, reaching probably 1–2 meters ground resolution. While the Zenit 4 MK and MKM (1970) were specifically designed to fly in lower orbits to improve image resolution, the Zenit 4 MT (1971) was a special version intended for mapping photogrammetry and carried an SA-106 topographic camera, a laser altimeter and Doppler apparatus, the latter two to be able to determine its own exact position.

The Zenit 6U was launched in 1976 and was engineered for both low-altitude, high-resolution missions and higher-altitude, general observation missions. The Zenit 8, launched in 1984, was the last of the series and was designed for military mapping photogrammetry (possibly in relation with the difficult soviet Afghani-

37 Peter GORIN, « Zenit – The First Soviet Photo-Reconnaissance Satellite », *Journal of the British Interplanetary Society* 50 (1997), pp. 441–448.

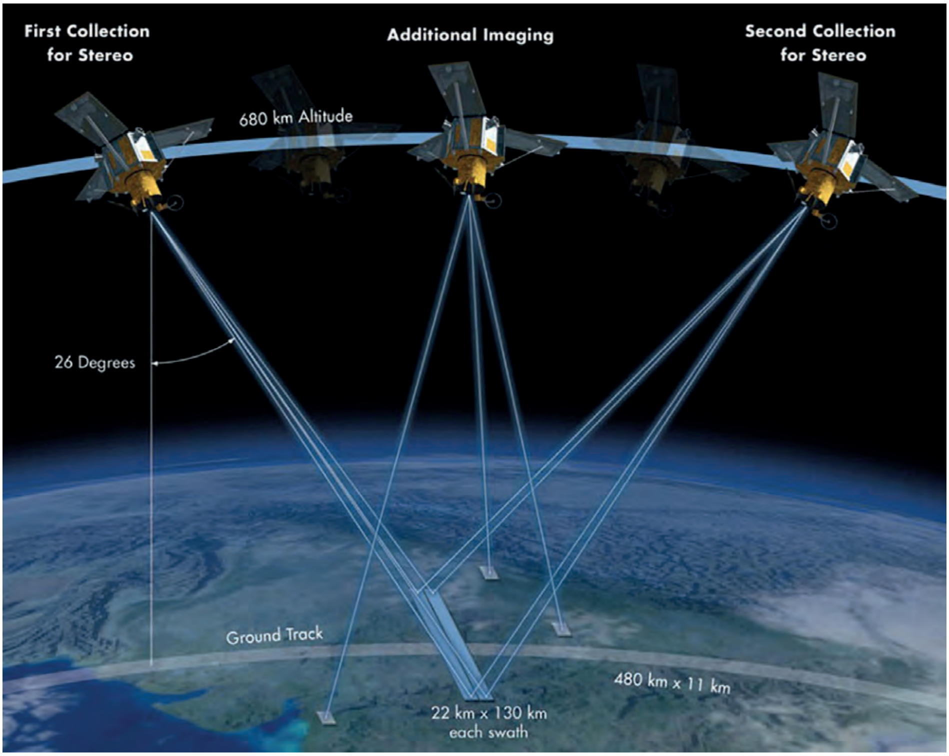


Fig. 20 For satellite imaging, it is better a low Earth orbit (acronym LEO) between 300 and 1,600 km above Earth surface. Many sensors are also able to perform in-line stereo collection. (https://eijournal.com/print/articles/buying-optical-satellite-imagery).

stan campaign): being heavier, it used a Soyuz launch vehicle instead of the previous Vostok module. It has to be noted that soviet reconnaissance remote sensing satellites maintained analogic photographic technology till the end.

There are different altitudes and orbits that a satellite can be put into, each with advantages and disadvantages for intelligence purposes. For imaging, it is better a low Earth orbit (acronym LEO) between 300 and 1,600 km above Earth surface. In this case, it is possible to observe a ground target for a short period (about 8 minutes). The medium Earth orbit (acronym MEO) at about 20,000 km allows surveilling a given area for a little longer, but image quality will be lower. The orbit at 40,000 km, which takes eastwards along the equator, takes the same time of the Earth's rotation (24 h) and is called Geosynchronous Equatorial Orbit (GEO) keeps the satellite over the same point of Earth all times and allows continuous surveillance, despite with a low resolution imaging. Furthermore, the inclination (angle of the orbit measured from the equatorial plane) determines what areas of the Earth can be observed.

Some low Earth orbit satellites use the polar orbit, which with its 90 degrees inclination allows a fixed north-south movement path across the poles while earth is rotating underneath and therefore provides access to the entire globe, provided that every point of the Earth is visible at one time or another. Imaging satellites often use the so-called sun-synchronous orbit, which has an inclination of 98 degrees and allows the satellite passing over any given point on the Earth at about the same time each day.

Across their first decade of service, the main limitation of photographic satellites was the long time between the shooting of the photographs and the printed images being available to Intel analysts. At the beginning of 1970s, new digital electro-optical sensors were developed. The first digital imaging satellite able to detect also multispectral bands was the Landsat which was launched in 1972, but due to its still limited resolution on ground (60 m) it was still not suitable for intelligence purposes. In December 1976 the KH-11 reconnaissance satellite was launched, which thanks to its electro-optical sensors was able to transmit its images through a relay satellite.

During the Cold War the US had a quasi-monopoly on reconnaissance satellites, but by 1980s the growing worldwide concurrency of satellite industry convinced the US Government about the opportunity to try to foster its own. This led to the approving of the 1984 Land Remote Sensing Commercialization Act, which allowed the development of a commercial satellite industry. In 1985 the governmental National Oceanic and Atmospheric Administration (NOAA) transferred the Landsat Program to the Earth Observation Satellite Company (EOSAT), but the bid to commercialize Landsat data finally failed. In 1992, through a new Land Remote Sensing Commercialization Act, the US Government decided to support its own companies (EarthWatch, Space Imaging and Orbimage) with purchasing contracts for its mapping agencies, but again with limited success. In the meantime, in February 1986 the French launched the remote sensing satellite SPOT (Systeme Pour l'Observation de la Terre). This platform provided higher resolution images with a shorter revisit time at lower prices and both for military and civilian use. The end of 1990s witnessed the growth of international and commercial satellite imaging with Ikonos (1999), QuickBird and OrbView (2003) and others with increasing resolution.

In 2019, there are around 700 Earth observation satellites in orbit, most of them are operating in LEO and are dual-use. Many sensors are also able to perform in-line stereo collection in order to allow production of elevation data as Digital Elevation Model (DEM) if including all objects (plants, buildings,…) of earth's surface or Digital Terrain Model (DTM) if representing the bare ground surface without any object. One of the most recent is the Chinese Gaofen-11, launched on 31 July 2018. Following the paths of the old Corona, it uses an elliptical near-polar orbit with and apogge of 690 km and a perigee of 250 km, which gives the best ground image resolution. However, both early photographs and recent digital images taken from space are affected by the cloud cover problem. In any case, it remains the fact that satellites are limited to predictable and non-modifiable orbits and transit times.

Since the 1980s, the development of Synthetic Aperture Radar (SAR) imaging has made it possible to survey areas of interest at night and through the clouds. In the 1990s this technology was also applied to planes like the U2 itself and the Joint STARS (modified Boeing 707) in order to obtain radar imagery from ranges around 250 km. In addition, since 1980 SAR was also installed into a new generation of tethered aerostats called Tethered Aerostat Radar System (TARS) which, together with optical and signal sensors, were intended to check illegal traffics including those on low flying aircrafts. TARS were also used in Iraq in 2004 and Afghanistan in 2007. In addition to electro-optical or radar images, the new military aerial photography uses Unmanned Aerial Vehicles (UAVs) to obtain updates on the area of operation.

During and after WWII, drones were used as gun targets for artillery and airplanes, but the first reconnaissance photographic drone entered in service in Vietnam and China in 1964 based on the existing jet-powered Teledyne Ryan Firebee, named Model 147 and flew until 1975. As happened for satellites, the problem of delivering photographic results were solved in the 1980s, when mounted video cameras could stream video directly to a ground site allowing not only reconnaissance, but also surveillance for an extended time. The first generation of modern UAV was the Israeli Tadiran Mastiff in the Israeli-Lebanon War, which still had the limit of being in line of sight of its ground station. Following UAVs were able to stream and receive commands through a communication satellite. While today most UAVs send oblique view motion video in the visible or near infrared spectrum[38], there are UAVs that perform systematic vertical footage of the terrain, such as the Buckeye system developed by the US Military Engineers.

The Buckeye provides high-resolution, high-precision, unclassified imagery for intelligence, surveillance, reconnaissance and urban mapping. The Buckeye system consists of a real color electro-optical digital camera, assisted by a Lidar (Light Detection and Ranging), sensor capable of measuring the elevation of the ground, in order to correct the geometry of the image. The strip of land recorded is about 500 m wide in the typical case in which the fixed-wing flight platform (usually a drone) flies at 3000 m of altitude. In this case the resolution on the ground is 10 cm, while it can go down to 3 cm if the platform flies at a height of 250 m. In November 2004, the Buckeye was deployed to Kirkuk in Iraq to be able to identify suspicious changes in areas that led to the identification of IEDs, but also to be able to map inhabited areas. In 2011 (the year the system was withdrawn) 85,000 km^2 had been covered, that is 11% of the Iraqi territory. The Buckeye was also deployed in Bagram, Kandahar and Shindad in Afghanistan, with coverage that at the end of 2013, when the system was withdrawn, reached 160,000 km^2. It is a well-known fact that since their appearance military aerial photographic and imagery archives constitute a valuable – and sometimes crucial – source of information for urban planners in the short term, but overall for historians and archaeologists in the long term.

Starting from the first balloon photographs in Rome through the battlefields and built-up areas of First and Second World War and the vast terrain views of the Cold War, military aerial imagery it has been used for to seek for ancient sites or to reconstruct old landscapes. But it must be remembered that military imagery coverage always followed a military logic. Therefore, it is normal that the areas of major intelligence interest were mostly photographed, even in repeated times in a short time, while some other areas were often neglected. As an example, in 2015 archival images of the Buckeye have been made available to Afghan urban planning authorities and archaeologists working on the positioning and study of the country's more than 2,000 archaeological and monumental sites.[39] Thanks to

38 Vladimír KOVAŘÍK, *Imagery Intelligence (IMINT)*, University of Defence, Brno 2011.

39 Elena LEONI, « Geospatial Accuracy Matters! A preliminary study about the impact on CP in Afghanistan », paper presented at Penn Cultural Heritage Conference, 2017.

Fig. 21 The US Buckeye Unmanned Air Vehicle is able to take digital imagery on the ground at 10 cm resolution. In the larger image, a view of the Indo-Parthian settlement of Spirwan Ghar in Qandar Province, Afghanistan, which was obliterated by a military infrastructure. (From Elena LEONI, « Geospatial Accuracy Matters! A preliminary study about the impact on CP in Afghanistan », paper presented at Penn Cultural Heritage Conference, 2017)

these images, many sites just mentioned in the literature have been identified[40], some even occupied by military installations. These include the Indo-Parthian settlement of Spirwan Ghar in the Qandahar area and the ancient city of Faizabad north-east of Kabul. However, it should be noted that Buckeye entirely covered, even with repeated passages, only the main areas of threat, which were normally found in correspondence with flat or built-up areas. As a result, most of the moun-

40 Warwick BALL, *Archaeological Gazetteer of Afghanistan*, Research publication on Civilization, Synthesis n. 8, Paris, 1982.

tainous areas, which make up a large part of Afghanistan, remained uncovered.

This last consideration could be extended to all military imaging datasets ever produced: with the exception of commercial dual-use satellites, it is a fact that all priority areas for an aerial imaging survey are always determined by the adversary threat. There is no exception to oblique image and motion video coverage by modern military UAVs.

Military aerial imaging through its history has given a huge contribution to many civilian applications – mapping above all – and despite nowadays its importance has somehow decreased, it still can contribute to the future public knowledge of otherwise invisible areas, like for example the ones that are currently hidden through security-commercial agreements or the ones that are under a status of crisis or conflict.

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