



Investigation of Unexploded Aircraft Ammunition from WW2 in Connection with Construction Proceedings

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<http://doi.org/10.29227/IM-2022-01-05>

Submission date: 12-02-2022 | Review date: 29-03-2022

Abstract

In the period 1939–1946, the territory of the Czech Republic was mapped for the purpose of renewing topographic maps of the territory of the Third Reich, and aerial reconnaissance (AR) of the CR territory was also carried out by the Allies. The AR was conducted in two directions. The first was to search for enemy targets, and the second was to verify the results of bombing these targets. Allied data indicated that up to 20% of the bombs did not explode. This unexploded aerial ammunition is to this day a threat to construction in the outskirts of towns and cities. This paper discusses the procedures for processing archival aerial photographs of bombed areas in the Czech Republic and the identification of unexploded ammunition on these images.

Keywords: aircraft, ammunition, AR, misfire

1. Introduction

After the release of the contents of the national archive of aerial photographs at the Military Geographic and Hydrometeorological Office (formerly the Military Topographic Institute Dobruška), the problem of the use and processing of historical images in the Czech Republic was and is being dealt with by a number of private researchers, geodetic companies, law firms, and research institutes (Research Institute for Soil and Water Conservation (VÚMOP v.v.i.), Research Institute of Geodesy, Topography and Cartography (VÚGTK v.v.i.), and others). In the past, a historical orthophoto map was prepared for the Ministry of the Environment (its organisation CENIA) from approximately 21 000 images taken between 1952 and 1957. Some of the authors of this paper participated in the creation of this historical orthophoto. To this day, this orthophoto has been the largest comprehensive body of work made from archival aerial photographs in the entire area of the Czech Republic. At present, the exact procedures of processing archival aerial photographs employing digital aerial photogrammetry are mainly dealt with in the Czech Republic by the company PRIMIS, which, within its internal development, is looking for the optimisation of processing procedures of archival aerial photographs within the framework of applied research. The company is dedicated to processing images from the Second World War period and works closely with the main wartime image processor in Europe, Luftbilddatenbank Dr. Carls GmbH, including jointly written scientific publications such as [1]. The aim of the project entitled Locating Unexploded Aerial Munitions of World War II (funded under the security research of the Ministry of Interior – code VI3VS/778) is primarily to compile the methodology for the accurate location of unexploded aerial ammunition (individual bombs) from archival aerial photographs taken by the RAF and US AAF and possibly the Luftwaffe using the exact procedures of modern digital photogrammetry. The

expected accuracy of the location of unexploded bombs is 2.5 metres (RMSE). Thus, in general, the result will be an increase in the safety of citizens and technical infrastructure by deploying the Institute of Bomb Survey in locations where unexploded aerial ammunition is likely to be present. This survey constitutes a licensed trade that can only be carried out by qualified persons according to the Trade Licensing Act. However, with few exceptions, this procedure is not used or is used only at the request of the builder or investor. However, building authorities, in their role as promoters of spatial analysis documents, which could order the survey to be carried out, do not usually have the qualified experts to carry out these activities. Unfortunately, even the new wording of the Building Act does not have a precise instrument requiring the investor to carry out a mandatory pyrotechnical survey or defining the places where it is indispensable to carry out such a survey. It is then common for unexploded ammunition to be found only in the course of earthworks, usually when the working attachment of construction machinery comes into physical contact with such ammunition. Subsequently, the ammunition could be initiated, and the explosion could have tragic consequences.

2. Current status of unexploded ammunition survey

At present, there is no comprehensive database of information on pyrotechnic loads in the Czech Republic that would accurately define (with known accuracy of localisation of potential unexploded ammunition) possible sites of finds. Records of air raids, bomb craters and potential unexploded ammunition areas can thus be found in various archives and historical publications dealing with air battles. However, the data given in these sources usually do not provide a precise (at least at the level of RMSE = 5 m) identification of the location to which the data refers. Hence, the data are traceable, interesting from a historical perspective, but practically unus-



Fig. 1. Historical drawing of craters in the cadastral map of the eastern part of Pardubice
Rys. 1. Historyczny rysunek kraterów na mapie katastralnej wschodniej części Pardubic

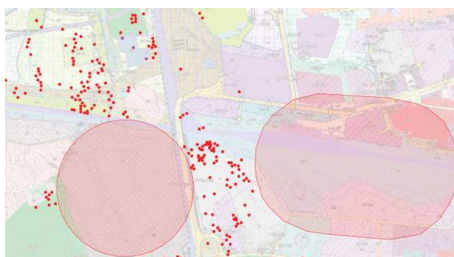


Fig. 2. Transfer of data from archive documents to the current ground plan of the station area and the Paramo plant
Rys. 2. Przeniesienie danych z dokumentów archiwalnych do aktualnego planu terenu stacji i zakładu Paramo

able to identify areas with possible unexploded ammunition. However, other data that can be processed to identify potential unexploded aerial ammunition sites are records kept, both in the form of plotting on maps and in the form of verbal descriptions by the personnel of the sanitation crews and official authorities of the Third Reich, such as the record in Fig. 1 and Fig. 2. It shows an example of a bombing record integrated from various sources into the current mapping. Data entry and data addition to contemporary map bases for exploded bombs can also be done by automated searches for exploded ammunition from archival aerial photographs. These searches have been done, for example, by authors at Leibniz University of Hannover [2] and [3] and by authors at J. E. Purkyně University in Ústí nad Labem [4] and [5]. However, the collective of authors dealing with the aforementioned security research project only deals with the identification of unexploded ammunition. The craters caused by exploded ammunition are identified in the framework of the task only for the purpose of comparing the number of dropped bombs with the number of bombs in the bomb racks of a given bomber type. The authors are not aware of any technology for locating unexploded aerial ammunition based on an automated procedure, either on CNN or by assessing the characteristics of lidar clouds or clouds obtained by correlating archival aerial imagery and creating a digital terrain model current as of the date of the imagery, i.e., after bombing inspection by aerial imagery. Another part of the data to be processed is the modern records of the Bomb Disposal Squad of the Police of the Czech Republic (BDSPCR), analysed in detail in [6]. In this work, the author processed all BDSPCR records from the actions carried out and recorded in Excel spreadsheets by the Bomb Squad from 2011 to 2017. These data include the obligation to record the location of the discovery or action in the WGS84 system, but nowhere is it noted with what accuracy these data are report-

ed. The resulting table integrating presumably all recorded data was not made available by the DP developer. The work related to the research project entitled “Interactive map of pyrotechnic loads and risk” (No. VI20152018038) is not publicly available except for the article [7].

2.1. Existing database of *Luftbilddatenbank Dr. Carls GmbH*

Luftbilddatenbank Dr. Carls GmbH has the exclusive representation for the scanning and exploitation of aerial photographs from the Second World War from the Canadian National Air Photo Library Ottawa, the American National Archives and Records Administration Washington, The National Collection of Aerial Photography, the Bundeswehr Archives, and a number of smaller archival institutions. The company is thus providing the supply of aerial photographs of the Second World War within Europe after the release of the war archives. The archive is organised as a database of scanned images and is subdivided by the territory of European countries. Successively acquired archival images and materials are systematically sorted and filed, including bomber crew reports and bombing success evaluations, crew lists, and other historically interesting information. However, aerial photographs are most important for identifying unexploded ammunition. The aerial photographs are organised in a database, and Fig. 3 shows the recorded basic data.

Each physical object number (analogue image form) is assigned an ID number; these numbers are usually identical. The next number identifies a block of images, followed by the BILDNR, which is the image number in a given imaging mission; the approximate scale figure is the next column in the database. Important data are the approximate (+/- 50 m) coordinates of the image centre in the WGS84 coordinate system in Mercator’s transverse cylindrical conformal view. From the approximate scale and the image centre, the image radi-

	A	B	C	D	E	F	H	I	J	K	L
1	OBJECTID	ID	SORTIE_ID	BILDNR	DATUM	MASSTAB	X	Y	RADIUS_BIL	Shape_Leng	Shape_Area
2189	2188	2188	25302	67	14.5.1943	14000	4870348	5477361	1540	9676	7450601
2190	2189	2189	25302	68	14.5.1943	14000	4869746	5477056	1540	9676	7450601
2191	2190	2190	25302	69	14.5.1943	14000	4869139	5476762	1540	9676	7450601
2192	2191	2191	25302	70	14.5.1943	14000	4868540	5476452	1540	9676	7450601
2193	2192	2192	25302	71	14.5.1943	14000	4867964	5476100	1540	9676	7450601
2194	2193	2193	25302	72	14.5.1943	14000	4867387	5475750	1540	9676	7450601
2195	2194	2194	25302	73	14.5.1943	14000	4866808	5475404	1540	9676	7450601
2196	2195	2195	25302	74	14.5.1943	14000	4866225	5475066	1540	9676	7450601
2197	2196	2196	25302	75	14.5.1943	14000	4865619	5474768	1540	9676	7450601
2198	2197	2197	25302	76	14.5.1943	14000	4865013	5474470	1540	9676	7450601
2199	2198	2198	25302	77	14.5.1943	14000	4800794	5546057	1540	9676	7450601
2200	2199	2199	25302	78	14.5.1943	14000	4800236	5546567	1540	9676	7450601
2201	2200	2200	25302	79	14.5.1943	14000	4799791	5547145	1540	9676	7450601
2202	2201	2201	25302	80	14.5.1943	14000	4787378	5528974	1540	9676	7450601
2203	2202	2202	25302	81	14.5.1943	14000	4788117	5528515	1540	9676	7450601
2204	2203	2203	25302	82	14.5.1943	14000	4788641	5529146	1540	9676	7450601
2205	2204	2204	25302	83	14.5.1943	14000	4772329	5539430	1540	9676	7450601
2206	2205	2205	25302	84	14.5.1943	14000	4772477	5540163	1540	9676	7450601
2207	2206	2206	25302	85	14.5.1943	14000	4772624	5540896	1540	9676	7450601
2208	2207	2207	25302	86	14.5.1943	14000	4772772	5541629	1540	9676	7450601
2209	2208	2208	25302	87	14.5.1943	14000	4772919	5542363	1540	9676	7450601
2210	2209	2209	25302	88	14.5.1943	14000	4773067	5543096	1540	9676	7450601
2211	2210	2210	25302	89	14.5.1943	14000	4773214	5543829	1540	9676	7450601

Fig. 3. Sample of information from the database of aerial photographs from the Czech Republic
Rys. 3. Przykład informacji z bazy zdjęć lotniczych z Czech

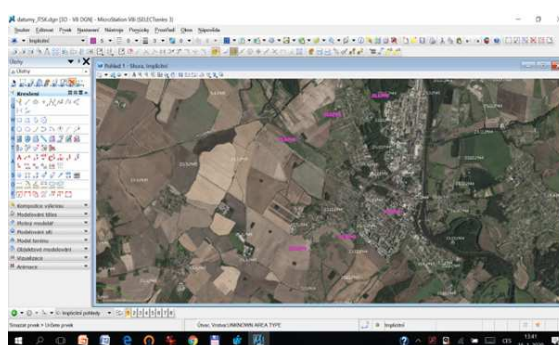


Fig. 4. The date of photographing (in purple) is the centre of the picture - area Neratovice 23.3.1945
Rys. 4. Data wykonania zdjęcia (na fioletowo) to środek zdjęcia - okolica Neratovice 23.3.1945

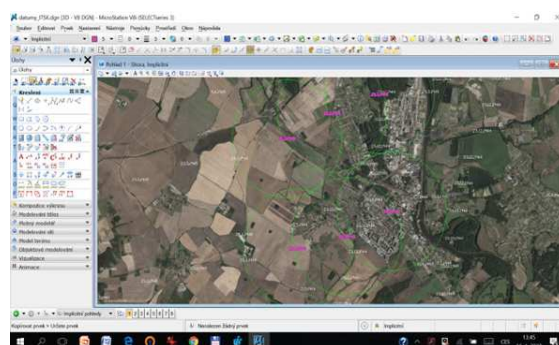


Fig. 5. Images with the marked circular circumference
Rys. 5. Obrazy z zaznaczonym kołowym obwodem

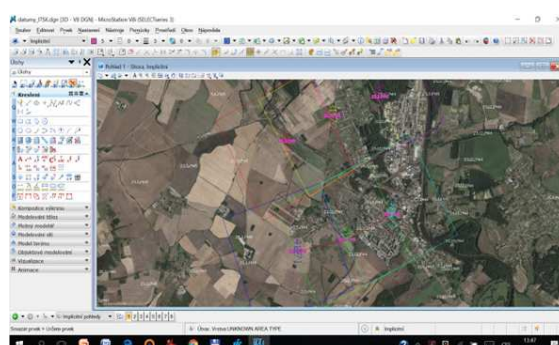


Fig. 6. Images redrawn to approximate real position according to the direction of the image base
Rys. 6. Obrazy przerysowane do przybliżonej rzeczywistej pozycji zgodnie z kierunkiem podstawy obrazu



Fig. 7. Identification of terrain objects in the historical and contemporary orthophoto
Rys. 7. Identyfikacja obiektów terenowych w ortofotomapy historycznej i współczesnej

us (RADIUS_BIL) is calculated according to the camera type and its focal length, which is then transferred to a graphical CAD drawing, for example, to a dgn file. The perimeter and area of this circle is then tabulated. This table is linked via the image ID to other crew records of their success rates etc.

2.2. Analysis of the process of selecting suitable aerial archive images

After a thorough analysis of the content of the database supplied by Luftbilddatenbank Dr. Carls GmbH, the data from the aerial image archive database was converted into three datasets of dgn drawings at Primis spol. s r.o. to facilitate the work with the information and ensure ease of reference. The first drawing consists of a graphical set with defined centres and radii of images from the whole area of the Czech Republic. The second drawing contains information about the day of imaging for each image. The date is placed at the approximate coordinates of the image centre. The third dataset consists of 257 dgn files, where each file contains all images that were taken on a given day. The file name encoded the date when the image was taken. The datasets, or individual drawings, were transformed from the WGS system to the national system of the Czech Republic to the SJTSK coordinate system so that the WMS services of the administrators of national and local geoportals could be used (for example, by calling the orthophoto service of the Czech Republic©, base maps, cadastral maps and other mapping documents from the State Administration of Land Surveying and Cadastre) in the search and selection of sets of images suitable for the identification of unexploded ammunition. The procedure for selecting suitable aerial archive images was specified based on the prepared datasets. The analysis of this procedure was carried out by several practical tests of the following procedure:

1. After receiving a request for the creation of the pyrotechnical survey documents, a new empty dgn file is created in the SJTSK coordinate system
2. The file is accompanied by a file with imaging data and a file with the approximate circular perimeter of the image as a reference drawing, or if the requirement is to study the raid from a specific day, a dgn file from that day can be attached as a reference, see Fig. 4.
3. For easier reference, it is also advisable to attach raster orthophoto files to the file, for example, as a WMS service of the State Administration of Land Surveying and Cadastre see Fig. 5.

4. The contents of the reference datasets are then visually checked, and the selected graphical information is copied into the open empty file.

5. According to the image centres and the lines connecting these centres, the circular image perimeter defined in the database is replaced by the actual square image perimeter of Fig. 6.

At present, approximately 112,000 aerial war photographs are documented in these drawings. From this data, among other things, the Allied war effort can be seen. If we compare that in the national archive of aerial photographs at the Military Geographic and Hydrometeorological Office in Dobruška, there are approximately 1 million images in 80 years from 1934 to the present (if we do not count the war period itself), the annual average of images taken is 12,500. It is very likely that around 130,000 wartime images were taken from the territory of the Czech Republic, which means that almost twice as many images were taken annually during the war. The images, however, are not distributed over the territory at an average density but are concentrated on strategic targets in the area of the Czech Republic, such as refineries, railway stations, airfields, or arms factories. This implies that in some areas of interest, one location of the earth's surface is covered by 30 to 40 images (mainly the Most area).

2.3. Procedure for selecting starting points for aerotriangulation

2.3.1. Procedure for deriving starting points by time series

The landscape changes dynamically with time due to human intervention. Evidence of this fact is, for example, geoportals, which allow observing on one monitor at the same time orthophotos from the present time and orthophotos from 1953, the production of which involved most of the members of the design team of another participant from the company Primis spol. s r.o. Historical orthophotos from 1953 are part of most geoportals of regional offices, and the data source is CENIA, the Czech Environmental Information Agency. One of the methods of obtaining the starting points is to interpret the points in a backward time series. The search for terrain objects interpretable on a historical image and, at the same time, identifiable and interpretable on a contemporary orthophoto is shown in Fig. 7.

The challenge of identifying these points is the content of the image itself, see Fig. 8.



Fig. 8. Sample aerial photo after the bombing of the production plant
Rys. 8. Przykładowe zdjęcie lotnicze po zbombardowaniu zakładu produkcyjnego



Fig. 9. Detail of a part of the image of the bombed-out production plant
Rys. 9. Fragment fragmentu obrazu zbombardowanego zakładu produkcyjnego

Selecting identical points (in the new background and in the historical image) to serve as starting points for AT or for image transformation is not easy in a bombed city; see detail in Fig. 9.

The selected points must have good natural signalling in both backgrounds. If we choose a corner of a building as a starting point, it is necessary to remember that the redrawing is done on the terrain in the current orthophoto. Therefore, it is necessary to identify and correctly interpret the starting point by the position of the intersection of the building and the terrain. Such a procedure will yield accurate results when establishing the basis for locating unexploded aerial ammunition. However, in some cases, the coordinates read from the orthophoto map can be replaced by the interpretation of points from the CR real estate cadastre if the viewer is used with the point quality information turned on (Fig.10).

Familiar interpretive features existing in the images and in reality will help us in locating the points.

2.4. Creating orthophotos from several sets of images of the same area as the way to find unexploded aerial munitions

After the aerotriangulation is completed and the digital terrain model - DTM is created (in case of successful calculation by standard aerotriangulation procedures), orthophoto maps from several time periods (raids) are created on the site. Based on the determined values of the parameters of the internal orientation of the images (or in the absence of fiducial marks on the wartime aerial photographs), based on the approximate internal orientation of the images, a procedure for selecting the starting points for the calculation of aerial aerotriangulation (AT) by correlation procedures is constructed and optimised, or in the case of failure of this procedure, these points are used to perform image transformations. If it is not possible to determine the interior orientation parameters

and deploy the standard procedures leading to the creation of orthophoto aerotriangulation procedures, alternative procedures of image redrawing and orthophoto mosaic creation using image transformations have been studied. However, for both aerotriangulation and image transformation methods, identical principles apply for the selection of starting points for these production procedures leading to the creation of a measurement basis by reprocessing aerial wartime imagery.

2.5. Standard orthophoto creation procedures

After determining the elements of the external orientations described in the previous paragraph, it is advisable to perform radiometric corrections on individual images for orthorectification of wartime images, i.e. correction of image defects caused by light aberrations of the aerial camera lens, terrain reflections, illumination of the terrain by the Sun at different angles, and imaging at different times of the year and with different flight parameters.

The next sub-stage of processing is orthorectification. To orthogonalise the images to the real terrain, a digital terrain model (DTM) is required. In the photogrammetric software (ImageStation-OrthoPro by Hexagon, INPHO by Trimble), the images are orthorectified after loading the external parameters of the images and the DTM. After the orthorectification, a visual inspection of the redrawn images is carried out to check the geometric quality based on the check points and to mark the faulty areas as well as the areas with image deformations. The digital terrain model from the selected pair of wartime aerial images is corrected stereoscopically at these marked locations, but only if it differs significantly in height from the current situation. For example, in the area of Pardubice, there have generally been only insignificant changes in terrain heights since the wartime, except the transport constructions of the last few decades. These possible repairs of the



Fig. 10. Sample from the real estate cadastre with quality code points displayed
 Rys. 10. Próbkę z katastru nieruchomości z wyświetlonymi punktami kodowymi jakości

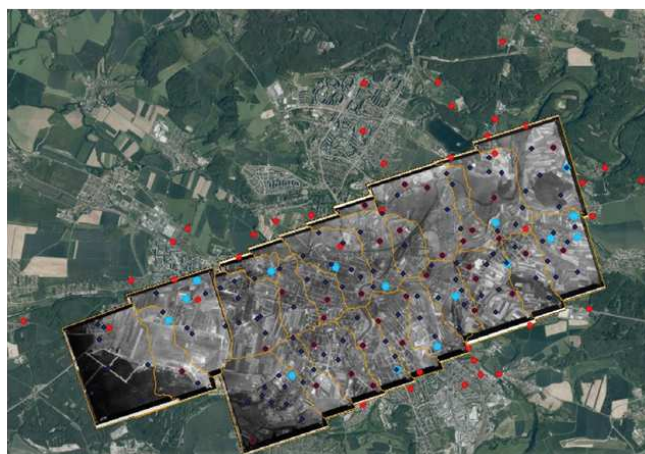


Fig. 11. Schematic of the distribution of points used in the case of mission 60_0572
 Rys. 11. Schemat rozmieszczenia punktów zastosowanych w przypadku misji 60_0572

DTM to the wartime condition are followed by redrawing and checking the orthorectification of the repaired sites. Next, the redrawn (orthorectified) images are combined into a single unit called a mosaic.

The mosaicking software automatically generates the connecting lines, called seamlines. The connecting lines define the part of the image that will be used in the final mosaic. A visual inspection of the automatic seamlines is performed and corrected in places causing any inadequacies. The following rules apply for the creation of the seamlines: all lines must be connected to each other; the shape of the line must be rather simple; lines that are generally chosen lead along natural dividing elements – along roads, boundaries, field furrows; in the inner city, lines are mainly along roads. The resulting mosaic is cut into individual map sheets or can be used as a whole, depending on the size of the area to be processed.

The final visual inspection of the created orthophoto maps focuses on the marked areas around the cut lines with image errors, on the compensation of contrast and brightness between images, on the removal of impurities, on the size of the resulting resolution and on the positional accuracy of the orthophoto maps.

2.6. Procedures for creating an orthophotomosaic

In the Mission 60-0572 test area, an orthophoto mosaic was created in two ways to verify the resulting accuracy of the tested procedures.

The first procedure is an orthophotomosaic created from georeferenced imagery, which in the above procedure fully re-

places the orthorectified imagery that is the direct input to the mosaicking process.

The second procedure was to create a mosaic from the calculated aerotriangulation using a standard procedure

Figure 11 shows a view of the resulting mosaic of mission 60-0572, where the individual input images are taken at a scale of 1:9500. The orange lines are the seamlines that were generated in the mosaicking process from the georeferenced imagery.

Dark blue shows the points that were used as identical points for each image in the georeferencing process by projective transformation. Pale blue marks points that were measured in the field and used to check the accuracy of the resulting mosaic. The red points are the other points measured in the field at the Pilsen site.

3. Conclusion

In order to fulfil the main objective of the project, which is mainly to create a procedure for the interpretation and identification of unexploded ammunition sites for the benefit of the investor or the builder, and to avoid possible serious consequences in the event of accidental initialisation of unexploded aerial ammunition, it is necessary to create orthophoto mosaics of the same area, which must be compiled from images showing the state before and after each bombing.

Since each reconnaissance mission was created under different weather conditions (with different percentages of cloud cover) and on a different scale, it is advantageous to have multiple missions from before and after individual raids. In par-

ticular, in the case of a reconnaissance flight conducted just after an air raid, it is common for the area to be fogged from destroyed targets, which may make it impossible to identify unexploded ammunition in part of the area surveyed. An example of this is the bombing of a selected part of the city of Pilsen, which occurred to varying degrees on 15.4.1945, 17.4.1945, 18.4.1945 and 25.4.1945. The created orthophoto mosaics (and individual images) of adequate accuracy from multiple time series are a suitable and unique basis for the evaluation of unexploded ammunition sites. The first phase

of the evaluation and interpretation of possible unexploded ammunition sites is shown in Figure 12.

Unfortunately, we are not able to determine from the photographs whether, for example, a month or a year after the bomb was dropped and did not explode, the bomb was not dug up and deactivated, because, in the post-war years, there were practically no records kept of this work, from which it would be possible to locate and time the actual digging of the aerial munitions. The aim this year is to excavate, based on our methodology, unexploded aerial ammunition.

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Niewybuchy amunicji do samolotów z II wojny światowej w związku z postępowaniem budowlanym

W latach 1939–1946 dokonano mapowania terytorium Republiki Czeskiej w celu odnowienia map topograficznych terytorium III Rzeszy, a rozpoznanie lotnicze (AR) terytorium CR było prowadzone przez aliantów. AR był prowadzony w dwóch kierunkach. Pierwszym było poszukiwanie celów wroga, a drugim weryfikacja wyników bombardowania tych celów. Dane alianckie wskazywały, że do 20% bomb nie wybuchło. Ta niewybuchowa amunicja lotnicza do dziś stanowi zagrożenie dla budownictwa na obrzeżach miast. W artykule omówiono procedury przetwarzania archiwalnych zdjęć lotniczych obszarów zbombardowanych w Czechach oraz identyfikacji niewybuchów na tych zdjęciach.

Słowa kluczowe: samolot, amunicja, AR, niewybuch