Early aerial photography and contributions to Digital Earth –
The case of the 1921 Halifax air survey mission in Canada

D Werle
Partner / Geoscientist, Ærde Environmental Research, 19 Forward Avenue, Halifax, Nova Scotia, Canada, B3P 1S3
E-mail: dwerle@ca.inter.net

Abstract. This paper presents research into the military and civilian history, technological development, and practical outcomes of aerial photography in Canada immediately after the First World War. The collections of early aerial photography in Canada and elsewhere, as well as the institutional and practical circumstances and arrangements of their creation, represent an important part of remote sensing heritage. It is argued that the digital rendition of the air photos and their representation in mosaic form can make valuable contributions to Digital Earth historic inquiries and mapping exercises today. An episode of one of the first urban surveys, carried out over Halifax, Nova Scotia, in 1921, is highlighted and an air photo mosaic and interpretation key is presented. Using the almost one hundred year old air photos and a digitally re-assembled mosaic of a substantial portion of that collection as a guide, a variety of features unique to the post-war urban landscape of the Halifax peninsula are analysed, illustrated, and compared with records of past and current land use. The pan-chromatic air photo ensemble at a nominal scale of 1:5,000 is placed into the historical context with contemporary thematic maps, recent air photos, and modern satellite imagery. Further research opportunities and applications concerning early Canadian aerial photography are outlined.

1. Introduction
A century ago, the First World War precipitated enormous changes and cataclysmic events overseas and at home in Canada. They had profound military, political, and societal impacts. Some of these changes were rooted in groundbreaking technological and scientific developments. For military reconnaissance in particular, the convergence of aviation and photography attained critical importance, reinforcing strategic decisions and guiding actions on the ground by aerial surveys. After the war, aerial photography spurred innovative applications in the civilian domain in Canada and elsewhere, with lasting influence on the surveying sciences and on how we view landscapes, analyze resources, and monitor the environment [1].

Promoted by the Canada Air Board in 1920 and supported by the Surveyor General, the idea of using air photos on an experimental basis for map making literally took flight at several locations across the country [2]. War-weary Halifax on the eastern seaboard emerged as one of the earliest focal points of this historic episode that resulted in a remarkable collection of vertical air photos. These early civilian surveillance missions exemplified not only a significant technological achievement, but they were also a precursor to the collection and analysis of millions of such photos for topographic mapping and resource analysis in Canada during the past century [3, 10].
Figure 1. Location and extent of flight lines of the first air photo survey mission, carried out over the Halifax peninsula in the spring of 1921 at a scale of 1:5,000, displayed against the background of a 1:50,000 scale air photo mosaic dated May, 1979. Sources: NAPL [3], Atlantic Air Surveys Ltd. [15]

Figure 2. Digitally re-assembled air photo mosaic of the 1921 survey mission of Halifax* displayed against the background of high-altitude air photos taken in 1960. Sources: NAPL [3], Werle [10]

* https://www.dropbox.com/s/webjhid5ffx77c/1921%20Halifax%20AP%20mosaic%201-58_D%20WERLE%202015%20copy.pdf?dl=0
The digitization of the vertical aerial photography of the early 1920s presents an opportunity to re-assemble and display the photos of Halifax in mosaic form as a detailed, map-like representation of land cover and urban land use at that time. Moreover, the geo-visualization of this historic set also lends itself for a comparison with and assessment of contemporary early twentieth century maps, older cartographic representations of the city dating back to the eighteenth and nineteenth century, as well as recent air photos and high-resolution satellite imagery. This paper explores the origin and utility of the 1921 aerial photography of Halifax and its digitally reconstituted mosaic as an analytical tool for Digital Earth research. Various examples illustrate the value of this unique and detailed source of historical geospatial information for linking the geographies of Halifax over more than two centuries.

2. The 1921 air survey mission of Halifax

Dating back to 1921, the collection of 61 black and white vertical air photos of Halifax is one of the oldest sets of its kind in Canada, revealing features at a spatial detail that matches that of modern high-resolution Earth observation satellites. The digital assembly of these photos into a map-like mosaic encourages synoptic study of the urban landscape at a pivotal time of the city’s history. It included the completion of major infrastructure projects, the devastating 1917 Explosion in Halifax Harbour, and related reconstruction efforts that concluded in 1921[4].

The 1921 survey mission covers much of the built-up urban area on the Halifax peninsula along five roughly parallel flight lines [5, 15], as shown in figure 1. The year of the survey is clearly indicated on the photographs as “1921”, confirmed by entries on an “Aerial Surveys Index Map” at the National Air Photo Library (NAPL). This map also contains a note that the negative film was destroyed. A set of paper prints has been preserved at NAPL and digital copies have been produced. The actual date of the survey is not known. However, small patches of snow, frozen ponds, and leaf-off tree vegetation suggest that it took place early in the year on a late winter day. The direction of shadows indicates that the photos were taken around the noon hour [6]. The National Air Photo Library records suggest that the original aerial photographs were captured at a scale of 1:5,000 on 7-inch by 9-inch large negative film. They were likely taken with an American Fairchild K-1 camera from an altitude of 3,500 to 4,000 feet. A magazine containing a roll of film for up to 100 frames could be placed above and advanced across the camera’s focal plane aperture for exposure [7].

For this study, the mosaic was re-assembled by digital means against the faint background of two high-altitude air photos taken over Halifax Peninsula in 1960 (Roll A17077, photos No. 6 and 7, see figure 2). The road network depicted on these photos provided a reliable reference for the orientation and alignment of the 1921 photos, with a satisfactory degree of accuracy. While the forward overlap of the individual photos is fairly consistent, there is an obvious lack of sideways overlap between the first and the second and the third and the fourth flight lines. One might suspect strong winds, as indicated by the consistent “crabbing” of individual photos along the flight lines. Another factor accounting for the coverage gaps is the experimental nature of this mission. It was one of the very first urban air surveys in Canada, and planners, pilots, and camera operators were still gathering experience.

Aeroplanes and photographic equipment were presented to Canada by Britain in 1919 as an “Imperial Gift.” The First World War had turned out to be a boom for aerial photography as the front lines were extensively surveyed at frequent intervals for pinpointing artillery fire and for reconnaissance of military matériel deployment and troop movements. Overall, several million prints were produced – and heavily relied upon – by armies on either side of the trenches. With Armistice in 1918, aerial surveillance equipment had become surplus, and dozens of planes and air photo cameras were shipped to six air bases across Canada. One of them was located in Halifax Harbour at Bakers Point near Dartmouth, from where British Felixstowe F3 and American Curtiss HS-2L flying boats, or seaplanes, operated during and after the war [1, 2].

Initially, there was little interest to use air photos for civilian survey missions, as resources were scarce. Some experimental flights were carried out at the request of the Canada Air Board in the early 1920s, including the brief mission over Halifax. More extensive surveys provided coverage of Vancouver in British Columbia, and Ottawa, London, and the Welland Canal area in Ontario.
Statistics of the Canada Air Board reveal that several thousand aerial photographs had been captured during the early 1920s [8]. These numbers seem inconsequential, considering that more than six million air photos were taken across the country in the 90 years hence and have since become part of Canada’s NAPL [3]. The cultural heritage, historical, and scientific value of the early air photos taken over several major urban centres in Canada is increasing over time. While a number of these old photos have been digitized, their long-term preservation as an important early part of the national and local geospatial data infrastructure will require special attention and resources.

3. Analysis of the 1921 air photo mosaic of Halifax

The 1921 air photos of Halifax represent a valuable time capsule of the city’s heritage and a unique source of information for historians, geographers, urban planners, and the public at large (figure 2 and figure 3). Witness the detail of numerous storage sheds and maintenance buildings on the busy Halifax waterfront, with its finger-shaped piers where a multitude of ships were tied up at the time of the survey (Air photos No. 1 to 3). In the South End, the future site of the Saint Mary’s University campus is still undeveloped (No. 45). The campus of Dalhousie University consisted of just a few buildings (No. 47). Several large institutional buildings along University Avenue (No. 35) and the old hospital complex at Camp Hill (No. 37) have since been replaced with even larger ones with similar functions. The area occupied by the Public Gardens and Camp Hill Cemetery (No. 36) remains largely unchanged. The same applies to the street network. The main north-south transportation corridors (e.g. Barrington Street, Agricola Street, Oxford Street, and Robie Street) are intercepted at right angles by the principal feeder streets (e.g. Spring Garden Road, North Street, Quinpool Road, Chebucto Road and Young Street) such that the entire street network forms an oblong grid around the prominent star-shaped Citadel complex (No. 20).

Recent changes and important developments in the urban landscape can be observed at either end of the flight lines. The scars of the devastating 1917 Explosion in Halifax Harbour are still very obvious in the city’s North End, where previously built-up lots and the footprints of destroyed houses dot the slopes of the Richmond area (No. 9 and 10). Equally noticeable are the building patterns of temporary housing schemes erected by the Halifax Relief Commission as part of the extraordinary and exemplary response to the disaster. They can be found on the Common (No. 20 and 21) and on the old exhibition grounds between Almon Street and Young Street (No. 25 and 26). The new and carefully planned Hydrostone district with its boulevards and back alleys (No. 27), as well as the construction of

![Figure 3. Interpretation key for major urban land use types and related features encountered on the 1921 aerial photography of Halifax. Each air photo tile covers an area of 100 by 100 meters.](image-url)
numerous residential homes to the west and east, are examples of the swift and vigorous recovery in the aftermath of the traumatic event in 1917 [9]. Through detailed photo analysis one can easily identify these very recent residential buildings by the hipped and pitched roofs, which appear in marked contrast to the relatively flat and uniform roof tops that characterize the older houses of the Victorian era (No. 23-25). Various stages of subdivision development with a gridded street network and residential housing (No. 48-51) are clearly depicted in the western portion of the peninsula.

The photography also documents significant modifications of the city’s transportation infrastructure during and after the war. Many of them resulted from an influx of federal funds exceeding $30 million. Examples in the North End include the alignment of Campbell Road (the extension of Barrington Street of today), with the new Devonshire Avenue branching off and traversing the steep Richmond slope and street grid (No. 7-10). Hastened by the 1917 Explosion, the severely damaged old rail yard (No. 5 and 6) and the North Street railroad station (No. 7) have already found their replacement in the new South End rail yard and station that were under construction during the war. The recently completed South End rail cut and various bridge crossings are in evidence (No. 31, 44, 53-57). Much of the excavated material was used for the construction of Pier A, signaling the expansion of the Halifax ocean terminals (No. 15).

Much smaller and less obvious are recent improvements to the city’s road network and the introduction of sidewalks in several neighbourhoods. New road pavement and sidewalk installations appear in relatively bright tone on the air photos (No. 19 and 24, No. 46-49). At the time, many citizens may have perceived the advent of paved streets and sidewalks as a tangible improvement in the quality of their everyday life. From today’s vantage point, the observer will likely be reminded of the more dramatic recent changes in the urban landscape. Examples include the enlightened redevelopment of the Halifax waterfront; the demolition of entire city blocks to make room for mixed commercial uses such as Scotia Square and two convention centers; or the Cogswell Interchange for re-routing city traffic (No. 1-4).

While the vertical perspective of the early aerial photography may be an unusual one, it invites comparison and opportunity for change detection with older maps of the same area, as well as contemporary and recent cartographic representations and imagery. The following section explores the forward and backward compatibility of the 1921 air photos, and the geographic information that can be gleaned from the various layers over time.

4. The 1921 aerial photography in the geo-spatial context of other landmark data sets of Halifax

Since the establishment of a British naval base in 1749, the city of Halifax has been mapped at different scales, for various thematic purposes and at various degrees of geometric precision. When viewed and analyzed in sequence, these maps offer insights into the spatial evolution of the urban landscape of Halifax. Table 1 summarizes several outstanding examples that are further illustrated in figures 4, 5 and 6. The historical maps lend themselves for direct comparisons by way of digitally overlay with the 1921 air photo mosaic, which in many respects represents the “old” fabric of the city prior to the onset of urbanization, transformation of entire city blocks through modern traffic infrastructure, and acceleration of residential subdivision development.

In 1777, the mapmaker J.F.W. DesBarres produced and published a detailed map The Harbour of Halifax, at an approximate scale of 1:5,000, revealing the spatial extent of the city and road network at that time. His map also renders in detail the natural terrain and hydrology prior to the transformation of the peninsula into an urban space [11]. A comparison with the 1921 photography clearly shows the conformity and geometric fidelity of the street network in the town core and its extension toward the north and south, including the dockyard of the British Navy with storage and maintenance facilities (figure 4) and the location of major wharfs along the Halifax waterfront. Many of these features have retained their configurations over more than a century; other features, such as the local stream network that was clearly marked on the 1777 map, have been covered in the course of urban expansion by 1921.
Table 1. Examples of geospatial data sets of significance for comparison and change detection with photos and mosaic of the historic 1921 air survey mission of Halifax.

| Source [Ref.]            | Year | Title and Scale                                      | Relevance to 1921 Photomosaic                                      |
|--------------------------|------|------------------------------------------------------|-------------------------------------------------------------------|
| DesBarres, JWF [11]      | 1777 | *Map of Harbour of Halifax*, Scale 1:5,000           | Topography, hydrology; change detection: coastline, houses, roads |
| Hopkins, HW [12]         | 1878 | *City Atlas of Halifax*, Index Map: Scale 1:12,000, Detailed Plates: Scale ~1:1,200 | Change detection: buildings, cadastral info, street layout         |
| Ruger, A [13]            | 1879 | *Panoramic View of Halifax, Nova Scotia* (no scale, pseudo bird’s eye view) | Building location, waterfront development, urban land use         |
| Board of Insurance       | 1918 | *Plan Showing Devastated Areas of Halifax* (post-1917 Explosion), Scale ~1:2,350 | Post-disaster change detection; infrastructure re-development      |
| Underwriters [14]        |      |                                                      |                                                                   |
| Atlantic Air Survey      | 1979 | *Halifax-Dartmouth Area, Air Photo Mosaic*, Scale 1:50,000 (see Figure 1) | Expansion of (sub-) urban and rural land use and land cover       |
| Limited [16]             |      |                                                      |                                                                   |
| High-resolution          | 2000 | Examples: *Google Earth, Bing Maps*, archival data; various scales | Most recent vertical image layers for change detection 1921-present |
| Satellite Imagery        |      |                                                      |                                                                   |

Figure 4. Cartographic, photographic and satellite image representations of the Halifax Dockyard area and adjacent residential neighbourhoods over three centuries, as shown in 1777 by DesBarres [11], in 1921 by the first air survey [3, 10], and in 2015 by Google Earth / DigitalGlobe satellite data.

Four decades before the first air survey of Halifax was accomplished, the American land surveyor H. W. Hopkins furnished a large, folio-size city atlas of Halifax in 1878 [12]. It recorded in great spatial detail the real estate and land ownership of the city (table 1). This survey and cadastral record is comparable to the 1921 photography in terms of spatial detail, although the latter allows for a greater variety of land use and land cover features to be identified. The two data sets offer a rare opportunity for change detection of the built-up area of Halifax in the period 1878-1921.

At the same time as Hopkins produced his survey, the cartographer and map artist Albert Ruger completed an innovative hand-drawn map of the Halifax peninsula using an oblique bird’s eye perspective [13]. Although his panoramic view of the city did not adhere to the rigor of a constant scale to illustrate street patterns, buildings, and the main landscape features, it showed details pertaining to all of these features in remarkable detail and accuracy. This was based on meticulously
Figure 5. Comparison of residential development along Brunswick and Gerrish Streets, based on the 1921 aerial photography, the 1878 Hopkins map, and the 1879 Ruger panorama map. The latter highlights the area covered by the 1878 map and 1921 photo. *Sources:* Refs. [12], [13], NAPL K-2 #4.

Figure 6. Air photo of 1921 (centre) showing building footprints of houses destroyed in the 1917 Halifax explosion and post-explosion construction, a fire insurance map of 1918 showing the pre-explosion housing footprints (left), and a satellite image taken in 2012 showing the same 100 by 100 meter area (right). *Sources:* Refs. [14], [3, 10], Microsoft Bing Map.

recorded street-side survey information transcribed into a pseudo-aerial view that predated the aerial photographic survey mission of Halifax by more than four decades. Figure 5 compares the late 1870s maps by Ruger and Hopkins with the 1921 aerial photography.

The fourth example relates to a 1:2,350 thematic map produced in 1918 to assess the destruction caused by the powerful explosion in Halifax Harbour on December 6, 1917, following the collision of a WW-1 munitions ship with another vessel in the Narrows [4, 14]. The devastated area was also largely covered by the 1921 aerial photographs (figure 6). While the 1918 map showed the pre-explosion building and transportation infrastructure and outlined various degrees of devastation in the affected neighbourhoods, the air photos clearly reveal the remaining footprints of destroyed houses and recent construction of new buildings. The oblique satellite image view of this area shows that all the houses built right after the explosion can be identified in 2012 (as indicated by yellow circles in figure 6); the area has been completely rebuilt, and mature trees line the old street pattern. The 1921
aerial photography is an early civilian example for documenting post-disaster damage and rehabilitation efforts by means of remote sensing.

5. Conclusion
The air survey of Halifax in 1921 ranks among the first that were conducted over major cities across the country. The re-assembly of 58 vertical air photos into a digital mosaic at a scale of 1:5,000 yielded a detailed and comprehensive synopsis of the urban landscape. A direct comparison with older maps and more recent air photos and images confirms the forward and backward compatibility of the 1921 air survey data of Halifax with other sources of geographic information. In fact, the geographic, thematic, and event-specific contents of the post-WW1 air photos represent a crucial link in portraying the evolution of the urban fabric and function of a port city over a period or more than two centuries. The examples of air photo interpretation and land use analyses presented in this paper suggest that other urban air surveys of the early 1920s may contain a wealth of geospatial information that warrants further study from educational, historical, environmental, and cultural heritage points-of-view.

References and Endnotes
[1] Finnegan T 2011 Shooting the Front: Allied Aerial Reconnaissance in the First World War (Stroud, UK: Spellmount / The Historic Press)
[2] Shaw S B 2001 Photographing Canada from Flying Canoes (Burnstown, ON: GSPH)
[3] Air photos of Canada and Halifax can be accessed through national and provincial air photo archives at https://neodf.nrcan.gc.ca/neodf_cat3/ . The 61 photos of the 1921 survey (ID: K-2 Nr. 1-61) are located at the National Air Photo Library, NAPL, in Ottawa, Ontario, Canada.
[4] Ruffman A and Howell C D (eds.) 1994. Ground Zero - A Reassessment of the 1917 Explosion in Halifax Harbour (Halifax, NS, Canada: Nimbus)
[5] Annotation includes a reference number (K-2), photo number (No. 1 to No. 58), and year (1921)
[6] Meteorological records for 1921 suggests a favourable date in mid- or late March.
[7] See NAPL calibration records of Air Board Cameras 1922, unpublished notes, 2 p., NAPL
[8] See Shaw 2001, op. cit., p. 17-30
[9] For ground photographs and 1931 oblique air photos see http://www.novascotia.ca/nsarm/virtual/explosion and http://www.novascotia.ca/nsarm/virtual/mccully
[10] Werle D 2014 Early Aerial Photography of Halifax The Griffin 39, No. 2, pp. 12-15, and Werle D (2016) Setting the Sights on the Cities – Civilian Aerial Surveys in Canada during the early 1920s (forthcoming)
[11] DesBarres, J W F 1777 The Harbour of Halifax. Map size 82 cm x 59 cm. Published in: The Atlantic Neptune for the use of the Royal Navy of Great Britain. London. See also: Dawson, J 1988 The Mapmaker’s Eye – Nova Scotia Through Early Maps. (Halifax, NS: Nimbus)
[12] Hopkins, H W 1878 City Atlas of Halifax, Nova Scotia. Province of Nova Scotia Archives Reference no.: H.W. Hopkins Nova Scotia Archives Library O/S G 1129 H3 H67 1878, http://novascotia.ca/archives/virtual/maps/hopkins.asp
[13] Ruger, A 1879 Panoramic View of Halifax, Nova Scotia. Map 42x 91 cm, Call No. G3424. H2A3 1879.R8, US Library of Congress Geography and Map Division Washington, DC http://www.loc.gov/item/73693337
[14] Nova Scotia Archives 1918 Plan Showing Devastated Area of Halifax City, N.S. Reference No.: N.S. Board of Insurance Underwriters Nova Scotia Archives Map Collection V6/240 - 1917 Halifax loc.4.2.3.2. http://novascotia.ca/archives/virtual/maps/archives.asp?ID=71
[15] Canada Department of Militia and Defence / Survey Division 1918 Topographic Map of Halifax, No. 133a. Nova Scotia Archives Map Collection: V5 1: 31 680. 133a http://novascotia.ca/archives/virtual/maps/archives.asp?ID=70
[16] Atlantic Air Surveys Limited 1979 Halifax – Dartmouth Area. Air Photo Mosaic, Scale 1:50,000, Date of photography: May 11, 1979