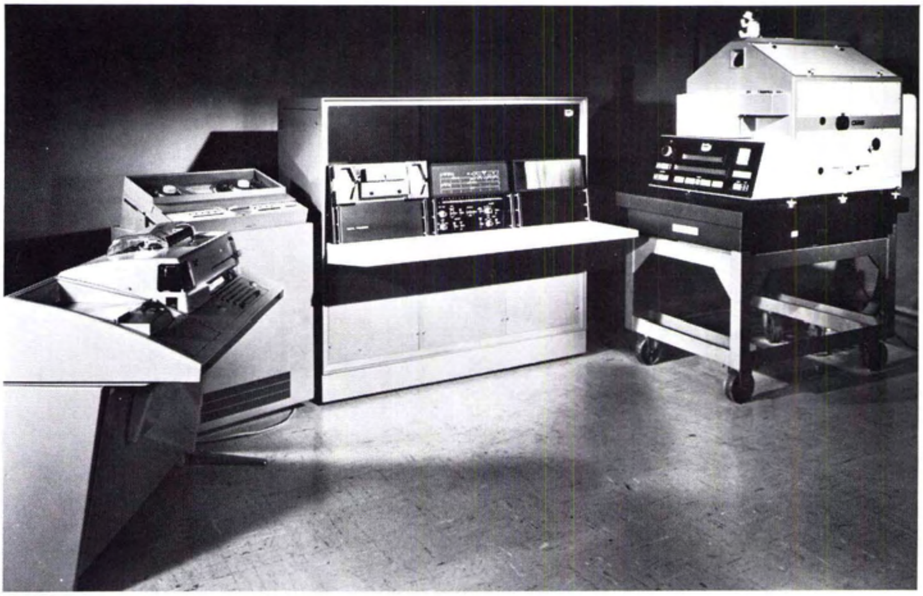

Frontispiece. Off-Line Orthophoto Printer.

FRANK SCARANO
ANTHONY JERIC
Rome Air Development Center
Griffiss Air Force Base, NY 13441

Off-Line Orthophoto Printer*

A computer-controlled Off-Line Orthophoto Printer is capable of printing high resolution rectified photos, orthophotos, and stereomates from vertical and oblique frame and panoramic photography

(Abstract on next page)

INTRODUCTION

Rome Air Development Center (RADC) recently has completed the development of an experimental optical orthophoto printer capable of operation in an off-line mode. The primary elements of the system (See Figure 16) are a mechanical-optical scanner/printer developed by Ottico Meccanica Italiana (OMI) of Rome, Italy, and the Bendix BX-272 control computer. In addition, an AMPEX TM-7 magnetic tape unit and an ASR-35 teletype are provided. The system operates independently of any stereoplotter, in the physical sense. Actually, the system in its present state of development requires elevation data generated by the AS-11B-1 analytical stereoplotter, and one photograph of the stereopair from which the elevation data was compiled. The necessary orientation data can be entered via a shut-down tape from the AS-11B-1, or by the control panel on the front of the printer unit.

The OMI Printer unit was developed by the Rome Air Development Center in a joint research & development program between

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the United States and Italian governments. Upon its receipt at RADC, a contract was awarded to the Bendix Research Laboratories to put the printer in an on-line operation with an automated analytical stereoplotter, the Chart Analysis Device. The printer was subsequently tested for performance evaluation. A second contract provided for an off-line capability and resulted in the system being reported upon in this paper. The system arrived at RADC in March of 1972 and was accepted in May. Since that time it has been exercised in generating various products and has been evaluated in terms of accuracy and quality of products.

ABSTRACT: *A new optical orthophoto printer has been developed by the Rome Air Development Center. Digital profile data is required as in conventional systems; however, the off-line capability provides greater flexibility than was previously possible. The source of profile data is not inherently limited to direct plotter output but can be obtained, for example, from a digital terrain data base. Previously compiled profile data could be used to produce an updated orthophoto from more current imagery over a specified area. The optical orthophoto printer operates from camera parameters, orientation data, and digital elevation profiles, using a special purpose computer which computes model-to-photo transformation and derives the necessary servo control signals for the optical transforming elements and input and output photo and film carriage motions. In addition to rectification and orthorectification of vertical and convergent frame photography, non-conventional imagery may be used, i.e., imagery from the convergent optical bar camera used during the Apollo flights. The analytical flexibility of the system, with proper programming, allows present capabilities to the expanded to cover essentially any transformation needed. A program has been developed providing a capability for stereomate production. The system has reproduced 72 line pairs per millimeter high contrast targets and has provided very good quality continuous-tone imagery at accuracies of 30-40u CMAS. Scanning of the input is done at up to 10mm/sec which allows production of 9 by 9 inch orthophotos in 50-60 minutes. Further details of the printer performance reflecting an ongoing test program are presented.*

System Concept

The Off-Line Orthophoto Printer (OOP) is a direct optical scanning/printing system and is in contrast to the conventional projection-type printers. The Gigas-Zeiss Orthoprojector, the Galileo-Santoni Orthophoto Simplex, and the SFOM Orthophotograph are examples of the latter and follow the design concepts of projection-type plotters wherein the entire photograph is illuminated and projected to a large table surface. That is, the projector uses a wide-angle lens, typically of 6 inch focal length. The elevation corrections are introduced by moving the entire table up and down, while the scanning is accomplished by a slit traveling back and forth. The slit intercepts a small element of the large cone of illumination, while the balance of the area is masked.

The Off-Line Printer is essentially an analytical printer designed in the concept of the analytical plotter. The optical system is fixed and has a narrow field of view. The bundle of light rays does not suffer from high refractive angles. The illumination is a thin slit of light created by projection of the actual filament of the illuminating lamp upon the input photo (Figure 1). Line elements of the imagery are transformed by a zoom lens and a dove prism and re-imaged upon the output film. This transformation also involves the computation of the proper photo coordinates on the input photo corresponding to the required model coordinates on the output film. In the scanning/printing process the control computer generates the appropriate signals to control the X and Y input photo position, zoom setting, filament and dove rotation, and X and Y positions of the output drum, referred to as model coordinates. Thus, the model coordinates are the orthophoto coordinates.

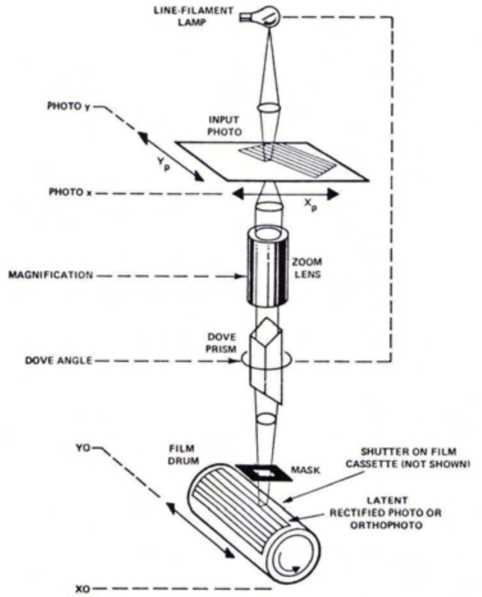

Fig. 1 The optical system.

Modes Of Operation

There are two basic modes of operation — orthorectification and plane rectification. The orthorectification process, a differential rectification, is the more complex of the two and results in properly relocating image points from their displaced positions in the original photograph based upon photo geometry and relief. The result is essentially a photomap, if the appropriate reference grids are annotated on the record. (Figures 8 and 11).

The rectification process is a special case of orthorectification and is accomplished in the same manner on the printer, with the elevation being held constant. (Figures 14 and 15).

A second special case of image transformation has been accomplished with the Off-Line Printer by an additional software package. This product is a stereomate (Figures 10 and 12), conceived and developed by the National Research Council of Canada. The stereomate, which is described in more detail later, involves the displacement of elemental image areas from their orthographic positions, in the positive X-direction only, as a function of elevation above some reference datum. Thus, false parallaxes are introduced in the new stereomate photograph and, when viewed with the orthophoto stereoscopically, a model is seen that has no Y-parallax and is absolutely oriented in terms of spatial content. The model is easy to view and can be exploited to generate various cartographic

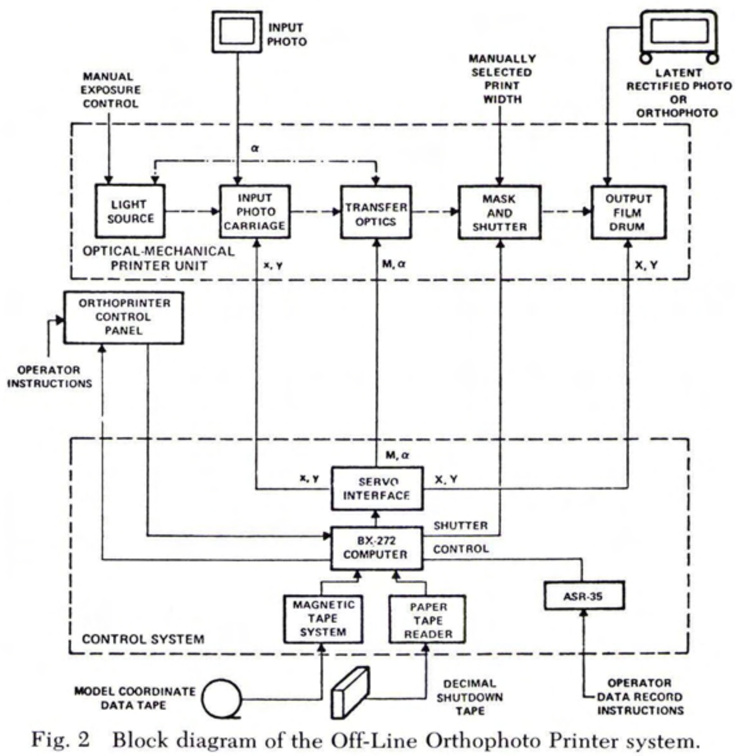

Fig. 2 Block diagram of the Off-Line Orthophoto Printer system.

products with relatively simple instrumentation.

A third special case of image transformation has been accomplished on the printer. This involves changes in perspective. In a process similar to rectification, but essentially a reverse process, a vertical photo can be converted to an oblique view.

System Description

The Off-Line Orthophoto Printer is referred to as a universal printer. It can provide the transformations discussed above from any focal length input, both frame and panoramic, that can be geometrically defined. Figure 2 depicts a block diagram of the system showing the separation of the optical-mechanical unit and the control system.

The printer provides for projection, transfer, and recording of the input image, plus manual viewing for orientation. The projector images the filament of the lamp to the photo plane at a line width of approximately 50 micrometers, and several millimeters in length. The orientation of the filament is in the local model X-direction of the input imagery. The rotation is also linked mechanically to the dove prism in the transfer optics so that, as the filament is rotated, the dove prism is counter-rotated to align the output image element in the model X-direction, which is the X-axis of the film drum. Just above the film drum is a mechanical mask, of variable width, which determines the length of the line element to be exposed upon the film. This mask permits a choice of 1, 2, 3, and 4mm profile widths.

This projection and image transfer technique eliminates the problem of discontinuities of image boundaries between profiles, due to changes in terrain elevation that can occur across the width of the profile and between profiles.

The method of generating the image profile boundaries is shown in Figure 3. The magnetic tape containing the digital profile data from the AS-11B-1 is read in by the Ampex unit. The decimal shutdown tape is read in for the particular photo, allowing the interior orientation of the photo to be determined after a reading of the four fiducials. The controller than reads in two profiles and determines the path to be followed in the input photo (between the two elevation profile paths). The computer performs a model-to-photo coordinate transformation for the area 1, 2, 3, and 4. This transformation can include several corrections such as earth curvature, atmospheric refraction, model distortion, and lens distortion. From these four coordinate positions, X and Y commands are generated to move the input photo from point 5 to point 6, and commands also are generated to translate the output drum in the Model Y direction. Simultaneously the four photo positions are used by the computer to calculate the commands for the zoom optics and rotation of the line element. At the end of the first printed swath, the third profile data is read in and the first is discarded. The next print path is in the reverse direction, using data from profiles 2 and 3. This process repeats itself for each profile in turn, within the boundaries established by the operator, until the area has been covered.

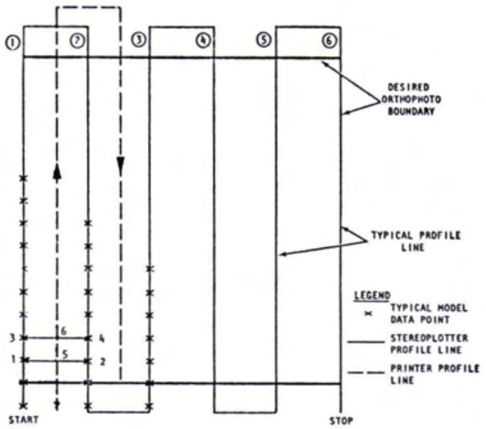

Fig. 3 Image profile boundary generation.

By this process, the measured coordinate information relates to the terrain along the boundaries of the swath being printed rather than to the terrain along the center line of the strip. The latter situation would result in possible errors in image placement along the edges of strips. Thus, the Off-Line Printer provides a continuous image in all directions, offering an aesthetic quality not common in orthophoto imagery, particularly when fairly wide profiles are generated. In the Off-Line printer, the width of the profile does not affect the quality of the image. However, the accuracy of the locations of image points between the profile data strings then becomes a function of terrain slope or terrain inflection.

The ability to rotate the filament dynamically, change magnification, provide the necessary differential movements of the input photo in X and Y, and to analytically determine the appropriate photo X and Y positions provides the universal aspect of the Off-Line Orthophoto Printer. With additional software programs the printer could provide other transformations, e.g., radar and IR restitution.

The printer exhibits a capability for excellent modulation transfer, essentially limited only by the numerical aperture of the lens system. The system has provided 72 line pairs per millimeter high-contrast image transfer, which essentially establishes the limiting resolution of the present unit.

With a relatively wide bandwidth light source, the printer is capable of producing its outputs on color emulsions. The experiments at RADC resulted in a choice of Ektachrome 6116 emulsion. The best color reproduction was achieved after several trials of varying the light intensity, a simple control provided on the printer.

Table 1 summarizes the characteristics of the off-line orthophoto printer.

Detailed Description

OPTICAL SYSTEM

Figure 4 depicts the optical schematic of the printer as it now exists, after a number of modifications of the original OMI unit. The upper portion of the optical train, consisting of a collecting lens and an imaging lens, comprises the slit forming optics. This system forms a 50-micrometer wide element of illumination upon the input photo with the long dimension of the line element being approximately 4 millimeters. The light filament is a line filament, exhibiting a near linear energy output. The filament can be rotated about the optical axis, and is mechanically linked to the dove prism rotation assembly. The filament is aligned with the local photo *X* direction, and the dove prism is rotated to align the projected line element image along the output drum's model *X* direction, which is always normal to the drum axis. As the input and output stages are translated, the filament alignment is controlled by the computer, based upon local photogeometry and computed terrain slope.

The viewing mirror, relay lens, and screen comprise the means for viewing the fiducials in the interior orientation process. The mirror flips up out of the optical path when this is completed.

The transfer optics are located below the input photo carriage and comprise elements to collect the rays from the illuminated line element and to collimate this light through the zoom lens, rhomboid prism, and dove prism. The objective lens then images the parallel light bundle to the emulsion on the drum surface by way of a final 90° prism. Just above the output film is a mechanical mask or aperture which truncates the light to provide the precise profile width. A shutter located on the cassette is actuated by the print signal and automatically closes when the model area has been exposed.

Control System

The motions of the printer as they are described above are controlled by a Bendix-272

Table 1. Off-Line Orthophoto Printer Characteristics

Printer	
Input Format Size	9 by 9-inch image area
Output Format Size	9 by 11-inch image area
Rotation of Slit	±1 Radian
Magnification Range	0.85× to 3.8×
Useful Magnification Range	2.0× to 3.8×
Output Print Widths	1, 2, 3 and 4mm
Maximum Output Print Speed	10mm/Sec
Limiting Resolution RTI	72 line pairs per mm
Input Format Geometry	Frame and Panoramic
Color Handling Capability	Yes
Computer	
I. D.	Bendix 272
Type	General Purpose, Digital
Memory Size	Core, 16,384 words
Word size	18 bits
Cycle Time	625 ns
Peripherals	
ASR-35 Teletype	
High Speed Paper Tape Reader, 300 cps	
High-Speed Paper Tape Punch, 50 cps	
AMPEX TM-7 Magnetic Tape Transport	

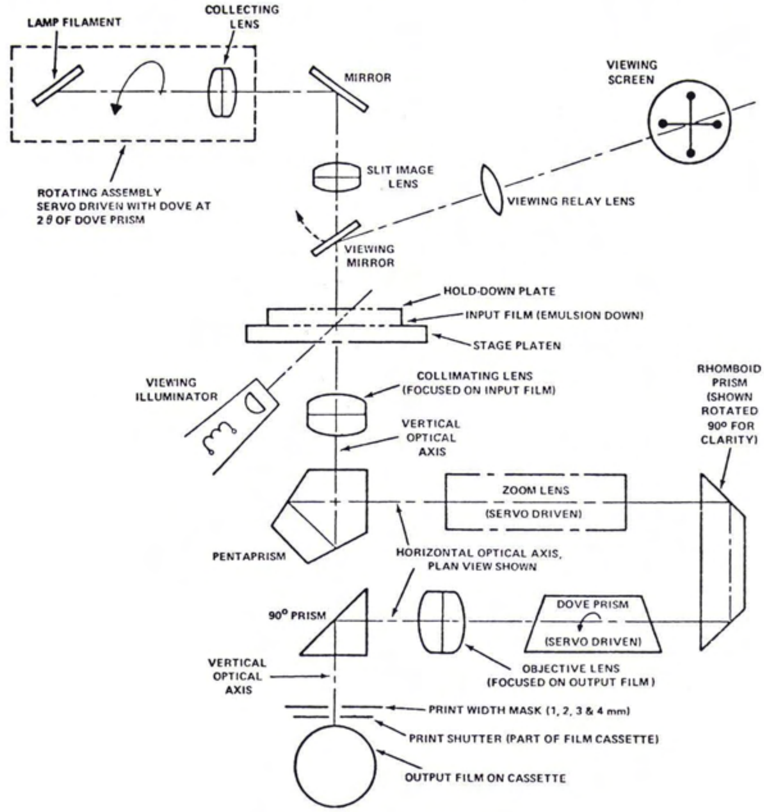

Fig. 4 Optical schematic.

computer, similar to that on the AS-11B-1, which also contains a high-speed paper tape reader/punch. The control system is shown in Figure 2. The computer is a high-speed, general purpose digital computer with 16,384 words of core. The six servo commands for the printer are generated by the computer based upon model coordinate and orientation data. The coordinate data is entered into the computer memory by the Ampex magnetic tape unit while the orientation data is entered by paper tape, teletype, or manually through the printer control panel.

Future Capabilities

The present Off-Line Printer is being provided with additional software to permit it to operate with terrain data generated independently of the AS-11B-1. This can be terrain data from a data bank, such as will be provided under RADC's Advanced Cartographic System. This program also will provide the ability to transform any photograph for which the camera and orientation parameters are known, without the need for the AS-11B-1.

Future plans provide for an orthographic transformation capability based upon limited terrain data. This can consist of control derived through analytical triangulation and the subsequent derivation of terrain data by interpolation. Such an orthophoto product would not be so precise as that derived from the present methods, but it could meet limited requirements. In the case of terrain of a gently rolling character, this type of product could be satisfactory for many applications.

The generation of tilted perspectives from vertical photographs can be accomplished on the printer at present, but only a limited number have been generated. More of this will be accomplished as part of the in-house experimental work being conducted.

The unique analytical transforming characteristics of the printer will be the basis for experiments with radar and infrared imagery. In the case of IR imagery, the inherent geometric distortions are due to the scanning method, wherein the scanner runs at a constant angular rate while the imagery is recorded at a constant linear rate. The characteristic image shows compression at the edges. There are other distortions to be considered, but these distortion corrections should be only a bit more complex than those

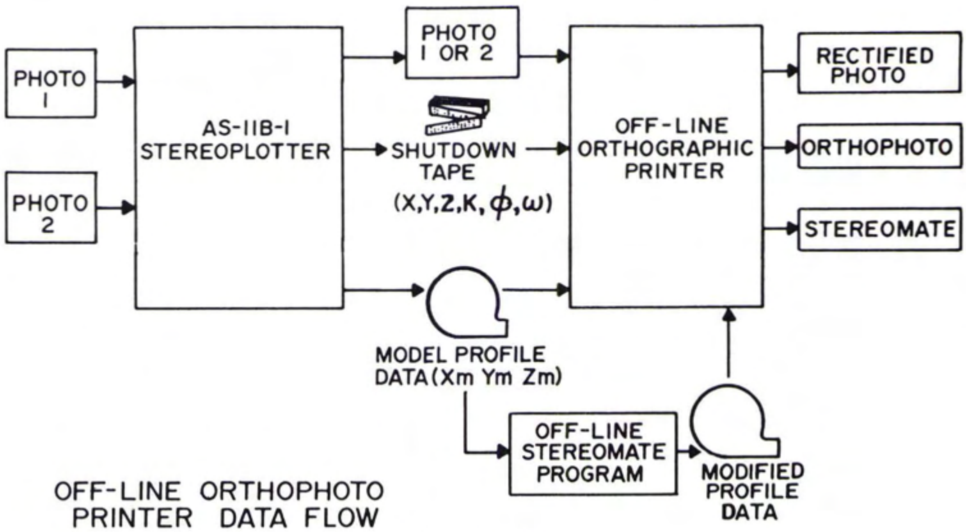

Fig. 5 Data flow.

now done with panoramic materials, and can be handled with software.

In a like manner, side-looking radar imagery will be experimented with. Here the primary distortions are due to terrain relief and flight line and attitude anomalies. Once these are reasonably defined, plane and orthorectification can be accomplished.

Strip camera imagery represents a recording that contains distortions along the flight line directions, due primarily to attitude changes. The imagery essentially has a principal point for each elemental line of exposure. If the locus of these principal points can be determined, the imagery can be rectified on the Off-Line Printer. With the addition of terrain data, the imagery can be orthorectified.

These possibilities are cited in order to emphasize the great flexibility of the Off-Line Printer, based upon its ability to position any chosen elemental area of the input record at the optical axis, under computer control.

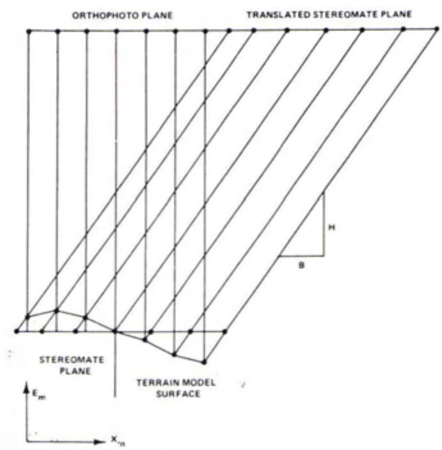

Fig. 6 Orthophoto stereomate relationship.

Orthophoto Production Procedure

The Off-Line Orthophoto Printer requires profile data, orientation data, and the input photograph to produce an orthophoto. At present the AS-11B-1 is being used to produce the orientation and profile data. It is not within the scope of this paper to describe fully the functions of the AS-11B-1. Only a simplified outline of its use will be presented here. (Figure 5)

The procedure starts with orienting a stereo pair of the desired area in the AS-11B-1 analytical plotter. A model coordinate system is established, usually at the nominal scale of the photography. Any desired corrections for atmospheric refraction and lens distortion are entered at this point. The photo-to-model orientation parameters are computed during relative and absolute orientation. The orientation and correction parameters are punched out on what is termed a shutdown tape and saved as an input to the OOP. The model is then profiled in the Y direction, profiles being simply a series of Z measurements of the terrain surface taken at regular intervals along a number of parallel, evenly spaced lines. This data is digitized and recorded on magnetic tape for direct input to the OOP.

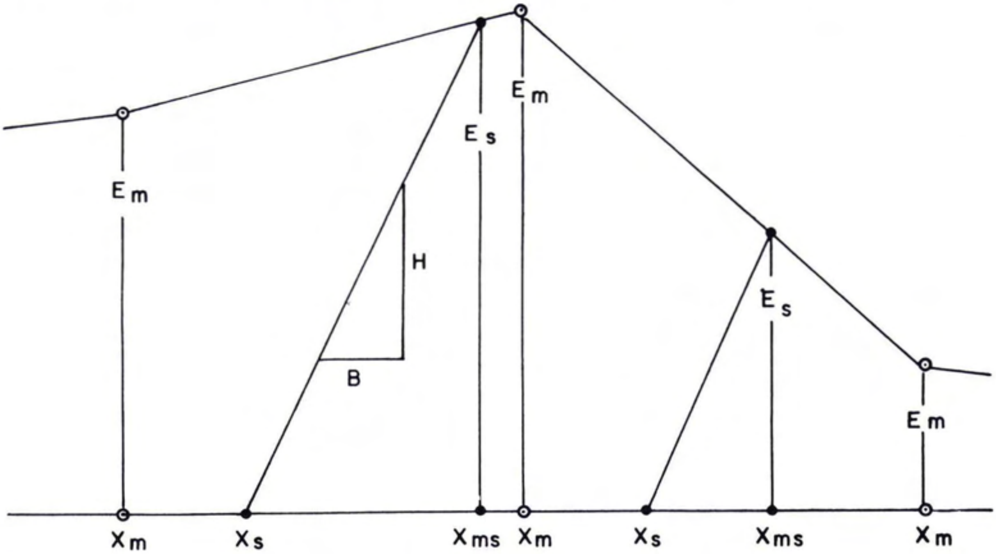

Fig. 7 Stereomate preprocessing.

The AS-11B-1 can automatically gather profile data by using an electronic correlator which greatly speeds up the data collection over standard manual means. The spacing between profiles is dependent upon the accuracy desired from the orthophoto. The magnetic tape containing the profile data, the shutdown tape, and either photograph from the stereopair are then taken to the OOP. The four fiducials of the input photograph are measured on the OOP photo carriage in order to establish the interior orientation. The fiducial measurements along with the shutdown tape, are used by the OOP control system to reestablish the photo to model orientation and make the necessary model-to-photo computations already explained. The following generalized steps are then taken:

- The output drum is initialized (i.e., set the zero x and zero y position).
- The desired print width, print speed, print scale (model-to-drum), and a light exposure are established.
- The model boundaries to be covered by the orthophoto are input.
- The start point for the output drum, magnetic tape, and input carriage is established (done with a single program button).
- Start.
- Printer stops automatically when the boundary limits have been satisfied.

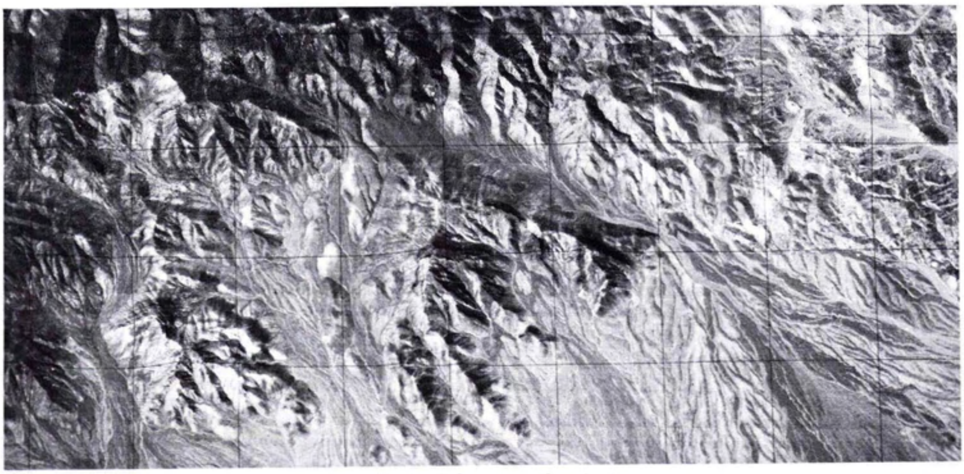

Fig. 8 California orthophoto.

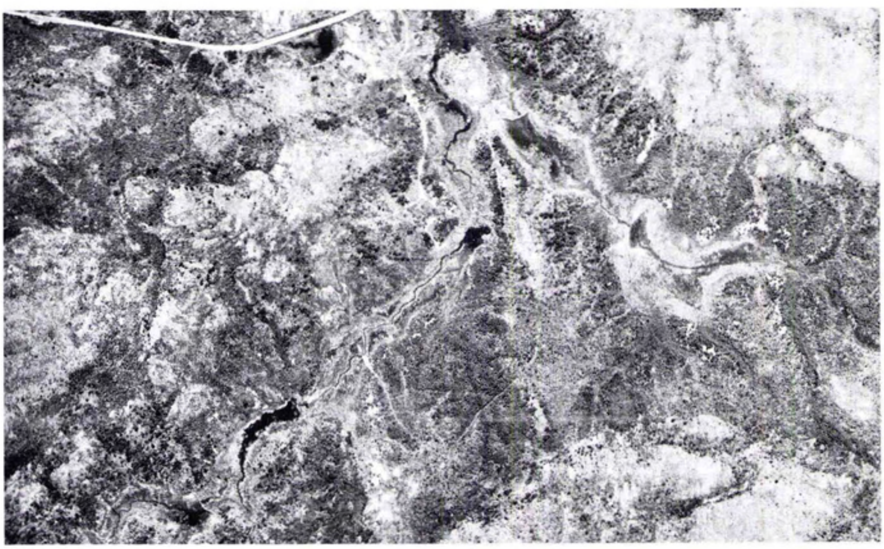

Fig. 9 Sudbury orthophoto

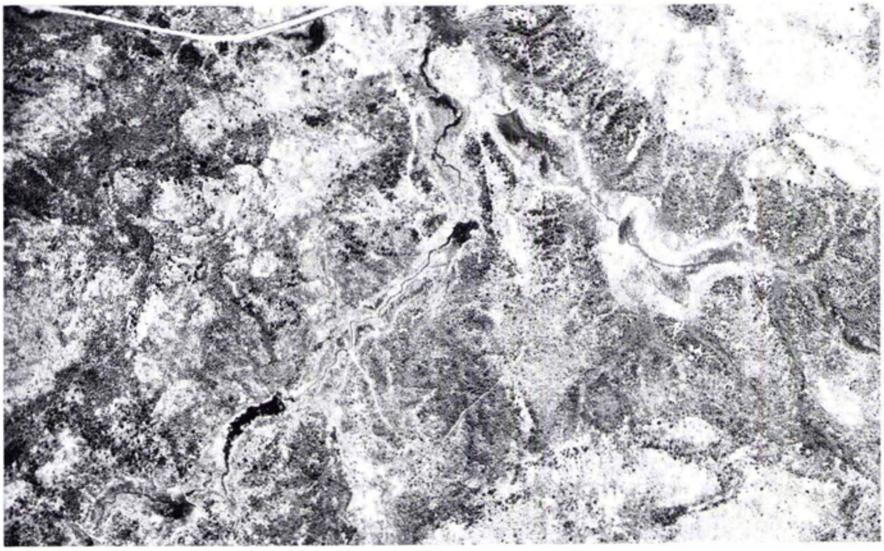

Fig. 10 Sudbury stereomate.

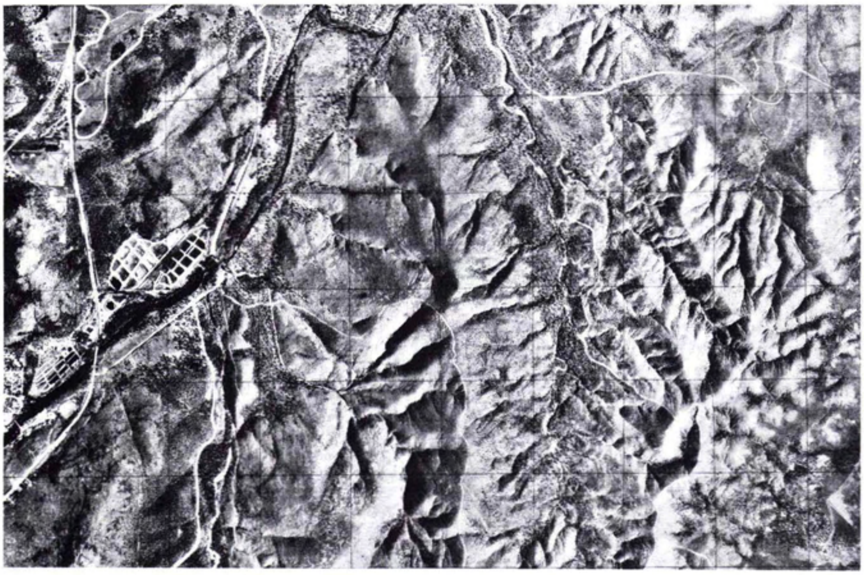

Fig. 12 Fort Sill stereomate.

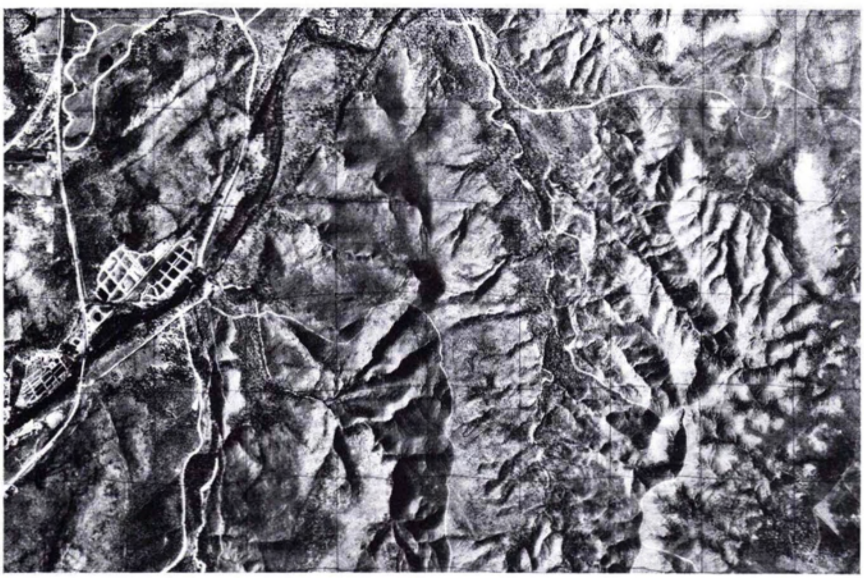

Fig. 11 Fort Sill orthophoto.

Stereomate Production

Stereomate production procedures require that the profile tape first go through an off-line preprocessing program. This program computes a set of pseudo profiles and outputs them on a new tape which is input to OOP along with the desired base-height-ratio (B/H). The remaining steps required to produce a stereomate are the same as those already described for the orhophoto.

Stereomate Data Processing

Figure 6 shows the relationship between an orthophoto and the stereomate. Stereomate printing requires the finding of photo coordinates that correspond to the stereomate coordinates. The general (somewhat backwards) approach taken here is to: (1) establish a stereomate grid that corresponds to the printer drum coordinate system, (2) find the x model coordinates whose correct parallax shift is represented by the stereomate's x grid coordinates, (3) compute the corresponding photo coordinates for those model coordinates, and (4) print the image represented by those photo-coordinates on the drum.

Figure 7 depicts the profile and pseudo profile data relationship. All the points are at a constant Ym (model Y). Em and Xm represent interpolated profile model elevations and model x coordinates respectively. Xs represents the stereomate x coordinates which are directly related to drum position. The stereomate preprocessing program establishes the stereomate grid and computes Es using any desired B/H. The pseudo profile tape is generated, containing Xs, Ym, and Es data. The OOP program computes Xms. Xms, Ym, Es is therefore a model point, and its X parallax shift point is represented by Xs. The shutdown data and the interior orientation data are used by OOP to compute the photo coordinates from Xms, Ym, Es. Each discrete image element corresponding to the appropriate photo coordinate is then printed on the drum (i.e., the photo coordinate corresponding to Xms will be shifted and printed at Xs). This last step is of course an optical projection/transformation similar to the original orthophoto printing step. Either a linear or logarithmic parallax shift can be employed.

Off-Line Orthophoto Printer Tests

Two tests were conducted in the evaluation of the Off-Line Orthophoto Printer (OOP). The first test used an orthophoto produced by Bendix Research Laboratories from a stereopair of KC-1 photography. The second was conducted with an orthophoto produced at RADC from RC8 imagery sent by the National Research Council of Canada of their Sudbury photogrammetric test range.

PRELIMINARY ACCEPTANCE TEST — CALIFORNIA TEST MODEL.

The Bendix test model was taken over California at a scale of 1/200,000 by the X-15. The KC-1 camera used has a nominal focal length of 6 inches and 9 by 9 inch frame format. Profiles were compiled from the model for which only a relative orientation was established. The orthophoto was produced by using a nominal print width of 2mm at a scale of about 1/100,000. (Figure 8). The stereopair was then sent to RADC along with the orientation data (shutdown tape) and the model was re-established on the AS-11B-1 analytical plotter. Because absolute control for this test was not available, relative model control was derived and used instead. The XY coordinates of the model surface lying directly under 37 grid intersections were measured and recorded. The corresponding grid intersections on the orthophoto were then measured by using one stage of the AS-11B-1 as a monocomparator. A least squares adjustment was used to translate, rotate, and scale the coordinates of the orthophoto grid intersections to those measured in the stereomodel. The residuals resulted in a CMAS of 37 micrometers (Circular Map Accuracy Standard, i.e., 90 percent probability that a point lies within a radius of $37\mu m$ (7.4 meters at ground scale, from its "true position.") These results were con-

Table 2 Orthophoto Evaluations

Model	Control	No. of Pts.	Organization	CMAS (RTI)*
Sudbury	UTM	44	RADC	$33\mu m$
Sudbury	B-1 Model Coordinates	30	RADC	$30\mu m$
California	"	37	RADC	$37\mu m$
Fort Sill	"	60	Bendix	$40\mu m$

* Referred to the input photography.

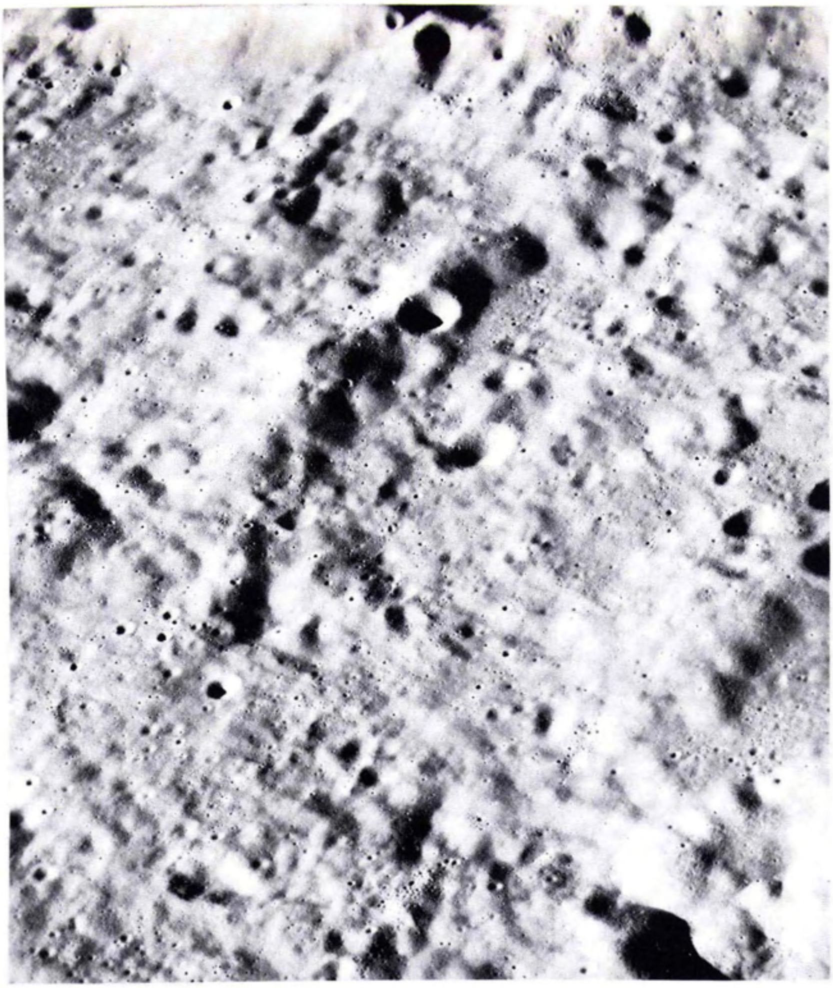

Fig. 13 Unrectified Apollo 16 panoramic photography.

sidered very encouraging because the contract specifications with Bendix had called for a standard deviation of 50 micrometers in position X and Y, or a CMAS of 105 micrometers, referred to the input.

FINAL ACCEPTANCE TESTS — SUDBURY MODEL

The final acceptance test was more comprehensive in that ground control was used in place of model control. The Sudbury stereopair was graciously provided by Dr. T. Blachut and his associates at the National Research Council (NRC), Canada. Sudbury was an excellent test model because of the abundant control available. The camera was an RC8 with a nominal focal length of 6 inches. The absolute model orientation, profiling, and evaluation were performed by Mr. Don Hall at RADC on the AS-11B-1 plotter. A one-pass relative and an absolute orientation were performed using 30 control points, which resulted in a CMAS of 0.2 meter earth scale, with the photo scale being 1/15000. No attempt was made to correct for atmospheric refraction, lens distortion, or film shrinkage. Profiles were spaced at 0.75mm in the model and points recorded every 0.25mm along the profile. Profiling was done automatically, using the correlator on the AS-11B-1, producing 187 profiles in about five hours. The total elevation range in the area covered by the orthophoto was about 4mm at a model scale of 1/15,000. Profiling accuracy at the 90 percent confidence level was one meter at ground scale (dynamic vs. static elevation check).

The orthophoto was produced from a portion of the model at 2× by using a nominal print width of 1mm (Figure 9). Forty-four photogrammetric ground targets were then measured on the AS-11B-1. The orthophoto

Fig. 14 Rectified Apollo 16 panoramic photography.

target coordinates were rotated, translated, and scaled to the NRC-supplied ground control by a least-squares adjustment. The residuals produced a CMAS of 33 micrometers referred to the input photography (0.5 meters ground scale), thus confirming the general accuracy level achieved in the first test. One might expect the first test to yield residuals smaller than the second since model control was used instead of absolute ground control. Thirty *reseaus* randomly selected from the Sudbury model did indeed produce a CMAS of only 30um, when fit to their corresponding model coordinates. It should be noted, however, that the California model contained more relief than the Sudbury. In addition, the California model was profiled at a 1mm interval whereas Sudbury was done at 0.75mm, which decreased the control available for the printer.

OTHER TESTS.

A stereomate was made from the same photo used in printing the Sudbury orthophoto (Figure 10). Elevations were calculated from x parallax measurements made on the orthophoto-stereomate. The error in these elevations, when compared to ground control, resulted in a standard deviation of 0.9 meters.

M. Alice and J. Abshier of Bendix Research Laboratories have also evaluated a stereomate and orthophoto (Figures 11 and 12) which were produced from 1/50,000 scale, 6-inch focal length photography over Fort Sill, Oklahoma. The model contained an elevation range of 4mm. The same photo was used for printing both the orthophoto and the stereomate. The resultant standard deviation of the elevation error derived from the

TABLE 3. STEREOMATE EVALUATIONS

Model	Control	No. of Pts.	Organization	Input Scale	Standard Dev.*
Fort Sill	UTM	44	Bendix	1/50,000	2.2 meters
Sudbury	UTM	43	RADC	1/15,000	0.9 meters

* Ground scale

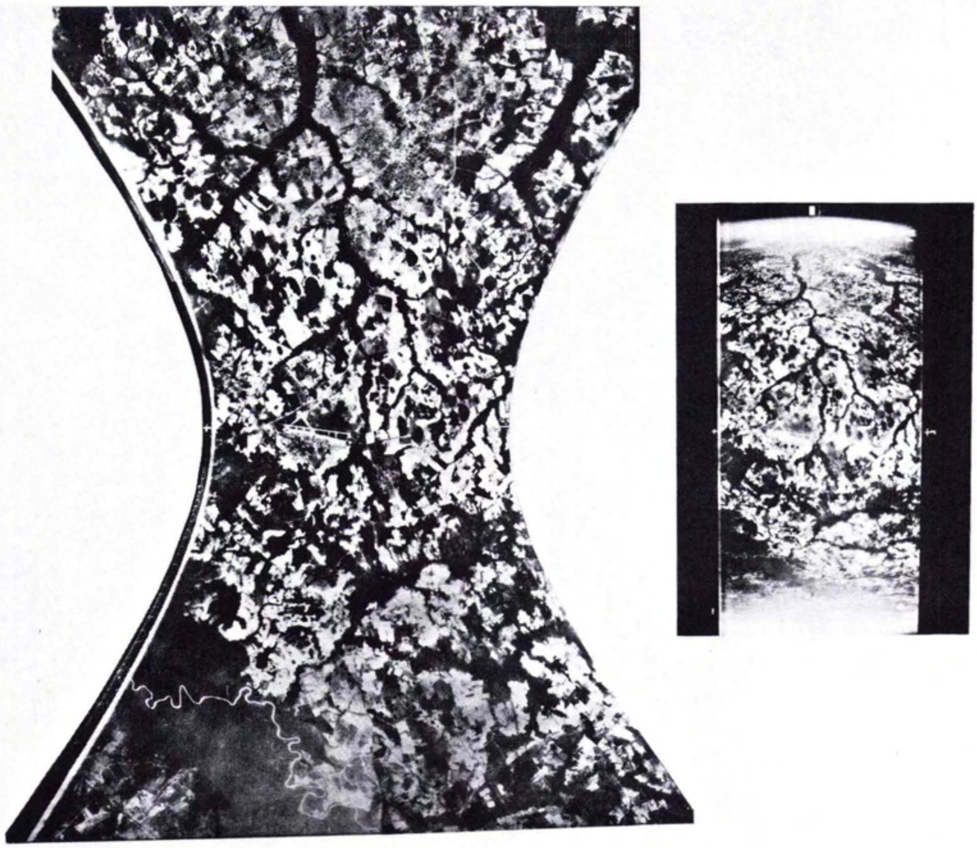

Fig. 15 Rectified and unrectified KA-56 panoramic photography.

orthophoto-stereomate was 2.2 meters. Bendix also evaluated their orthophoto in a manner similar to the California model and obtained a CMAS of 40 micrometers referred to the input photography. Tables 2 and 3 give a summary of the orthophoto and stereomate tests to date.

Orthophotos have been successfully produced from panoramic imagery but have not at the time of this writing been evaluated. Panoramic imagery, such as that obtained from NASA's 24-inch lunar panoramic camera (See Figures 13, and 14), and the 3-inch KA56 (Figure 15, mosaic 3.3 reduction), have been rectified on the OOP.

Resolution tests were made by using

TABLE 4. PRINTING SPECIFICATIONS

Figure Number	Printing* Time (hr)	Nominal Print Width (mm)	Print Speed (mm/sec)	Output Magnified
8	0.5	2	6	2×
9	2.1	1	6	2×
10	1.1	2	6	2×
11	0.9	2	6	2×
12	0.9	2	6	2×
14	0.7	2	10	≈2×
15	4.2 (mosaic 6 chunks)	2	10	1.5×-3.6×
**	0.7	4	10	2.2×-3.1×

* Printing times originally presented in September 1973 were in error and the corrected times are given here.

** Vertical photograph transformed to an oblique, figure not in text.

high-contrast Ronchi rulings in a dynamic mode and produced 72 l/mm regardless of the print speed. Due to limitations of the printer, this resolution is not presently achievable at magnifications of less than 2 ×.

Table 4 summarizes the parameters of the off-line orthophoto printer tests.

Conclusions

The Off-Line Orthophoto Printer represents a development that has been conducted in the proper spirit of research and development. Each phase of the development concluded in evaluation of the work accomplished and the formulation of the next logical effort to carry the program to its ultimate objectives. These objectives can be briefly summarized: to develop a fast, high-resolution, transforming printer capable of producing restituted photo products at accuracies that will support military mapping and targeting requirements. RADC feels that most of these objectives have been met or will be met with additional software.

The Off-Line Orthophoto Printer exhibits a flexibility of operation that is not available in any known instrument. Finally, the capability represented by the equipment has been achieved at a reasonable cost to the Department of Defense as compared with other comparable research and development programs, and has directly resulted in the non-military version now available commercially as the OP-C.

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