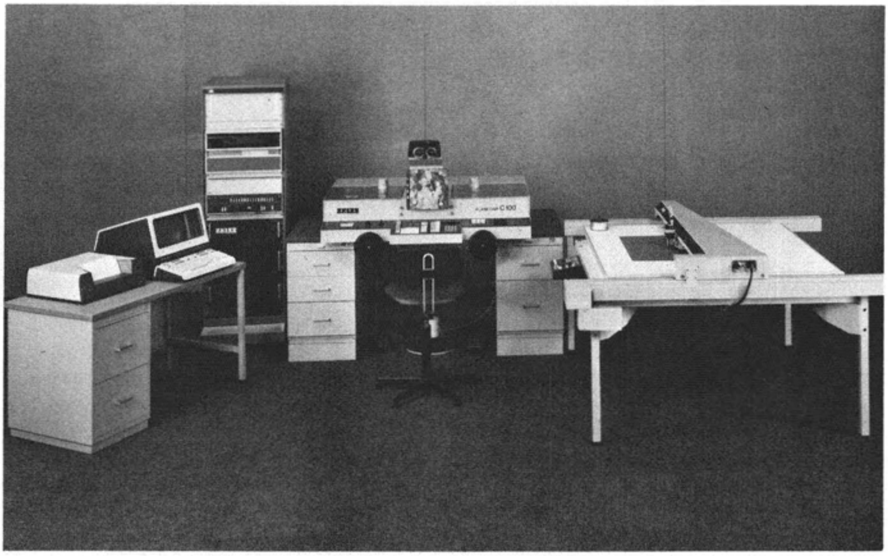

FRONTISPIECE. The C-100 PLANICOMP analytical stereoplotting system with DZ-6 tracing table.

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C-100 PLANICOMP, the Analytical Stereoplotting System from Carl Zeiss*

The C-100 PLANICOMP features a great variety of user programs.

(Abstract on next page)

INTRODUCTION

THE HISTORY OF THE ANALYTICAL STEREOPLOTTER goes back fully two decades. Helava first published the basic concept and thereafter introduced this new technology in the field of photogrammetry (Blachut *et al.*, 1970; Helava, 1958a, 1958b).

However, these machines have not yet been able to gain a foothold in practical work, although their use has opened up new possibilities. This may be due to the fact that analytical instruments were technically feasible at the time but could not actually compete with mechanical analog instruments in their overall efficiency due to the technical means available in those days. This was in part due to

- the still insufficient computing speed which on the one hand was responsible for excessive "inertia of the numerical guide rod" by comparison with a mechanical one and, on the other, for excessive computing time during orientation;
- a lack of flexibility in plotting capabilities due to inadequate use of software;
- insufficient reliability of electronic components;
- high price which was several times that of analog equipment; and
- operation of the computer by an operator

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who had to have special training for this purpose.

These drawbacks were not offset by advantages such as the possibility of plotting photography taken with unusual camera geometry, orientation with rigorous adjustment calculation, or high accuracy.

The picture now has changed completely. Electronic components have become more compact, more reliable, and cheaper. Computers now are much faster, likewise more reliable and cheaper, but above all easier to operate. On the other hand, higher requirements are made of plotting machines. These have resulted in frequent expansion of analog instruments by electronic components allowing digital take-off of coordinates for recording and transmission to on-line computers as well as in development of computer-supported drawing tables. This clearly reflects the growing trend towards relieving operators of monotonous and time-consuming routine work as well as the efforts made by photogrammetric organizations to achieve higher productivity.

It may therefore be expected that reliable and reasonably priced analytical stereoplotters supplied with efficient software that corresponds to actual practical requirements will find a growing market (Meier, 1976). These are the considerations that prompted Carl Zeiss of Oberkochen to develop the C-100 PLANICOMP analytical stereoplotting system. The corresponding work was in the hands of a research team equally experienced in optics, precision engineering, electronics, and EDP and entirely familiar with everyday problems of photogrammetric practice. This new instrument (Frontispiece) which on account of its overall concept may also be called a photogrammetric plotting center, is described in the following paragraphs.

ABSTRACT: *The C-100 PLANICOMP analytical stereo-plotting system by CARL ZEISS of Oberkochen, consists of a basic opto-mechanical unit, a photogrammetric control panel, control unit, computer, computer terminal in the form of a teleprinter or video screen, peripheral equipment, and plotting table. In conjunction with some 70 existing user programs, it offers a multitude of advantages over analog equipment: rapid and objective adjusting orientation with output of residual errors, single and incremental recording with great flexibility regarding increments, measurement setup and output format, aerial triangulation with direct data checking during measurement and subsequent overall adjustment in the instrument without data transfer, computation of secondary geometric magnitudes such as center of gravity, distance, length, angle, area, and volume; and computer-supported graphical plotting (on-line mode) in the form of straight-line plotting, supplementary plotting, plotting of symbols, point numbers, spot heights, and lettering, as well as fully automatic grid plotting. At a cost comparable to that of larger analog systems, a "photogrammetric plotting center" has thus become available, which makes allowance for future developments going well beyond its present capabilities.*

General Concept

The basic concept is a photogrammetric plotting system of high accuracy, reliability, flexibility, and economy, which should be capable of handling any kind of plotting work normally encountered in photogrammetric production. In addition, simple modification should allow the handling of unusual kinds of work so that the system can also be used in the fields of research and training and for other special projects. In spite of all this, however, ordinary photogrammetric work, in which reliability and productivity are decisive for the success of a plotting system, remains the primary target area.

As a result, the design of the PLANICOMP was determined by the following guidelines:

- High accuracy commensurate with present-day mechanical precision instruments.
- Computer-supported graphical plotting.

- Computer-supported measurement of digital terrain models.
- Computer-supported measurement of input data for aerial triangulation.
- General support and simplification of routine work, for example, during orientation phases.
- High operator comfort making allowance general operating conventions and making full use of new possibilities.
- Minimum training requirements. In other words, operators experienced in handling mechanical analog instruments should be able to use the analytical plotter within a few hours and should be capable of utilizing all existing possibilities after a few days.
- Specific computer training and computer operations during plotting should be restricted to an absolute minimum; in other words, the elimination of routine work should not be offset by additional computer manipulations.
- High reliability in conjunction with comprehensive error messages in clear text in the case of operating errors and plotting irregularities as well as suitable safeguards against power failure.
- Roughly identical in price to analog plotters with comparable equipment, production rate, and uses.
- Possibility of using the computer for general computations.
- Possibility of expansion due to modular design of hardware and software; in the case of software, by exchange with other customers using FORTRAN.

The result of this development is the C-100 PLANICOMP analytical stereoplotting system which essentially consists of a basic opto-mechanical unit with a photogrammetric control panel, the electronic control unit, a minicomputer as well as operating and user software (Figure 1). The following sections will describe these elements as well as potential peripheral equipment.

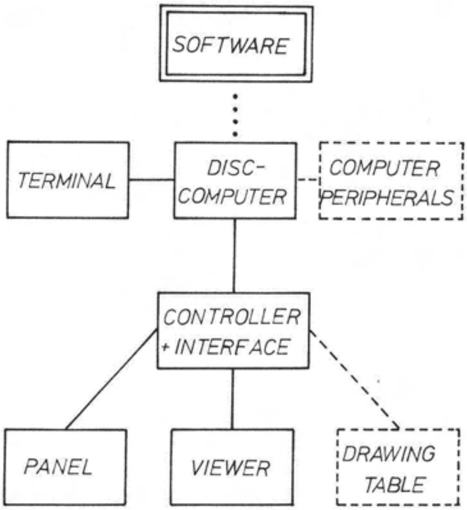

FIG. 1. Configuration of the C-100 PLANICOMP.

THE BASIC OPTO-MECHANICAL UNIT

The basic opto-mechanical unit (Figure 2) serves to view and measure the photography. It is of very compact, self-supporting design so that it can be set up on a desk-like base. The housing contains two independent, servo-driven photocarriage systems moving in x and y and a comfortable fixed viewing optical system. In front of the viewing unit is a control panel for all important settings and work cycles, the coordinate display and drive elements such as handwheels, pedal disk, joy stick and the speed control.

The photocarriages are designed as cross slides and driven by precision screws with 1 mm lead and multi-mesh roller nuts via closed servo loops, shaft encoders generating 1000 pulses per revolution allowing positioning of the carriages with a resolution of 1 μm. Travel in either of the two coordinates is 240 mm. A three-step system of limit switches is used: interior "numerical" limits controlled by the computer; central electrical limit switches; and outer, spring-loaded mechanical stops.

The photocarriers are rigidly connected to the carriage system; they are not rotatable. Range marks facilitate rough positioning of the photograms. In addition, a 9-point grid of 90 mm intersections is provided for calibration.

The viewing system consists of photograph illuminators, a black measuring mark of 40 μm diameter in a fixed intermediate image plane, which is turned into a luminous mark by a variable light source. Dove erecting prisms for separate rotation of each image through about ± 100°, a prism system for changeover between orthoscopic and pseudoscopic stereo viewing or binocular viewing of the left and of the right-hand photo, as well as interchangeable eyepieces for 8× or 16× viewing magnification. Other features include an interpupillary-distance setting between 52 mm and 82 mm, eyepiece focusing, principal-distance focusing, 30 mm field of view at 8× magnification, high resolution of 100 line pairs per millimeter, squint-correcting prisms, etc. The prism control unit can be switched over both manually and by the computer, a feature that

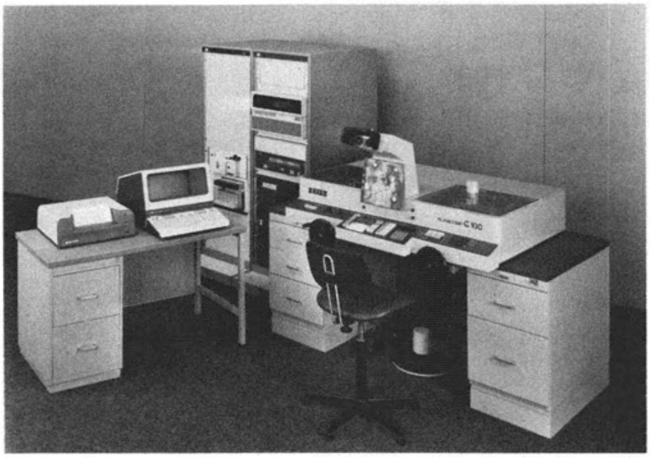

FIG. 2. The C-100 PLANICOMP with tape reader and tape punch unit.

is very useful, particularly during orientation.

THE PHOTOGRAMMETRIC CONTROL PANEL

The control panel (Figure 3) allows control and checking of practically all operations involved in orientation and numerical or graphical plotting. A first keyboard with luminous display indicates the operating status of the machine. This "instrument-status" assembly includes a "viewer on" signal lamp indicating the position of the master switch of basic and control units as well as illuminated "computer on-line" and "table on-line" buttons for coupling the computer and the drawing table, respectively.

Two handwheels and a pedal disk serve to shift the floating mark in the stereoscopic model or in individual photographs (accomplished by photocarriage motion). In addition to the usual fine adjustment, depression of a foot control allows rough travel at four times the normal speed. Moreover, a joy stick is available for freehanded guiding in x and y. Because its action is non-linear, the joy stick even allows exact fine adjustment. Profile control is provided by an additional speed control in conjunction with a fixed angle to be entered. The operation of these input controls is defined by an illuminated "moving-status" keyboard: "model normal," "model-terrestrial," "model profiling," "photo left and right," "photo left," and "photo right." An additional toggle switch serves to change the coarse/fine switching action of the aforementioned foot control for change-over between common and parallactic photograph motions, a feature that is very useful for direct photograph displacement to clear parallax during relative orientation.

There is a similar keyboard for the "viewing status" with illuminated "binocular left," "binocular right," and "stereo" buttons as well as a toggle switch for "ortho/pseudo."

A coordinate display with four registers of eight digits each can be switched alternatively to display of ground coordinates or photocarriage coordinates by means of a three-position toggle switch. In the case of ground or model coordinates, the fourth register can be switched off if it is not used for other purposes (for example, point-number display) by certain programs.

Ample space has been reserved on the control panel for buttons, switches, and displays for starting and controlling service programs. Of central importance is the

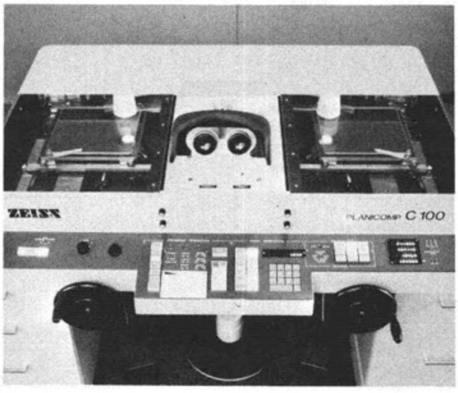

FIG. 3. View of the control panel and photocarriages of the basic opto-mechanical unit of the C-100 PLANICOMP.

"program-status" panel with "busy" and "standby" lamps indicating whether the service programs are in operation, a "wait" lamp showing whether the service program in progress is waiting for a positive or negative decision by the operator via the decision buttons "continue/yes/start" (with which the second foot control is connected in parallel) or "repeat/no/stop," as well as a "limit" display for computer-controlled limits of photocarriage travel, in which case the signals "wait" and "limit" are also given acoustically. An offset "execute" button triggers computer interrupt and causes the status of the operating panel to be read by the computer so that an activated program selector button will be recognized and the corresponding program started. In other words, erroneous activation of a button will have no effect and can still be corrected before "execute" is depressed.

The program selector buttons are subdivided into the "program operation" and "point operation" blocks. The former of these includes the permanently defined program buttons "parameter control," "interior orientation," "relative orientation," "absolute orientation," "table orientation," and the general buttons "call A progr. no." and "call B progr. no." which in conjunction with a program code figure entered on the decimal keyboard with input register define further programs. Beside this column of buttons there are three toggle switches which permit selection among up to three independent jumps on the service programs chosen, for example, whether the first six parallax points should be approached automatically or manually during relative orientation.

The "point operations" block consists of buttons for the programs MOVE TO, RECORD, DISPLAY, STORE, DELETE and CLEAR POINT MEMORY, as well as the corresponding flag buttons to determine whether these programs refer to the image-coordinate memory or the ground-coordinate memory as well as whether they apply to only one photo or only one ground-coordinate direction.

The aforementioned decimal keyboard, in conjunction with the 12-digit input register, allows the characters "-.0123456789" to be entered, the register to be erased, and the last-entered character to be corrected. It serves to enter program code figures, point numbers, and coordinates as well as other code figures (for instance, for symbols).

In view of this general concept, conversation via the computer console (teleprinter or display screen, Figures 4 and 5) boils down to a variation of the parameters of the COMMON data that will be explained later, for the purpose of entering alphanumeric characters and for output of lists and clear-text error messages.

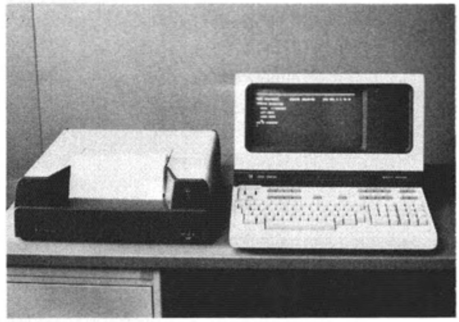

FIG. 4. Video display terminal and printer.

THE ELECTRONIC CONTROL UNIT

The electronic components operating between the basic opto-mechanical unit and the computer are referred to as the control unit. In a wider sense, a few important activities of the computer described in the following section also fall under this definition.

The different functional assemblies of the control unit are located in three slide-in units in the computer cabinet and, in part, below the control panel. Two entire slide-in units contain the DC power supply and the supply unit for the four photocarriage drive assemblies. There are additional functional assemblies for pulse counters, register for carriage-shift values, input register, button illumination and interlocking of button assemblies, data conversion, and time-base generation, as well as the input/output control of the computer via interfaces.

The data transmitted to the computer include the counted pulses of the drive ele-

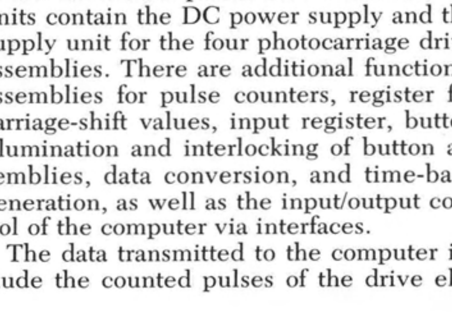

FIG. 5. Teleprinter used as a computer terminal.

ments and the contents of the input register as well as switching status. The data received by the computer are, among other things, carriage-shift values, coordinates to be displayed, status information, switching commands for the optical change-over assembly, and the acoustic signals, as well as erase commands for the input register.

The Computer

In an analytical stereoplotter, several requirements are made of the computer. It has to take care of the transmission and conversion of handwheel motion into photocarriage motion, which in analog instruments is done by mechanical guide rods. In other words, it should read the pulses counted at the handwheels and pedal disk as often as possible, process them, and transmit them in the form of shift values to the photocarriages and the tracing table. Control is sufficiently free from inertia if there are at least 40 computation cycles every second and if the shift values output are transformed into linear motion by the servosystem before the next output cycle follows.

In addition to the desired high computing speed, high computing accuracy is required in order not to impair the presently attainable high accuracy of photogrammetric techniques of 10^{-5}, equivalent to approximately 20 bits, by insufficient computer resolution.

In view of all these factors, the Hewlett-Packard HP 21 MX computer was chosen for the C-100 PLANICOMP, which for this purpose has a storage capacity (semiconductor memory) of 32 K words and a magnetic-disk station with 4.9 Mbytes distributed over a fixed and an interchangeable disk. The calculating accuracy of this 16-bit computer is raised to the necessary level by floating-point hardware without any serious loss in calculating speed. Possible expansions are, among other things, memory protect, power fail recovery, time-base generator, dual channel port controller, and disk loader ROM. A teleprinter or a video display terminal is connected as a computer console. In the latter case, an additional line printer is used as a subsystem.

The storage capacity of the computer can be increased to 64 K or, in further steps, to 128 or 256 K. The usual peripheral equipment can be added, such as tape punch and tape reader, magnetic tape deck, additional disk drive, independent line printer, etc.

The Drawing Table

For graphical plotting, the DZ-6 digital drawing table[9] is provided with the C-100 PLANICOMP. This is largely identical to the DZ-5 already described in technical literature. With an illuminated plotting surface of 1200 mm by 1200 mm, a maximum speed of 100 mm/sec, a positioning resolution of 0.01 mm, and a coordinate accuracy of 0.03 mm, as well as several plotting tools, this table fully satisfies present-day requirements regarding on-line plotting. Further characteristics of the table-control unit in the DZ-6 are switchover between internal and external control, positioning by a separate joy stick during internal and external control, exchange of signs, secondary enlargement between 9:1 and 1:9, switchover to dashed-line plotting with line-to-interrupt ratio adjustable on decade switches, and push-button-controlled plotting of crosses in two different sizes, as well as selector deciding whether depression of the foot control lowers the plotting tool only while the pedal is kept depressed or until it is actuated again. Also included in the control unit of the DZ-6 are a system of limit switches, master switch, and clear button, but not the functions of straight-line plotting and positioning by coordinates. In the present case, these functions are taken over by the PLANICOMP software, since in the external mode the positioning commands as well as lowering of the plotting pencil are controlled by the computer or the program.

The Operating Programs

A computer without software is like an inanimate human body. If we wish to bring it to life, it is not enough just to start its heart beating, that is, to switch on the power supply. We also have to start its brain operating in order to make the body ready for action. In a computer, this is the job of operating programs.

Even in this state, however, both man and machine are still incapable of performing certain tasks. Only if the human body functions properly in its physical aspects and, in addition, responds to external communications and is prepared to learn, will it be capable of performing work. In the case of a computer, we have to develop user programs in order to make full use of its capabilities. It is only these user programs (which we call service programs if supporting the use of the PLANICOMP) that mold the character and productivity of a computer or of a computer-controlled system and thus lay the groundwork for its successful application. Before discussing the service programs in the following sections, we shall first describe the operating programs.

In the operating programs, the so-called operating system occupies a special position. It is generally procured together with the computer from the computer manufacturer and it controls the different operating functions such as the administration of storage content, the control of program cycles, and triggering of the peripheral equipment. The expandable RTE II (Real Time Executive II) by HP was selected for the C-100 PLANICOMP. Features such as multiprogramming, 99 priority levels, foreground/background, communication and loading routines, device handler, file manager, compilers for FORTRAN, ALGOL, ASSEMBLER, etc., characterize the efficiency and the components of RTE II. Users of the PLANICOMP will not normally be confronted directly or at best only indirectly with the RTE II.

The operating programs consist of LOOP and PANEL as well as numerous operating routines. LOOP is restarted cyclically every 20 msec, reads the pulses generated at handwheels and the pedal disk or the joy stick of the PLANICOMP, adds them to the model coordinates and in several transformation steps computes the ground coordinates corresponding to the new model position as well as the new photocarriage and drawing-table positions, and finally outputs the necessary shift values for the photo and plotting carriages (Figure 6). In other words, the LOOP program takes the place of the mechanical guide rod in a mechanical analog instrument.

In connection with input and output of the differential data, certain status information required for LOOP computation is transmitted, for instance, whether ground, model, or photocarriage coordinates are to be displayed on the control panel, whether plan or elevation are to be plotted on the drawing table, or whether computation of drawing-table control can be omitted because the table is disconnected. If, in addition, no shift increments have been entered by the controls, only input/output will be performed and the different transformation steps need not be computed. In this case, LOOP terminates after only 1 msec, and 19 msec are available for other computations (service programs or background programs). In the case of photo drive, LOOP takes from less than 5 msec, to about 9 msec, so that on request the cycle rate could be increased to 100 Hz by simple adjustment.

The PANEL program serves to initiate the service program chosen. It is started by the "execute" button of the control panel and reads and analyzes the position of buttons and switches that cannot be read by LOOP as well as the input register of the control panel and it starts the service program selected.

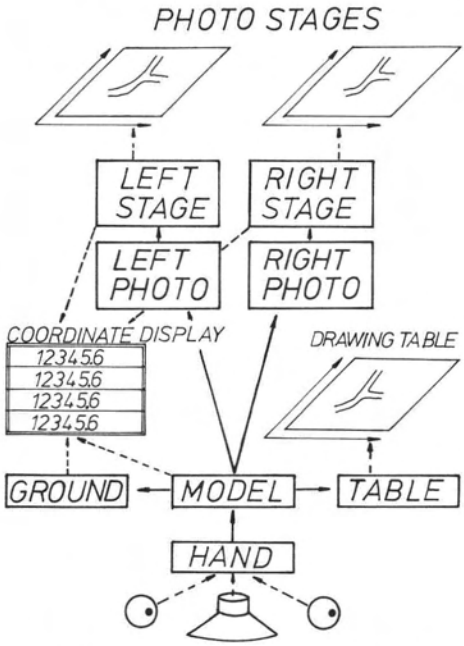

FIG. 6. Diagram showing the coordinate transformation by the LOOP operating program of the PLANICOMP.

Examples of operating routines are the LIGHT, CORE, MOVE, and NUREG subroutines which allow user programs to act on the status display and the numerical input register, as well as on photocarriages and drawing table and to activate the position buttons "continue/yes/start" and/or "repeat/no/stop." With the aid of these routines, which can be called by means of conventional FORTRAN statements, users of the system will be able to write their own, additional interactive user programs.

THE SERVICE PROGRAMS

While for several reasons some of the operating programs and subroutines have been written in ASSEMBLER, all service programs are in FORTRAN to facilitate subsequent modification, allowing for practical experience or special uses. All programs can be handled in largely the same manner, following the pattern of analog plotters. In spite of the complexity of analytical systems and the multitude of service programs listed below, the operation and computation in the C-100 PLANICOMP remain fully transparent in any stage of the work.

At present, the PLANICOMP system includes about 70 programs. Since many of these allow various uses due to flags controlled from the control panel, the actual number of tasks to be performed is much higher. The existing software can be subdivided into several categories:

MODIFICATION/CHECKING OF INDIVIDUAL PARAMETERS OF COMMON DATA

The PARAMETER CONTROL program serves to display the instantaneous value or status of important parameters interactively on the computer terminal so that they may be corrected, if necessary. To do this, the parameter to be checked is entered in the form of an alphanumeric code of two to four characters (practically the variable identifier used in higher programming languages). All independent parameters such as camera focal length, distortion, model and plotting scale, model designation and name of operator, parameters for incremental recording, etc., as well as other important parameters automatically resulting from orientation can be checked and modified in this manner. In the case of many uniform jobs within more extensive projects, the independent parameters will remain constant over a long period so that this program will then be used only very rarely.

ORIENTATION

The four programs INTERIOR ORIENTATION, RELATIVE ORIENTATION, ABSOLUTE ORIENTATION, and TABLE ORIENTATION are employed for orienting the stereo pair to be plotted in the PLANICOMP as well as for orientation of a map manuscript that may already have been started.

The program INTERIOR ORIENTATION checks interior orientation by automatic rough setting of the four fiducial marks to be measured and, after fine adjustment of all marks (either two or four fiducial marks per photo), computes the position of the photographs on the photocarriages and thus the transformation parameters required for LOOP. If four fiducial marks are measured, allowance is made for affine film shrinkage.

The program RELATIVE ORIENTATION requires a minimum of six and a maximum of 24 parallax measurements, computes the relative orientation parameters by the condition of collinearity by the necessary number of iterations, and retains either the left or righthand photo (optional). Finally, it displays the residual parallaxes including RMS value on the terminal. The results of orientation become effective only after approval by the operator in the form of depression of the "yes"-button on the control panel (Figure 7). In the bridging mode the already known tie points may be automatically prepositioned.

The program ABSOLUTE ORIENTATION is used both for independent orientation and for bridging. It allows for up to 24 measurements of partial or full control points or tie points in any desired order. In the case of independent orientation, at least two horizontal and three vertical control points must be measured. A comparison with the control data is performed in the computer. After the necessary number of iterations it produces corrections of orientation which, in turn, become effective only when the operator accepts the residual control errors displayed (Figure 8). If bridging is desired, scaling is performed with the aid of at least one tie point, with output of residual errors if there is more than one point. Here also, the operator must give his approval before the result is actually implemented. However, if additional control points are available and have been measured in the new model which is automatically detected by the program by a comparison of point numbers absolute orientation will automatically be computed as well. On the basis of the output coordinate errors for the status "before reorientation" and "after reorientation," the operator may decide whether or not the computed reorientation should become effective.

The program TABLE ORIENTATION computes the correlation parameters model to table required for LOOP after measurement of two previously identified points in the stereo model and on the drawing sheet. If additional points (maximum 24) are measured, an adjustment is made, and affine paper shrinkage is taken into account if the operator accepts the residual errors at the map points.

A new MANUAL ORIENTATION allows incremental orientation setup or change as in any analog stereoplotter.

MANIPULATIONS IN REGARD TO MEASURED IMAGE POINTS OR CONTROL POINTS

The POINT OPERATIONS comprise six separate programs permitting simple input/output and the use of coordinates in the corresponding memories.

```
MODEL OBERSCHWABEN 282/286   OPERATOR BMSLAB/HBB   DATE 1976. 5.13.11.34

INTERIOR ORIENTATION
   USING  4 FIDUCIALS

   RIGHT PHOTO

   OK
END OF INTORIENT


RELATIVE ORIENTATION
   WITH LEFT  PHOTO FIX IN  ORTHO MODE
  USING 12 PARALLAXE POINTS

   COMPUTATION BY 3 ITERATIONS
   SIGMA 0 =  1.666

   RESIDUAL PARALLAXES IN PHOTO
   POINT Y-PARALLAXE
       1        -.005
       2        -.006
       3        -.011
       4         .000
       5         .011
       6         .010
       7        -.020
       8        -.002
       9         .014
      10         .002
      11         .007
      12        -.008
    MEAN         .010

** ACCEPTED ?

MOVE TO POINT             7
   NO
** RESULTS IGNORED
** CHECK,CORRECT,DELETE OR STORE ADDITIONAL PARALLAXE POINTS
** BY USING POINT OPERATIONS
** AND REPEAT COMPUTATION BY PRESSING >REPEAT<
** OR TERMINATE RELORIENT BY PRESSING >CONTINUE<

STORE POINT               7 XL=  33.692 YL= -79.745 XR= -45.814 YR= -81.357

MOVE TO POINT             9

STORE POINT               9 XL= -14.897 YL=  46.744 XR= -94.253 YR=  44.196

   REPETITION OF COMPUTATION WITH 12 PARALLAXE POINTS

   COMPUTATION BY 2 ITERATIONS
   SIGMA 0 =    .958

   RESIDUAL PARALLAXES IN PHOTO
   POINT Y-PARALLAXE
       1        -.021
       2        -.026
       3        -.005
       4        -.002
       5         .004
       6         .025
       7        -.028
       8        -.020
       9         .003
      10         .002
      11         .009
      12        -.002
    MEAN         .005

** ACCEPTED ?
   YES

   NEW MODEL PARAMETERS :
                 LEFT       RIGHT       MODEL BASE
   OMEGA         .394       -.005     BX    95.503
   PHI           .712        .522     BY    -3.497
   KAPPA      -3.356      -3.994     BZ     -.099

   OK
END OF RELORIENT
```

FIG. 7. Usual printout of interior and relative orientation in the C-100 PLANICOMP.

```
ABSOLUTE ORIENTATION
   ALREADY MEASURED ORIENTATION POINTS
    I  POINT           XG           YG              ZG
    1    204    61999.000    60955.500         484.130  CONTROL POINT
    2    212    61383.100    60240.500         534.250  CONTROL POINT
    3    208         .000         .000         493.420  CONTROL POINT
    4    209    59882.200    60030.100         494.950  CONTROL POINT
    5    207    62164.200    59942.000         509.830  CONTROL POINT
    6    206    60066.800    60851.300         509.860  CONTROL POINT
   NEW MEASURED POINTS
    7    254         .000         .000         505.410  CONTROL POINT
    8    257         .000         .000         506.700  CONTROL POINT
    9    205         .000         .000         484.000  CONTROL POINT

   COMPUTATION BY  2 ITERATIONS
   SIGMA 0 =    .293
   RESIDUALS AT CONTROL POINTS AFTER ABSORIENT
    I  POINT         DXG          DYG          DZG
    1    204        .297         .000         .271
    2    212        .180        -.453        -.101
    3    208                                 -.275
    4    209       -.195         .000         .349
    5    207       -.336         .469         .042
    6    206        .047        -.023        -.040
    7    254                                 -.065
    8    257                                 -.210
    9    205                                  .028
        MEAN        .262         .326         .204

** ACCEPTED ?
   YES
   ABSOLUTE ORIENTATION EFFECTIVE AND THUS FIX PHOTO CORRECTED

   NEW MODEL PARAMETERS
                 LEFT     RIGHT      MODEL BASE      MODEL CENTER
   OMEGA         .028      .107   BX   115.821  XG0   60937.250
   PHI          1.076      .363   BY     4.335  YG0   60539.070
   KAPPA        -.000      .695   BZ      .265  ZG0    2355.568
   MODEL SWING     98.644

   NEW POINTS
   POINT           XG           YG           ZG
   NONE

   OK
END OF ABSORIENT
```

FIG. 8. Usual printout of independent absolute orientation in the C-100 PLANICOMP.

The MOVE TO POINT program controls the automatic approach of stored points or by ground coordinates input. RECORD POINT records the instantaneous floating-mark position on the desired peripheral unit. STORE POINT stores the instantaneous position or ground coordinates to be entered by the control panel in the point memory. DISPLAY POINT displays stored coordinates on the terminal. DELETE POINT erases individual points in the point memory either completely or only individual coordinates. CLEAR POINT MEMORY erases all points in the point memories either completely or in individual coordinates only, for example, all Z ground coordinates.

Points are selected by entering the point number in the input register of the control panel and by selecting the corresponding memory (photo or ground-memory) and the coordinates (*X*, *Y*, *Z* or left and/or right-hand photo) by the corresponding conditional flag buttons.

All the programs mentioned up to this point can be called from the control panel by depression of separate illuminated buttons. The following programs require addressing by a two-digit code, but this is likewise done from the control panel of the basic unit.

OUTPUT OF PRINTOUT AND LISTS

Several programs allow printout of model data in English, French, Spanish, and German (Figure 9); the listing of effective camera data; contents of photo and ground-coordinate memories, transformation data; and the effective data of the last calibration as well as a listing of presently installed programs available for use.

COMPUTING GEOMETRIC MAGNITUDES

This covers programs for computing the center of gravity of *n* points (also suitable for averaging in the case of multiple pointing), computation of horizontal/vertical distances, and of the lengths of straight lines or curved lines in space, determination of solid angles, azimuth, or slope angles, and areas and volumes, the latter by continuous or incremental tracing of boundaries (Hobbie, 1976).

RECORDING DIGITAL TERRAIN MODELS

Four programs allow recording in differ-

```
LIST MODEL DATA E =====================================================

MODEL DAUN-MEHREN 209/213    OPERATOR BMSLAB/HBB   DATE 1975. 4. 1. 8.13
-----------------------------------------------------------------------

   MODEL SCALE 1:  10000   TABLE SCALE 1:   5000   PHOTO SCALE 1:  12185

   ORIENTATION DATA  LEFT PHOTO  RIGHT PHOTO                       MODEL
   ----------------
                  F    153.220      153.220  FLIGHT HEIGHT          1868
              OMEGA       .039         .126   ABOVE GROUND
                PHI      1.084         .396
              KAPPA      -.000         .688          AZIMUT       98.638
                 BX    -57.964       57.964  MODEL    ( XG0    60937.88
                 BY     -2.148        2.148  CENTER   ( YG0    60539.49
                 BZ      -.106         .106  POSITION( ZG0      2355.56

   MODEL BASE: B =    115.928 (ORTHO)    EARTH CURV.CORR.: R =   6370000

   ORIENTATION REPORT
   ------------------
   ABSOLUTE ORIENT.  USED CONTROL POINTS  PLANIMETRY  4 ELEVATION 14
                     POINT NO.    250  204  253  255  212  208  254  205
                     POINT NO.    257  261  259  258  206  209
                     RESIDUAL COORDINATE ERRORS          MEAN          MAX
                                                  X      .080         .101
                                                  Y      .164        -.168
                                                  Z      .135        -.224

   RELATIVE ORIENT.  USED PARALLAX POINTS  11
                     RESIDUAL PARALLAXES         MEAN    .005  MAX    .009

   INTERIOR ORIENT.  USED FIDUCIALS    4                  LEFT       RIGHT
                                      X-SHRINKAGE    .999825     .999849
                                      Y-SHRINKAGE    .999816     .999791
                                      RECTANGUL.        .000        .000

   REMARKS:
   --------

END OF MODEL DATA E ===================================================
```

FIG. 9. List of model data of the C-100 PLANICOMP (English language printout).

ent formats and on different output units with incremental triggering. RECORD TERRAIN MODEL is intended for free motion (for instance, for digitizing contours) and for supplementing separate recordings. RECORD TERRAIN PROFILE includes profile control by parameters entered and, among other things, the possibility of triggering premature profile increments. In either of the two programs time, travel, or elevation can be chosen as triggering increment. In addition to this primary increment, a secondary increment with upper and lower thresholds can be chosen, for instance, to suppress recording in the case of primary time intervals if an insufficient distance is covered or to trigger the recording earlier if a very large distance has been covered.

The RECORD TERRAIN GRID program is based on a grid with optional squares, independently in x and y, and may be used either as an incremental configuration or for automatic positioning in conjunction with a static height setting entered by the operator.

RECORD CROSS SECTION controls digitizing or entering a center line and then scanning along cross sections for getting incremental or individual measurements.

AERIAL TRIANGULATION

G. Koneeny (1976) has reported that analytical stereoplotters are excellent for aerial triangulation. Direct numerical checking allows a correction of data already in the measurement phase and guarantees largely error-free material for final adjustment. It may be expected that, in connection with the PLANICOMP and the existing programs, a new form of a "numercial aerial traverse" will develop due to the corresponding relative orientatuon of every consecutive model. Consequently, only a small program is required for the orderly storage of the models measured as well as larger programs for strip or block adjustment by models. The Institute of Photogrammetry of Stuttgart University under the direction of Prof. Dr.-Ing. F. Ackermann is presently preparing minicomputer variants of the strip and block-adjustment programs of models (Ackermann, 1970) successfully used in large computers, which will then be offered to supplement the C-100 PLANICOMP and will presumably allow the processing of up to a few hundred models per adjustment.

GRAPHICAL PLOTTING

Pencil following in the manner of analog plotters is already made possible by the LOOP operating program. The graphical user programs offer additional functions. PLOT ON LINE allows continuous alternation between pencil following and controlled, non-simultaneous plotting such as is required for straight lines or spline-interpolation. In addition, this program allows "supplementary" plotting, such as the addition of the fourth corner of a house with the necessary straightline connections, if only three corners are actually set (filling-in a parallelogram). PLOT SYMBOL allows the plotting of a number of cartographic symbols and the addition of figures, such as point number, elevation or planimetric coordinate with optional character size, rotation, and position. PLOT ALPHA allows the plotting of text keyed on the terminal (any ASCII characters available on the terminal keyboard may be used), likewise with optional size, rotation, and position. GRID PLOTTING controls the plotting of a grid consisting of crosses or lines, with or without frame and with or without marginal coordinates, practically in off-line mode. POINT PLOTTING controls off-line plotting of a selectable array of control points.

INPUT AND OUTPUT OF ORIENTATION DATA

In view of the fact that the plotting of certain models may be repeated or continued later on, it is advisable to store the model-defining data externally on a disc file or on punched tape, magnetic tape, etc., and then to read it in whenever necessary. In this case, subsequent reconstruction of the model only requires interior orientation to determine the different position of the photograph in relation to the photocarriage. As a result, the time required for reconstruction is reduced to about one-third of the very fast overall orientation process in the PLANICOMP, that is about 5 minutes. SAVE, ENTER, RECORD, and READ ORIENT DATA then allow output and repeated input of the model data. TRANSFORM ORIENT DATA converts the orientation data obtained in the PLANICOMP into setting values for analog instruments and lists all data in a final printout.

A second group of programs refers to the total area of COMMON data and thus not only covers model data but also calibration data, equipment constants, and point measurements: SAVE, ENTER, RECORD, and READ COMMON DATA and LIST COMMON DATA. SET COMMON DATA allows the model parameters, calibration data, equipment constants, or similar groups of parameters to be reset to an initial state by means of flag switches.

INPUT AND OUTPUT OF GROUND CONTROL DATA

A similar program as for handling orientation data is for transfer of control point information between ground memory, a large disc file, and peripheral input/output devices. SAVE, ENTER, and RECORD AND READ GROUND DATA control the transfer of points, while LIST and CLEAR GROUND FILE list or clear part or all of ground file.

INPUT AND OUTPUT OF EVALUATED GENERAL DATA

Any digital information gained during use of DTM-programs, aerial triangulations, and similar procedures may be saved in one of a set of disc files for later use by an off-line program for transformation, adjustment, etc. LIST and CLEAR GENERAL FILE list or clear part or all of selected general files. RECORD and READ GENERAL DATA allow output/input to or from any peripheral device.

CALIBRATION AND FUNCTIONAL CHECKOUT

The program C-100 CALIBRATION allows semi-automatic calibration of the two photocarriages or the on-line DZ-6 drawing table by automatic rough setting of the intersections of a grid plate (in the case of the photocarriage, this is generally the integral 9-point grid) with optional number and spacing of squares as well as complete adjustment of the calibration measurement right up to output of the computed screw lead, rectangularity, and all residual errors of grid intersections. The result of this program likewise becomes effective only if it is accepted by the operator.

Functional testing of the PLANICOMP system is possible by means of the C-100 FUNCTION TEST program which checks all essential functions of the basic unit, the control panel, and the control unit of the PLANICOMP directly from the computer. Certain operations must be performed by the operator following programmed instructions (via terminal). The resulting printout will reveal possible malfunctions. Diagnostic programs for the computer periphery already form part of the material supplied by computer manufacturers. This program-controlled functional test cannot be used should the computer fail. In this case, a special test device may be connected to the PLANICOMP control unit instead of the computer.

All the programs described before include extensive diagnostic routines providing error messages in clear text and not in the form of a code figure as is frequent practice elsewhere. With the aid of the bit switches on the front panel of the computer, the information displayed by the computer on the terminal within the user programs can be expanded step by step, for instance, by additional hints on operation for beginners, detailed intermediate or final results in the case of apparently inexplicable program results, right up to the matrices of error and normal equations in the case of adjustments.

A special characteristic of the program structure that is of great importance for operation of the PLANICOMP is the subdivision of the user programs into three priority levels: A-programs of high priority, B-programs of medium, and C-programs of low priority. This order corresponds to the procedure usually employed by human operators who will briefly perform other manipulations or obtain information required for further operation (A-level) during their primary work (B-level). In addition, certain work is frequently performed simultaneously, the results of which are not directly related to the primary work (C-level). This is why a subdivision into short programs (A), main programs (B), and background programs (C) has been chosen. The operating system RTE II will process simultaneously requested programs of identical or different priority following the rule that in the case of programs of identical priority, the one started last kills the one in progress, that a program of higher priority interrupts one of lower priority, and that an interrupted lower program will be reactivated only after the end or suspension of all higher-priority programs that may be in progress.

Performance of the C-100 PLANICOMP

Accuracy

The photocarriages are positioned with a resolution of 1 μm. The reproducibility of settings by the operator is not only limited by the accuracy of photocarriage motion but also by the 8× eyepieces of the standard viewing optical system as well as by point definition. In the case of clearly defined objects such as grid crosses, it is about 2 μm in the PLANICOMP. It will be correspondingly lower for signalized and natural points in aerial photography, depending on image quality. The absolute measurement accuracy in the photocarriage axes and thus the image coordinates is 3 μm standard deviation over the entire photograph area. Maximum errors remain within 7 to 8 μm. Grid measurements over 24 points gave RMS errors as referred to the image plane of $\sigma_x' = \sigma_y' = 4$ μm and $\sigma_z' = 6$ μm, equivalent to 0.04 % of H in wide-angle photography (which corresponds to a C-factor of 7500).

Speed

A decisive factor for the economical use of a photogrammetric plotter is its operating speed. Pure computing time in on-line work is practically negligible; the computing time required for adjusting relative or absolute orientation is only about 2 and 5 seconds, respectively, for an average number of measured points and iterations. Thus, the overall time needed is essentially determined by finding and setting points, by entering point numbers, and—unless this was done in advance—by entering the control data. Complete orientation of a stereo model takes about 15 to 20 minutes, of which approximately 5 minutes correspond to the positioning of the photographs and interior orientation, 8 minutes to relative orientation using approximately 12 parallax points and assuming one correction process due to a few erroneous parallax measurements, and 7 minutes to absolute orientation after measurement of approximately 6 to 8 control points, once more assuming individual repeat measurements and a second arithmetic operation. Manual input of control coordinates takes about 30 seconds per control point.

The values indicate that about 30 minutes per model would have to be assumed in model measurements for aerial triangulation if approximately 12 to 18 tie and control points were measured. This already includes a rough correction of measurement data on the basis of the residual bridging errors.

In graphical plotting, a considerably higher production rate may be expected at large and medium scales due to the consistent use of computer-supported plotting functions.

Plottable Camera Geometries

Central-perspective photography of any desired focal length can be plotted. Allowance for the nominal fiducial-mark separations and radial distortion (linear interpolation between given reference values, up to 17 values with optional spacing being possible) makes it possible to correct for affine film shrinkage and radial-symmetric distortion. In addition, major asymmetry can be compensated by entering a principal-point shift. Focal length, fiducial-mark separations in x and y, and distortion values may vary for the pair of stereo photos.

PLOTTABLE FLIGHT CONFIGURATIONS

Stereoscopic plotting is predicated on sufficient overlap between the two photos, which requires sufficient parallelism between camera axes. Apart from this, the mathematical formulation of the PLANICOMP software does not restrict the flight configuration. Near-vertical or near-horizontal (terrestrial) photography, oblique photography, and, unless coarse differences of scale between the photos impair stereoscopic vision, swung as well as convergent photography can be plotted. Model height is corrected for earth curvature even in the case of oblique photography. By varying the radius of the spherical reference surface it would thus also be possible, for example, to make allowance for "lunar curvature."

OUTPUT

The standard user programs allow a multitude of different output versions.

Numerical output

Recording of points.
Incremental recording by intervals of time, travel or height.
Both primary and secondary increments.
Output in the form of visual display, clear text, or in coded form on compatible data media to suit existing peripheral equipment.
Different output formats.
For digital terrain models and digital maps.
Computation of derived geometric magnitudes such as center of gravity, distance, length, angle, area, volume.

Graphical output

Pencil following.
Computer-supported plotting.
Plotting of symbols, point numbers, coordinates, lettering.
Fully automatic plotting of grids, point arrays, etc.

The standard version of the C-100 PLANICOMP "photogrammetric plotting center" will handle the routine production work of photogrammetric organizations.

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