

DESIGN CONSIDERATIONS FOR A HIGH ACCURACY  
ANALYTICAL STEREOPLOTTER

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### INTRODUCTION

The design considerations for, and the approach taken by Canadian Marconi Company to the design of the Anaplot II Analytical Stereoplotter reflects to a large extent the heritage of the instrument and the form of the Company's commitment to the photogrammetric market.

The analytical stereoplotter was conceived at the photogrammetry section of the National Research Council of Canada, and the related technology was developed to a high degree in the Anaplot instrument constructed by the Council at Ottawa, Canada.

The Canadian Marconi Company has become the licensee of this technology, with the intent of commercializing the work done by the Council, and of further developing the technology to generate a family of related products.

The specification of the instrument designed by the Company was formulated in consultation with the National Research Council, and based upon the intent of fully utilizing the technology developed by the Council, and the decision of the Company to enter the field of photogrammetric instrumentation from the high technology end by the introduction of a truly state of the art first order instrument, priced to compete in the commercial marketplace.

It was decided in laying the groundwork for the specification that the precision of measurement should be at least an order of magnitude better than the expected resolution of the photographic material expected to be used. This implied that the mechanical measurement of accuracy of the instrument be on the order of two micrometers, and the optical resolution of the instrument be on the order of three to four hundred line pairs per millimeter.

In specifying the operator interface to the instrument, it was decided that speed of response to operator inputs must be sufficiently superior to the reaction time of human perception and response to prevent the intrusion of the mechanism of the instrument on the concentration and effectiveness of the operator.

It was also decided that considerable effort should be expended on the ergonomic design of the instrument to ensure adequate eye relief, exit pupil size, strabismus correction, and placement of controls.

In view of the Company's commitment to developing a family of related products based upon the Anaplot technology, a modular design approach was chosen in keeping with modern trends,

the modules consisting of photostages, viewing system, control electronics, control computer and input-output devices.

The functional software as developed by the National Research Council was incorporated on an as-is basis, with the addition of human engineering features, rendering the operating systems more conversational, less vulnerable to operator error, and easier to learn to use. This software provides the means of satisfying the needs of the classical mapping process, aerotriangulation, and the semi-automatic production of digital terrain maps, to name a few uses.

The initial version of the Anaplot II to be marketed was designed around the following requirements:

- two independantly moveable photostages accommodating 9 inch x 9 inch (23 cm. x 23 cm.) photographs on bases up to 0.25 inches in thickness.
- each photostage provided with two axis motion provided by a servo system providing position measurement precision of one micrometer.
- continuously variable photostage illumination.
- luminous measuring marks associated with each photostage.
- computer controlled zoom and rotation optics in each viewing channel.
- conventional hand and foot wheel controls in conventional locations with respect to eyepiece placement.
- joystick control to replace X and Y handwheel functions.
- fields of programmable switches providing direct computer communication, to provide the operator with simple command communication with programs.
- all operator functions (footwheel, handwheels, switches, indicators, etc.) be exchanges with the control computer, and all instrument functions be under direct computer control.
- the real-time computation cycle be repeated completely every ten milliseconds.

These basic requirements were met, with due respect to target price and design cycle schedule by the use of Canadian Marconi Company electronics and mechanical design and manufacture, Bausch and Lomb optics, and Digital Equipment Corporation computing systems.

MECHANICAL CONFIGURATION AND PHOTOSTAGE SYSTEM

The mechanical structure of the Anaplot II is based upon a rigid, flat surface plate mounted on vibration isolating supports. The rigidity, flatness and vibration isolation are controlled such that they do not have more than second order effects on measurement accuracy.

The photostages ride directly on the surface plate, supported by air bearings and guided by air bearings on crossed ways, and are driven by D.C. motors and friction nuts.

Each photostage is surmounted by a glass plate that supports the photographic material and serves as a part of the measuring system. Two edges of each glass plate are polished smooth, straight and mutually perpendicular, and the glass plates are aligned with the mutually perpendicular ways.

Linear encoders of one micrometer resolution ride against the edges of the glass plates, two encoders per plate, on graphite buttons, with the axes of the encoders lying in the plane of the photographic imagery and intersecting the optical axes of the viewing instrument.

Careful alignment of ways, encoders, and glass plates provides an RMS measurement accuracy over the 9 inch x 9 inch viewing area of the photostages of better than 1.5 micrometers before the application of corrections.

In the interest of modularity of design, the optical viewing subsystem is mounted on the mechanical structure of the surface plate as an interchangeable unit.

The complete mechanical and optical system is enclosed in a metal shroud, which is supported by the base of the instrument below the antivibration mounts of the surface plate, so that the measuring/optical system is fully protected from the working environment. The only contact the operator can have with the measuring system is by touching the eyepieces.

The shroud, as well as protecting against mechanical shock, ensures that the instrument is enclosed in an atmosphere of dry, filtered air which is provided by the exhaust of the air bearings.

The glass measuring system, and the metallic parts of the optical system and the photostage are matched for thermal expansion, so that the instrument functions as expected at any stable temperature.

### OPTICAL VIEWING SYSTEM

The optical viewing system used was the Bausch and Lomb Zoom 500 stereoscope modified specially for use with the Anaplot II stereoplotter. The Zoom 500 was chosen as a starting point for the optical system because it was a proven instrument with basic characteristics which were in accord with the general design objectives.

The specifications imposed upon the Canadian Marconi Company's modified version of this instrument were as follows:

- two optical trains for viewing the photographs mounted on the two photostages.
- low optical distortion to minimize operator fatigue. Distortion limited to less than 5 %.
- low field curvature.
- vertical and horizontal strabismus correction of up to + 2.5 degrees in each optical train.
- independantly focusable oculars adjustable in the range of + 4.5 diopters.
- interocular distance adjustment from 50 mm to 75 mm.
- head rest mounted on shroud mechanically independant of the optical system.
- eye shield mounted on shroud mechanically independant of optical system.
- eye relief of at least 15 mm at maximum magnification to accommodate eyeglass wearers.
- minimum exit pupil of 1.1 mm diameter of 27 x magnification.
- operator's line of sight depressed at 10 degrees from horizontal.
- incorporation of optical switches to permit normal stereoscopic viewing, pseudostereoscopic viewing, stereoviewing of left photostage, stereoscopic viewing of right photostage.
- luminous circular measuring marks of selectable size inserted in the optical train at the objective end, ensuring measuring mark/imagery fusion independant of instrument operation.

- independant computer controlled zoom magnification in each optical train over the range of 4.6 x to 27.4 x.
- independant computer controlled image rotation in each optical channel over a range of 360 degrees.
- resolution of at least 7 line pairs per mm per magnification.
- field of view magnification product of 200 mm (i.e. 30 mm at 6.6 x).
- independant, continuously variable measuring mark intensity.
- independant, continuously variable photostage illumination intensity.
- the whole optical subsystem bolt onto the surface plate structure of the instrument as an interchangeable unit.
- the various features of the optical system be modular such that future optical systems be assembled to meet specific user requirements.

#### CONTROL ELECTRONICS

The control electronics and associated power supplies are located in a separate cabinet from the stereoplotter instrument in order to isolate all possible sources of heat from the measurement mechanism.

Operator inputs are presented to the control electronics as switch closures, and as pulse trains generated by the handwheels, joystick, and footwheels.

Stereoplotter status is presented to the control electronics as switch closures, potentiometer positions, and pulse trains from linear encoders.

The control electronics provides for operator/computer interaction, stereoplotter/computer interaction, and the closure of the servo loops for stage positioning, image rotation, and image zoom.

Image rotation and zoom are accomplished by D.C. servos matching potentiometer positions to values produced by digital/analogue conversions of data held in registers updated by the control computer. The same mechanism is used by the computer for measuring potentiometer positions set by the operator in manually positioning the zoom and rotation settings.

Photostage positioning is accomplished by digital servos in order to provide the performance required for the man machine interface. That is, to ensure that the response of the instrument be sufficiently superior to the reaction time and perceptions of the operator to ensure no degradation of operator performance.

Hardware registers in the control electronics count pulses generated by the linear encoders to maintain photostage position status. Registers containing demanded photostage position data are updated every ten milliseconds by the control computer as the output of the real time calculations.

The positioning servo loop for each axis is closed by a micro processor that compares position with demanded position, and calculates the drive requirements of the DC motor driving the axis on the basis of the rate of change of position and position error. The drive requirement data is transformed into a D.C. voltage by a digital-analogue converter and applied to the D.C. motor.

The algorithms used by the microprocessors for closing the servo loops are designed to minimize following error and maximize speed, while allowing no overshoot.

Smooth response to operator input is accomplished, with slewing speeds of 80 mm per second available.

The control electronics also provides for operator numerical read-outs, status indication, numerical keyboard inputs, and programmable operator control switches.

#### CONTROL COMPUTER

The control computer used is the Digital Equipment Corporation PDP 11-34, with the RSX-11M shared user operating system. Two hard disks are used, one serving as a repository of application programs, and one serving as a medium of file transfer. Operator communication with the computer, at operator option, is accomplished via the stereoplotter control panel, CRT terminal, or a hard-copy terminal.

#### OPERATOR CONTROLS

The specification for operator control form and location was arrived at as a result of a study of human factors. A theoretical study, experimentation with human subjects, and a survey of instruments and tools relating precision muscular activity to visual stimuli resulted in elaboration and quantification of the generalized objectives of the ergonomic design of the instrument.

The placement and function of the operator controls of Anaplot II was based upon the result of this study.

An operator's control console is located below the level of the eyepiece assembly so that all controls are accessible to the operator at normal viewing position without disruptive movements of the head from the eyepiece assembly. It consists of buttons, switches, lights, displays, and a joystick control.

Handwheels are located in conventional positions so that the median operator, when looking through the eyepieces, has the upper arms vertical and the forearms horizontal when operating the handwheels. The footwheel and foot switches are operator locatable.

#### SOFTWARE

The applications software associated with Anaplot II was written by the Photogrammetry Section of the National Research Council of Canada, and is well described elsewhere. (Notably, The Canadian Surveyor, June 1979.) This software, in the Anaplot II configuration is, as far as possible, operator forgiving. That is, it allows the operator to correct transient errors, and has extensive syntax and error checking logic. Great care is taken with all of the application software to ensure that an incorrect command cannot cause irretrievable damage.

#### CONCLUSION

The design of Anaplot II is seen as an unusually interesting exercise, in that it can be seen not only as a system engineering problem, but also as a computer with a specialized peripheral device.

Seen as a computer peripheral, it is a device for relating photographic material to software through the offices of a human operator, and design considerations in the end must be based upon this fact.