THE ELEMENTARY PRINCIPLES OF STEREO-PLOTTERS FOR AIR PHOTOGRAPHS*

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(PAPER DELIVERED BEFORE THE THIRTIETH ANNUAL MEETING OF THE CANADIAN INSTITUTE OF SURVEYING, FEBRUARY 3, 1937)

INTRODUCTORY

THE AIM IN THE PRACTICAL APPLICATION OF AIR-PHOTOGRAMMETRY IS TO CONVERT THE INFORMATION REGISTERED BY PHOTOGRAPHY INTO A CONVENTIONAL MAP, AND PARTICULARLY TO PRESERVE THE METRICAL ACCURACY OF THIS MAP. IN ALL CASES THIS IS DONE BY THE APPLICATION OF THE RULES OF PERSPECTIVE PROJECTION, USUALLY WITH MORE OR LESS AID FROM SPECIALLY DESIGNED INSTRUMENTAL EQUIPMENT.

IN CANADA WE HAVE BEEN PRINCIPALLY CONCERNED WITH SMALL-SCALE MAPS, OFTEN WITH VERY LIMITED GROUND CONTROL AVAILABLE, AND HAVE, THEREFORE, NOT MADE SO MUCH USE OF EXPENSIVE PHOTOGRAMMETRICAL PLOTTERS AS IN COUNTIES WHERE DIFFERENT CONDITIONS PREVAIL. ON THE OTHER HAND, EXCELLENT PROGRESS HAS BEEN MADE IN THE DEVELOPMENT OF WHAT MIGHT BE CALLED HAND-GRAPHICAL METHODS OF PLOTTING, AND SOME OF OUR MEMBERS HAVE DONE VALUABLE SERVICE IN PERFECTING THESE.

THE QUESTION ARISES, HOWEVER, AND I THINK IS WORTHY OF INVESTIGATION, WHETHER THESE METHODS COULD NOT BE IMPROVED IN THE DIRECTION OF INCREASED ACCURACY, SPEED AND ECONOMY IF ASSISTED BY PLOTTING MACHINES DESIGNED FOR EXTENDING MINOR CONTROL, AND, IN CERTAIN CASES, FOR GIVING MORE INFORMATION CONCERNING RELIEF.

SOME PROGRESS HAS ALREADY BEEN MADE IN THIS DIRECTION THROUGH THE ASSOCIATE COMMITTEE ON SURVEY RESEARCH, OF THE NATIONAL RESEARCH COUNCIL, AND, THANKS TO IMPERIAL OIL LIMITED, WE HOPE SOON TO HAVE IN OTTAWA A PLOTTING MACHINE OF THE LATEST TYPE, WHICH WILL BE A VALUABLE AS WELL AS INTERESTING AND INSTRUCTIVE ADDITION TO OUR PHOTOGRAMMETRICAL EQUIPMENT.

I WILL SAY HERE THAT, EXCELLENT THOUGH THE WORK MAY BE THAT HAS BEEN ACCOMPLISHED BY THE CONTINENTAL EUROPEAN PLOTTING MACHINES, THEY ARE NOT ALL DESIGNED ON SOUND PRINCIPLES AND, PERHAPS, ARE SOMETIMES UNNECESSARILY COMPLEX. THEREFORE WE CANNOT REGARD FINALITY AS HAVING BEEN APPROACHED IN PLOTTING EQUIPMENT, AND THERE IS STILL PLENTY OF OPPORTUNITY FOR THE EXERCISE OF INVENTIVE ABILITY, PARTICULARLY ON THE PART OF THOSE WITH FIRST-HAND KNOWLEDGE OF THE REAL NATURE OF THE PROBLEMS INVOLVED.

THIS AFTERNOON YOU WILL HAVE THE OPPORTUNITY OF EXAMINING THE PHOTOGRAMMETRICAL EQUIPMENT OF THE GEOGRAPHICAL SECTION, GENERAL STAFF, DEPARTMENT OF NATIONAL DEFENCE, AND, AS A SORT OF INTRODUCTION, I PROPOSE TO EXAMINE BRIEFLY THE UNDERLYING CONSIDERATIONS OF STEREO-PLOTTING FROM VERTICAL PHOTOGRAPHS FROM THE POINT OF VIEW OF ONE TRYING TO APPLY THESE TO INSTRUMENTAL DEVICES. I SHALL CONFINE MYSELF TO ELEMENTARY PRINCIPLES, BUT MY PURPOSE WILL BE SERVED IF I AM ABLE TO CONVEY TO YOU SOME ACCOUNT OF THE LINES ALONG WHICH PRESENT-DAY STEREO-PLOTTERS ARE DESIGNED.

GEOMETRICAL RELATIONS IN VERTICAL STEREO-PHOTOGRAPHY

IN VERTICAL AIR PHOTOGRAPHY, AS YOU PROBABLY KNOW, IT IS CUSTOMARY TO EXPOSE AT INTERVALS THAT WILL GIVE ABOUT SIXTY PER-CENT OVERLAP BETWEEN SUCCESSIVE PHOTOGRAPHS--THE PILOT MEANWHILE ENDEAVOURING TO MAINTAIN A UNIFORM HEIGHT, SPEED, DIRECTION OF FLIGHT AND LEVEL TRIM OF HIS AIRCRAFT.

IN FIG. 1 TWO CONSECUTIVE NEGATIVES, OR A STEREOSCOPIC PAIR, ARE REPRESENTED AS BEING RESTORED TO THEIR POSITIONS AT THE TIMES OF EXPOSURE. THE PHOTOGRAPHS MAY BE CONSIDERED AS PERSPECTIVES THROUGH THE LENSES. JOINING THESE TWO PERSPECTIVE CENTRES IS THE AIR-BASE. TRACING NOW SOME RAYS FROM IMAGE POINTS TO THE CORRESPONDING GROUND DETAIL, WE HAVE FIRST THE VERTICAL LINES CONNECTING THE PLUMB-POINT BELOW EACH PHOTOGRAPH WITH THE CORRESPONDING IMAGE POINT--WHICH WILL BE THE POINT MARKED WITH A CROSS IN UNTILTED PHOTOGRAPHS TAKEN BY THE R.C.A.F. SELECTING SOME OTHER GROUND DETAIL IN THE COMMON, OR OVERLAPPED, PORTIONS OF THE TWO PHOTOGRAPHS, SUCH AS THE VERTICAL POST I HAVE TRIED TO REPRESENT IN THE FIGURE, WE NOTICE THAT THE RAY FROM ITS BASE IN A SINGLE PHOTOGRAPH DETERMINES WITH THE PLUMB-POINT RAY A PLANE--I HAVE MARKED THEM "RADIAL PLANES." IT IS READILY SEEN THAT THE INTERSECTION OF THESE PLANES IS A VERTICAL LINE PASSING THROUGH THE POINT PHOTOGRAPHED ON THE GROUND--THAT IS, THE PLANE HAS THE SAME LOCATION

*REPRINTED FROM THE "CANADIAN SURVEYOR", JANUARY, 1937.

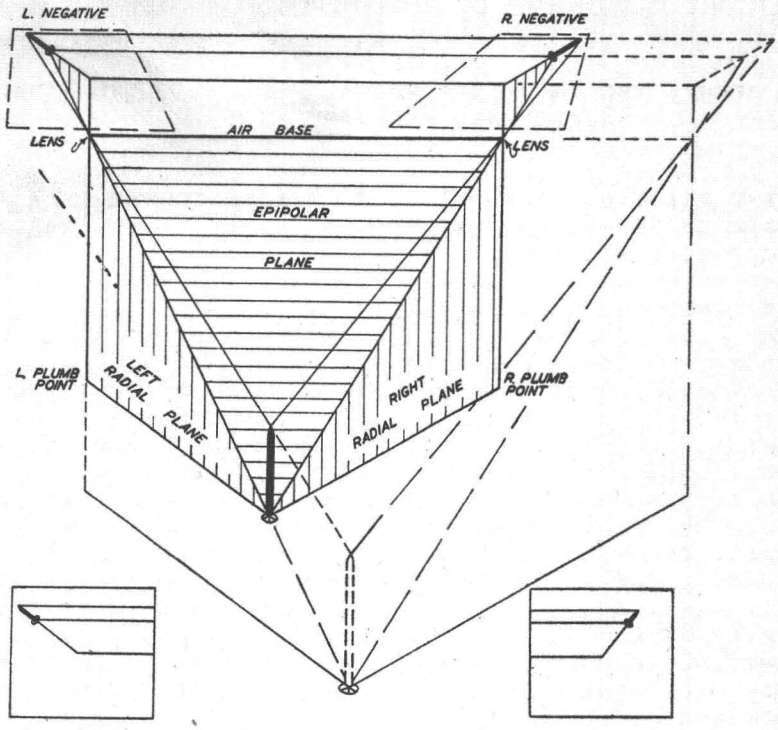


FIG. 1

WHATEVER THE ELEVATION OF THE POINT. FURTHER, IT FOLLOWS THAT THE TRACE OF A RADIAL PLANE ON ITS PHOTOGRAPH WILL CONTAIN THE IMAGES OF ALL POINTS IN THE PLANE AND, THEREFORE, OF THE INTERSECTION OF THE TWO PLANES. FOR EXAMPLE, OUR VERTICAL POST WILL BE REGISTERED IN A LINE RADIATING FROM THE IMAGE OF THE PLUMB-POINT.

THIS SUGGESTS ONE SCHEME WHICH MIGHT FORM THE BASIS FOR A PLOTTING DEVICE. IMAGINE A PAIR OF STEREO VERTICAL PHOTOGRAPHS TO BE RESTORED TO THEIR AIR POSITIONS AT THE TIMES OF EXPOSURE, AND TAKE TWO VERTICAL PLANES, FREE TO ROTATE ABOUT THE PLUMB LINES THROUGH THE PERSPECTIVE CENTRES. IF EACH PLANE BE ROTATED UNTIL ITS TRACE ON THE PHOTOGRAPH PASSES THROUGH THE IMAGE OF THE POINT WE WISH TO PLOT, THE INTERSECTION OF THE TWO PLANES WILL BE THE ORTHOGONAL PROJECTION LINE OF THE POINT IN QUESTION. HENCE, WE COULD PLOT IN THIS WAY, POINT BY POINT, THE PLAN POSITIONS OF THE DETAIL RECORDED ON THE OVERLAPPED PORTION OF THE TWO PHOTOGRAPHS. AS THE POSITION OF A RADIAL PLANE IS INDEPENDENT OF THE ALTITUDE OF THE POINT PHOTOGRAPHED, THIS METHOD, WITHOUT EXTENSION, WOULD NOT YIELD INFORMATION REGARDING THE ELEVATION OF THE PLOTTED DETAIL.

LOOKING AT THE SUBJECT IN ANOTHER WAY, WE CAN CONSIDER THE TWO RAYS TO THE GROUND OBJECT, E.G. THE BASE OF OUR POST IN FIG. 1, AS DETERMINING A PLANE WITH THE AIR-BASE--THE EPIPOLAR PLANE. THIS PLANE IS ALSO OF GREAT IMPORTANCE IN PHOTOGRAMMETRY. IT CAN BE PICTURED AS ROTATING ABOUT THE AIR-BASE AS WE PASS FROM POINT TO POINT ON THE GROUND. HERE, THEN, IS A CLUE TO ANOTHER SCHEME FOR THE CONSTRUCTION OF A PLOTTING MACHINE. MAKE TWO POINTERS PASSING THROUGH THE PERSPECTIVE CENTRES, TO REMAIN ALWAYS IN A PLANE FREE TO ROTATE ABOUT THE AIR-BASE; LET THE UPPER ENDS OF THE POINTERS PASS THROUGH THE IMAGES OF A POINT ON THE NEGATIVES, AND THE INTERSECTION OF THE POINTERS WILL DETERMINE THE POSITION AND ELEVATION OF THAT POINT ON THE GROUND. IT WILL BE APPARENT FROM FIG. 1 THAT THE EPIPOLAR PLANE CONTAINING THE IMAGES OF THE TOP OF OUR POST WILL BE DIFFERENT FROM THAT CONTAINING THE IMAGES OF THE BASE, AND FURTHERMORE, THAT THE ANGLE BETWEEN OUR HYPOTHETICAL SIGHTING RODS HAS INCREASED IN THE FORMER PLANE. THEREFORE THIS METHOD, AS DISTINGUISHED FROM THE RADIAL PLANE PRINCIPLE, YIELDS BOTH PLAN POSITIONS AND ELEVATIONS OF THE POINTS MAPPED.

TURNING TO THE ACTUAL PHOTOGRAPHS, THE NEGATIVE WITH OUTWARD OVERLAP AND THE POSITIVE WITH INWARD OVERLAP, THE TRACES OF THE RADIAL PLANES WILL BE LINES RADIATING FROM THE IMAGES OF THE PLUMB-POINT. SIMILARLY, THE EPIPOLAR PLANES WILL SHOW THEIR TRACES AS STRAIGHT LINES, WHICH WILL BE PARALLEL TO THE PROJECTION

OF THE AIR BASE IN AN UNTILTED OR LATERALLY TILTED PHOTOGRAPH, BUT INCLINED TO IT WHEN THERE IS FORE AND AFT TILT.

THERE IS ANOTHER FEATURE, OF A HELPFUL NATURE, TO BE CONSIDERED. IMAGINE THE RIGHT PHOTOGRAPH TO BE MOVED TO THE POSITION I HAVE SHOWN DOTTED--BY EXTENDING THE AIR-BASE. TRACING BACK THE RAYS FROM OUR IMAGE POINTS AS BEFORE, IT IS EASILY DEMONSTRATED THAT THE SHAPES OF OUR PLANIMETRIC FIGURES ARE THE SAME AS IN THE PREVIOUS CASE, BUT THAT THE SCALE OF THE PLOT HAS INCREASED IN PROPORTION TO THE INCREASED LENGTH CHOSEN FOR THE AIR-BASE. THAT IS TO SAY, IT IS NOT NECESSARY TO MAINTAIN THE RATIO OF FOCAL LENGTH TO AIR-BASE THE SAME AS IN THE FIELD, BUT A VALUE OF THIS RATIO MAY BE CHOSEN TO YIELD A PLOT TO ANY DESIRED SCALE.

OPTICAL PLOTTERS

THIS LEADS TO ONE OF THE SIMPLEST DEVICES FOR PLOTTING. IF A LIGHT BE PLACED BEHIND THE NEGATIVES, PREVIOUSLY ORIENTED AND ADJUSTED CORRECTLY RELATIVE TO THE AIR-BASE, AND A PIN-HOLE OR LENS BE FITTED AT THE PERSPECTIVE CENTRE, THE RESPECTIVE PROJECTED RAYS FROM AN IMAGE WILL INTERSECT AT THE SCALE POSITION OF THE OBJECT. ONE OR TWO SYSTEMS HAVE BEEN INVENTED IN EUROPE FOR PLOTTING BY PROJECTION ALONG THESE LINES, AND IN CANADA A METHOD (WHERE, HOWEVER, LOW OBLIQUE PHOTOGRAPHS WERE EMPLOYED) WAS DEVELOPED BY MAJOR NELLES AND MR. FORTIN OF OTTAWA. PROBABLY THE BEST KNOWN EXAMPLE IS THE ZEISS AERO-PROJECTOR WHICH YOU WILL SEE THIS AFTERNOON. IN THIS INSTRUMENT, SMALL REDUCTIONS OF THE PHOTOGRAPHS ARE UTILIZED, TO KEEP THE MACHINE TO MANAGEABLE DIMENSIONS AND TO GIVE THE REQUIRED DEPTH OF FOCUS AT THE PROJECTION TABLE. THE POINTS OF INTERSECTION OF RAYS ARE FOUND BY PROJECTING ALTERNATE PHOTOGRAPHS WITH RED AND BLUE LIGHT. THE OBSERVER, WEARING GLASSES IN WHICH ONE EYE FILTERS OUT THE RED AND THE OTHER THE BLUE, SEES THE RIGHT AND LEFT PROJECTIONS RESPECTIVELY WITH HIS RIGHT AND LEFT EYES* AND SO BEHOLDS A STEREOGRAM, OR SPACE MODEL, OF THE LANDSCAPE.

THE ZEISS PARALLELOGRAM

TURNING AGAIN TO THE REQUIREMENTS OF MECHANICAL PLOTTERS, THERE IS A SIMPLE LINKAGE, EXTENSIVELY USED IN THEM, WHICH CALLS FOR SOME CONSIDERATION.

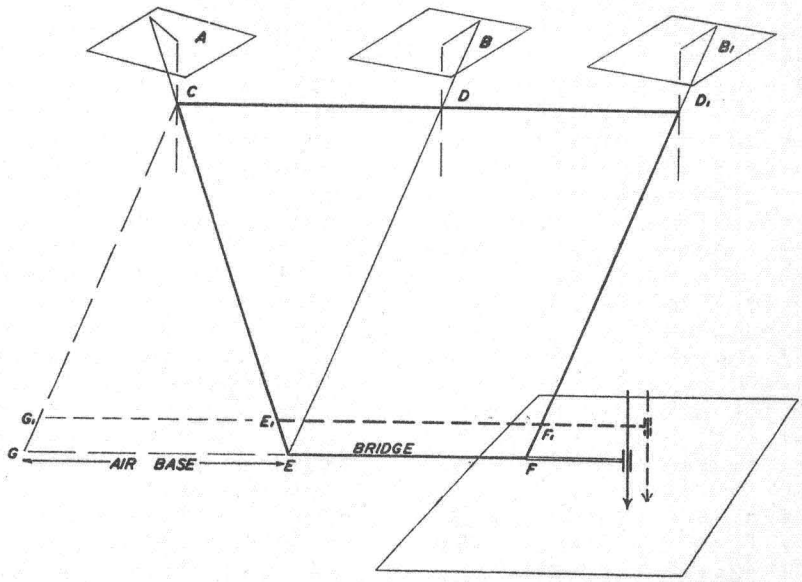


FIG. 2

IN THE HYPOTHETICAL PLOTTING DEVICE I MENTIONED WHERE TWO POINTERS MOVE IN, AND WITH THE EPIPOLAR PLANE; WHEN MATERIALIZING THR POINTERS WE ARE CONFRONTED WITH THE PROBLEM THAT THEY INTERSECT AT THE PLOTTED POINT. FURTHERMORE, UNLESS THE PLOTTING SCALE IS CONSIDERABLY LARGER THAN THAT OF THE AIR PHOTOGRAPH, DIFFICULTIES MAY ARISE DUE TO INTERFERENCE OF THE GONIOMETERS OR HOLDERS IN WHICH THE PHOTOGRAPHS ARE SET UP. IN ADDITION, AS THE SCALE OF THE PLOT DEPENDS ON THF

*THE CANADIAN SURVEYOR, VOL. V, NO. 6, PAGE 7.

LENGTH OF THE AIR-BASE, THIS LENGTH WOULD HAVE TO BE ADJUSTED FROM TIME TO TIME BY MOVING THE PHOTOGRAPH HOLDERS TOGETHER OR APART TO ACCOMMODATE VARIATIONS IN FLYING HEIGHTS AS A STRIP OF PICTURES WAS PLOTTED. OTHER DIFFICULTIES OF A MECHANICAL AND OPTICAL NATURE WOULD ARISE IN AN ACTUAL PLOTTING MACHINE, AND IN MOST EXAMPLES A MECHANISM IS EMPLOYED WHICH PERMITS SCALE VARIATIONS TO BE MADE WHILE THE PERSPECTIVE CENTRES REMAIN AT A CONSTANT DISTANCE APART.

IN FIG. 2, A AND B ARE THE TWO PHOTOGRAPHS RESTORED, AS IN FIG. 1, TO THEIR POSITION IN SPACE, RELATIVE TO THE PERSPECTIVE CENTRES. THE LENGTH CD, PARALLEL TO THE AIR-BASE, DETERMINES THE SCALE OF PLOTTING, AND CE AND DE ARE TWO SPACE RODS IN THE EPIPOLAR PLANE, CDE, WHICH PLOT THE SPACE POSITION OF THE POINT E, ON THE TWO CORRESPONDING PHOTOGRAPHIC IMAGES OF WHICH THE SPACE RODS ARE DIRECTED. IF, NOW, B BE MOVED TO A NEW POSITION B_1 BY EXTENDING CD TO D_1, AND DE BE LIKEWISE MOVED PARALLEL TO ITSELF TO D_1F, AND THE ENDS OF THE SPACE RODS BE JOINED BY A BRIDGE EF, AN INSPECTION OF FIG. 2 WILL SHOW THAT ANY POINT OF THE BRIDGE WILL PLOT THE SAME RELATIVE POSITIONS FOR STEREO IMAGES AS THE ORIGINAL POINT E, WHICH WAS THE INTERSECTION OF THE SPACE RODS IN OUR ORIGINAL HYPOTHETICAL PLOTTER. INASMUCH AS E, FROM WHAT HAS BEEN PREVIOUSLY SAID, PLOTS BOTH PLAN AND ELEVATION OF DETAIL, THE WHOLE BRIDGE MUST BE MOVED VERTICALLY WHEN, TO DIRECT THE RODS CORRECTLY ON TO CORRESPONDING IMAGES OF A POINT, IT IS NECESSARY TO SPREAD THE RODS IN THE EPIPOLAR PLANE, I.E., WHEN THERE IS RELIEF, OR, AS IT MAY BE PUT, A CHANGE OF PARALLAX IN THE IMAGES. IN OTHER WORDS, THE BRIDGE MOVES SO THAT ALL POINTS IN IT REMAIN IN HORIZONTAL PLANES SO LONG AS LEVEL DETAILS ARE BEING PLOTTED BUT IT MUST BE MOVED VERTICALLY TO A NEW POSITION WHEN THERE IS A CHANGE OF ELEVATION IN THE PLOTTED DETAIL-THE BRIDGE LENGTH REMAINING CONSTANT. USUALLY A PENCIL IS ATTACHED TO THE BRIDGE, AS I HAVE INDICATED DIAGRAMMATICALLY BY THE ARROW, WHICH PLOTS THE RELATIVE PLAN POSITIONS OF THE POINTS ON WHICH THE SIGHTING RODS ARE DIRECTED. ELEVATION DIFFERENCES ARE FOUND FROM THE AMOUNT IT IS NECESSARY TO RAISE OR LOWER THE BRIDGE TO RESTORE CORRESPONDENCE BETWEEN THE STEREO IMAGES.

THIS DEVICE IS KNOWN AS THE "ZEISS PARALLELOGRAM" HAVING FIRST BEEN USED BY WORKERS OF THE ZEISS FIRM WHEN DEVELOPING PLOTTING MACHINES FOR TERRESTRIAL STEREO PHOTOGRAPHS. IT HAS ONE OR TWO PROPERTIES WHICH ARE OF INTEREST, AND WE WILL GIVE IT A LITTLE CONSIDERATION.

IF WE COMPLETE A PARALLELOGRAM BY DRAWING CG PARALLEL TO DE OR D_1F, GE IS EQUAL TO CD WHICH WAS THE ORIGINAL LENGTH OF AIR-BASE WHICH DETERMINED THE SCALE OF PLOTTING FOR THE CONDITIONS SHOWN IN FIG. 2. THIS LENGTH GE IS EQUAL TO CD_1 MINUS EF, AND IS USUALLY SPOKEN OF AS THE INSET OF THE BRIDGE FOR REASONS WHICH WILL BE APPARENT FROM THE DIAGRAM. SHOULD WE CHOOSE A NEW LENGTH E_1F_1 FOR THE BRIDGE, THE SCALE OF OUR PLOT WILL NOW BE SUCH THAT G_1E_1, THE NEW INSET, REPRESENTS THE LENGTH OF THE AIR-BASE TO SCALE. HENCE, BY ADJUSTING OUR INSET WE CAN ADJUST THE SCALE TO ANYTHING WE PLEASE.

YOU WILL RECALL THAT I EXPLAINED HOW THE ELEVATION OF THE BRIDGE REMAINED UNCHANGED SO LONG AS THE PLOTTED DETAIL WAS LEVEL. THIS SUGGESTS THE MEANS BY WHICH CONTOURS COULD BE PLOTTED MECHANICALLY. HAVING SET THE SIGHTING RODS SO THAT EACH IS DIRECTED ON THE CORRESPONDING IMAGE OF A POINT, FIND A NEIGHBORING POINT WHERE THE RODS ARE STILL SIGHTED CORRECTLY WITHOUT ALTERING THE ELEVATION OF THE BRIDGE. A SERIES OF SUCH CONNECTED POINTS DETERMINES A CONTOUR.

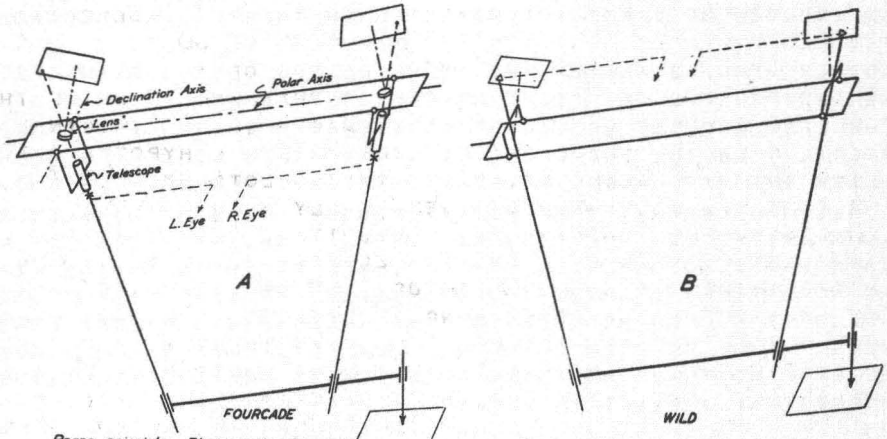
IN ACTUAL PRACTICE STEREOSCOPIC SIGHTING IS EMPLOYED. BY A SUITABLE OPTICAL TRAIN (WITH LINE OF SIGHT ENDING AT THE INTERSECTION OF SIGHTING ROD AND PHOTOGRAPH), THE OBSERVER VIEWS SIMULTANEOUSLY THE RIGHT PHOTOGRAPH WITH HIS RIGHT EYE AND THE LEFT PHOTOGRAPH WITH HIS LEFT EYE. AT THE SAME TIME, HE SEES WITH EACH EYE ONE-HALF OF A "FLOATING MARK", SITUATED AT THE FOCUS OF ONE OF THE LENSES. WITH A PROPERLY ADJUSTED OPTICAL SYSTEM, THE APPARENT COMPLETE FLOATING MARK APPEARS TO LIE ON THE GROUND WHEN THE SIGHTING RODS ARE CORRECTLY DIRECTED ON THE RESPECTIVE CORRESPONDING IMAGES OF A DETAIL. IF THE RODS ARE DIRECTED IN THE CORRECT EPIPOLAR PLANE, BUT ARE POINTED SO THAT THE IMAGES FALL BETWEEN THEM, THE FLOATING MARK WILL APPEAR AS IF SITUATED ABOVE THE GROUND, AND WILL APPEAR AS BENEATH THE GROUND IF THE RODS ARE NOT SPREAD FAR ENOUGH.

TO PLOT A CONTOUR, THEN, THE OBSERVER MOVES HIS BRIDGE ABOUT HORIZONTALLY IN SUCH A WAY THAT THE FLOATING MARK SEEMS TO TRAVEL ALONG THE SURFACE OF THE GROUND WHILE THE PENCIL RECORDS THE FIGURE TRACED. IF THE BRIDGE BE THEN RAISED TO A NEW ELEVATION (WITHOUT ALTERING ITS LENGTH) A SECOND CONTOUR CAN BE PLOTTED, AND IN THIS WAY THE COMPLETE OVERLAPPED PORTION CAN BE COVERED.

Applications to Actual Examples

Fourcade Plotter.

In Fig. 3 I have sketched the schematic design of two modern machines where the arrangement I have been outlining is employed. The first of these is the most recent proposal for the Fourcade machine, designed in part by Dr. Fourcade of South Africa and in part by officials of the British War Office, after some consultation with our own Survey Research Committee and with the cooperation of the firm of Barr and Stroud of Glasgow, Scotland, who are building the instrument. This is the plotter donated by Imperial Oil Limited.



Porro principle: Photographs observed through lenses similar to camera lenses by means of telescopes attached to space rods moving in epipolar planes, about air base, or polar axis.

Space rods actuate small prisms, moving parallel to planes of negatives - giving normal observation of all parts of overlap.

Fig. 3

The photographs are set up in two skeleton cameras, or goniometers. These can be tilted together or independently about the polar axis, corresponding to the air-base, and about axes perpendicular to this--the declination axes. Each photograph can also be rotated in its own plane, and these three movements permit complete correspondence to be restored by an appropriate systematic setting program.

Sighting rods are used in epipolar planes swinging about the polar axis and forming a Zeiss parallelogram, with a plotting pencil actuated by the bridge. Lenses of the same focal length as the camera lenses are fitted at the intersection of the polar and declination axes, and the direction of the sighting rods is continued optically (through the lenses) by telescopes at their upper ends, as indicated in Fig. 3A. The semi-floating marks are placed at the foci of the objectives of these telescopes, and the lines of sight are continued and brought to two fixed eyepieces by means of a suitable optical train. The observer guides the bridge along the direction of the polar axis by means of a control actuated by one hand, and in the perpendicular horizontal direction by means of the other hand, while a foot disc changes the elevation of the bridge. By suitably operating these three controls, the floating marks can be apparently moved about the landscape in three dimensions and plan positions or contours plotted at will.

Wild Autograph

Fig. 3B is a diagrammatic representation of the most recent model of the Wild Autograph, of Swiss origin. In most features the general principle is like that of the Fourcade instrument, with somewhat the same setting movements. In the Autograph, however, the sighting rods are continued up, through the intersection of the polar and declination axes, and at their upper ends actuate reflecting prisms which are guided by the rods but remain in the plane of the photograph. The photograph itself is placed a short distance above this plane, but parallel to it. The line of sight is normal to the photograph from the latter to the prism, and is thence continued to two fixed eyepieces, where the observer sees the semi-floating marks apparently lying on the images at which the sighting rods

ARE DIRECTED. THE USUAL ZEISS PARALLELOGRAM SYSTEM IS EMPLOYED FOR PLOTTING.

ADVANTAGES AND DISADVANTAGES OF THE PORRO PRINCIPLE

THE METHOD OF OBSERVING INDICATED IN FIG. 3A IS KNOWN AS THE PORRO PRINCIPLE AND HAS BEEN OF GENERAL APPLICATION IN UNIVERSAL PLOTTING MACHINES FOR AIR PHOTOGRAPHS. IT HAS THE ADVANTAGE THAT IF A LENS OF THE SAME TYPE AND CHARACTERISTICS AS THAT EMPLOYED IN THE ACTUAL PHOTOGRAPHY BE USED FOR PROJECTION, ANY DISTORTION EFFECT (WHICH RESULTS IN AN APPARENT BENDING OF THE LINE OF SIGHT AT THE LENS) IS COMPENSATED. THE SIGHTING RODS IN FIG. 3A, FOR EXAMPLE, WOULD IN THIS CASE CORRECTLY REPRESENT THE DIRECTIONS OF THE LIGHT RAYS FROM GROUND TO LENS FORMING THE IMAGE WHEN THE PHOTOGRAPH WAS EXPOSED, NO MATTER WHAT THE LENS DISTORTION. THIS CONSIDERATION BECOMES OF FIRST IMPORTANCE WHEN THERE IS APPRECIABLE LENS DISTORTION PRESENT.

ON THE OTHER HAND, AS ONE OR THE OTHER OF THE OBSERVED IMAGES APPROACHES THE MARGIN OF THE PHOTOGRAPH, THE SIGHTING TELESCOPE IN QUESTION IS DIRECTED OBLIQUELY THROUGH THE LENS AND THE VISUAL DEFINITION FALLS OFF, RESULTING IN SOME DIFFICULTY IN CORRECTLY PLACING THE FLOATING MARK. THIS OBJECTION CARRIES VERY MUCH MORE WEIGHT WITH THE WIDE-ANGLE LENSES NOW BEING PRODUCED FOR AIR CAMERAS.

IN THE WILD AUTOGRAPH, THE PHOTOGRAPHS ARE VIEWED NORMALLY AT ALL PARTS OF THE OVERLAP, AND, WITH GOOD PHOTOGRAPHIC DEFINITION, IT SHOULD BE POSSIBLE EVERYWHERE TO OBTAIN SATISFACTORY STEREOSCOPIC OBSERVATIONS. AGAINST THIS MUST BE SET THE FACT THAT NO ATTEMPT IS MADE TO COMPENSATE FOR LENS DISTORTION; BUT IN FAIRNESS TO DR. WILD IT SHOULD BE OBSERVED THAT MODERN AIR CAMERA LENSES ARE CLAIMED BY THEIR MAKERS TO BE FREE FROM APPRECIABLE DISTORTION AND, FURTHERMORE, EVEN LENSES OF THE SAME NOMINAL CONSTANTS DO NOT HAVE EQUIVALENT DISTORTION.* THE NEW WILD SYSTEM CERTAINLY APPEARS PROMISING.

SIMPLER PLOTTING DEVICES

IN THE TWO UNIVERSAL PLOTTING MACHINES OUTLINED IN FIG. 3, SOMEWHAT ELABORATE OPTICAL AND MECHANICAL DEVICES ARE REQUIRED, AND THE MACHINES ARE CORRESPONDINGLY EXPENSIVE. FURTHERMORE, THE SETTING OF THE PHOTOGRAPHS TO CORRESPONDENCE IS A SOMEWHAT PROTRACTED OPERATION, AND THE TIME SPENT REDUCES THAT AVAILABLE FOR ACTUAL PLOTTING, WHICH IS A SERIOUS MATTER IN THE CASE OF A COSTLY MACHINE.

IF WE COULD DEAL ONLY WITH UNTILTED PHOTOGRAPHS, OR IF TILTS WERE SMALL ENOUGH TO BE DISREGARDED AT THE SCALE OF PLOTTING, CHEAPER MACHINES, REQUIRING SHORTER SETTING TIMES, AND HENCE OF INCREASED EFFICIENCY OF PRODUCTION, COULD BE EMPLOYED. FURTHERMORE, SUCH MACHINES COULD BE USED FOR PLOTTING BY THE SAME SYSTEMS AS THE HAND-GRAPHICAL METHODS MENTIONED AT THE COMMENCEMENT OF THIS LECTURE.

TILT IS THE BUGBEAR IN PLOTTING. IT CAN BE REDUCED WHEN AUTOMATIC CONTROL IS USED IN PHOTOGRAPHIC AIRCRAFT, WITH A CONSEQUENT REDUCTION IN SETTING TIME IN THE CASE OF UNIVERSAL PLOTTING MACHINES, OR INCREASED ACCURACY WHEN APPROXIMATE METHODS ARE EMPLOYED FOR PLOTTING MINOR CONTROL, EITHER BY HAND OR MACHINE.

IT HAS ALSO BEEN SUGGESTED THAT A UNIVERSAL PLOTTER, E.G., THE FOURCASE INSTRUMENT, COULD BE EMPLOYED FOR THE DETERMINATION OF ABSOLUTE TILTS (BASED ON GROUND CONTROL POINTS IN THE FIRST OF A STEREOSCOPIC SERIES), THE RESULTS BEING USED TO PREPARE RECTIFIED PHOTOGRAPHS..

THE PLOTTERS OF COLONEL BURNS

COLONEL BURNS, FORMERLY IN CHARGE OF THE OFFICE OF THE GEOGRAPHICAL SECTION, HAS DESIGNED TWO PLOTTING INSTRUMENTS FOR DEALING WITH PHOTOGRAPHS COMING WITHIN THESE CATEGORIES. THE FIRST OF THESE, THE RADIAL-STEREOPLOTTER, IS BASED ON THE RADIAL LINE INTERSECTION METHOD, AND IS ACTUALLY IN OPERATION IN THE GEOGRAPHICAL SECTION. A PAPER FULLY DESCRIBING THIS PLOTTER WILL SHORTLY BE PUBLISHED IN THE CANADIAN JOURNAL OF RESEARCH AND WILL PROBABLY BE REPRODUCED, IN WHOLE OR IN PART IN A FUTURE ISSUE OF THE "CANADIAN SURVEYOR."

THE RADIAL-DIRECTION METHOD IS NOT SUITABLE FOR PLOTTING POINTS OTHER THAN THE PRINCIPAL POINTS, WHICH LIE CLOSE TO THE PROJECTION OF THE AIR-BASE. IN COLONEL BURNS' SECOND PLOTTER, HE PROPOSES A MECHANISM WHICH WILL PLOT AT ANY PORTION OF THE OVERLAP. THE PHOTOGRAPHS ARE TO BE PLACED ON HORIZONTAL TABLES,

*FIELD--"A DETERMINATION OF THE DISTORTIONS IN A NUMBER OF AIR-CAMERA LENSES.", THE CANADIAN JOURNAL OF RESEARCH, VOL. 10, PP. 239-243 (1934).

AS IN ORDINARY TOPOGRAPHICAL STEREOSCOPES, AND PROJECTIONS OF THE ZEISS PARALLELOGRAM ON VERTICAL PLANES (1) PARALLEL TO THE AIR-BASE AND (2) PERPENDICULAR TO THE AIR-BASE ARE UTILIZED TO GIVE THE CORRECT RELATIVE MOVEMENT OF PLOT AND PENCIL AT THE DESIRED SCALE. A MODEL HAS DEMONSTRATED THE PRACTICABILITY OF THIS PLOTTER, AND WE HOPE SHORTLY TO PRODUCE A DESIGN AND THEN TO CONSTRUCT A FULL-SCALE MACHINE IN ORDER THAT ITS CAPABILITIES MAY BE GIVEN A TRIAL UNDER ACTUAL WORKING CONDITIONS.

CONCLUSION

I DO NOT SUGGEST THERE ARE LIKELY TO BE MANY INSTANCES IN CANADA WHERE IT WOULD BE ECONOMICALLY SOUND TO PLOT ALL THE DETAIL BY MEANS OF MACHINES. BUT FROM EVEN THE LIMITED EXPERIENCE ALREADY GAINED WITH THE RADIAL-STEREOPLOTTER IT APPEARS THAT THE EXTENSION OF MINOR CONTROL THROUGH STRIPS OF PHOTOGRAPHS CAN BE CARRIED OUT MUCH MORE ACCURATELY AND SPEEDILY THAN IS POSSIBLE BY HAND METHODS. IF RECTIFIED PHOTOGRAPHS WERE AVAILABLE IT IS AT LEAST FEASIBLE THAT EVEN GREATER PRECISION WOULD BE REACHED BY THE USE OF THIS MACHINE.

THE SECOND OF COLONEL BURNS' PLOTTERS WILL, WE HOPE, BE CHEAPER TO CONSTRUCT THAN THE RADIAL-STEREOPLOTTER--WHICH ONLY COSTS A FRACTION OF THE PRICE OF A EUROPEAN UNIVERSAL PLOTTING MACHINE--AND BE EVEN MORE EASILY OPERATED.

ONE USE FOR WHICH THIS SECOND PLOTTER SHOULD BE ADMIRABLY ADAPTED WOULD BE CONTOURING. I DO NOT KNOW OF ANY METHOD MORE ACCURATE THAN THE FLOATING MARK SYSTEM FOR CONTOURING FROM AIR PHOTOGRAPHS, AND FOR A NUMBER OF PURPOSES CONTOURED MAPS ARE VERY DESIRABLE.

PRESIDENT: MR. FIELD, WE ARE VERY MUCH INDEBTED TO YOU FOR THE MOST INTERESTING AND INSTRUCTIVE LECTURE ON THE PRINCIPLES OF STEREOSCOPIC PLOTTERS, I MUST SAY THAT YOUR METHOD OF PRESENTATION WAS A NOVEL ONE AND YET EXTREMELY SIMPLE, AND I BELIEVE THAT WHEN THIS PAPER IS PUBLISHED IT WILL REFLECT GREAT CREDIT ON YOU AND ON OUR INSTITUTE. MR. W. DEMARY IS TO LEAD THE DISCUSSION.

MR. DEMARY: MR. FIELD HAS GIVEN A VERY COMPLETE DESCRIPTION OF THE PRINCIPLES OF STEREO-PLOTTERS, AND ALSO OF THE VARIOUS INSTRUMENTS NOW IN USE.

AS I HAVE CARRIED OUT CONSIDERABLE WORK WITH THE RADIAL-STEREOPLOTTER INVENTED BY COLONEL BURNS AND CONSTRUCTED BY MR. FIELD, I AM SURE YOU WILL BE INTERESTED IN HEARING SOMETHING ABOUT THE ACTUAL OPERATION OF THE MACHINE NOW IN USE IN THE GEOGRAPHICAL SECTION, DEPARTMENT OF NATIONAL DEFENCE, AND THE RESULTS OBTAINED.

THERE ARE SEVERAL OUTSTANDING IMPROVEMENTS OVER THE PREVIOUS METHOD OF RUNNING RADIAL STRIPS, AND MAY I MENTION AT LEAST THREE OF THEM.

1. WE ARE ABLE TO PLACE, ON THE PHOTOGRAPHS, THE PRINCIPAL POINT BASE LINES, OR POSSIBLY BETTER KNOWN AS THE AIR-BASE LINES, WITH PRACTICALLY ABSOLUTE ACCURACY, DUE TO THE MAGNIFICATION OF THE PHOTO IMAGE, AND THE APPARENT MAGNITUDE OF THE FLOATING MARK.

I MIGHT REMARK HERE, THAT THIS FORM OF FLOATING MARK, IS A GREAT IMPROVEMENT OVER THE GRID SYSTEM USED ON THE PRECISION STEREOSCOPES, IN THAT WANT OF CORRESPONDENCE IS MORE READILY DISCERNED.

THE FLOATING MARK IN THIS INSTRUMENT IS IN THE FORM OF A CROSS, ONE HALF BEING VIEWED BY EACH EYE, SO THAT WHEN THERE IS NO WANT OF CORRESPONDENCE, THAT IS TO SAY, WHEN THE PHOTOGRAPHS ARE CORRECTLY ORIENTED, AND NO TILT EXISTS, THIS FLOATING MARK FORMS A SOLID CROSS. PHOTOGRAPHS MAY BE PLACED IN THE INSTRUMENT TO AN ACCURACY OF 3/100 MM. AND THE AIR-BASE LINES SCRATCHED ON BY A NEEDLE POINT TO ABOUT 1/10 MM.

A CHECK MAY BE PUT ON ORIENTATION BY MOVING THE FLOATING MARK IN THE "X" DIRECTION, THAT IS ALONG THE AIR-BASE LINE, ANY ERROR BEING APPRECIATED BY A SEPARATION OF THE CROSS IN THE "Y" DIRECTION.

THE STEREO-PLOTTER, IS THEN, OF EXCEPTIONAL VALUE IN RULING IN THE AIR-BASE LINES, AND AS YOU ALL KNOW, THE LEAST ERROR IN THE ORIENTATION OF ANY OVERLAP, WILL GIVE A FALSE AZIMUTH, THEREBY CAUSING A SWING OR BEND IN THE STRIP.

2. MINOR CONTROL POINTS WHICH FORMERLY HAD TO BE LABORIOUSLY PICKED OUT AND MARKED UP ON THREE SUCCESSIVE PHOTOGRAPHS CAN NOW BE CHOSEN STEREOSCOPICALLY AS THE STRIP IS BEING RUN, AND HAVE ONLY TO BE MARKED ON ONE PHOTOGRAPH, THUS ELIMINATING ERRORS IN FAULTY IDENTIFICATION.

3. IN THE RADIAL LINE METHOD, A STRIP IS RUN ON THE SCALE OF THE FIRST PHOTOGRAPH OF THE STRIP. WITH THE RADIAL STEREO-PLOTTER, AS MR. FIELD HAS POINTED OUT, A STRIP CAN BE COMMENCED AT THE SCALE OF THE MEAN SCALE PROJECTION, AND AL-

TERED AS EACH PAIR OF PHOTOGRAPHS IS PLACED IN THE INSTRUMENT.

THE OBJECT IN VIEW IS TO BE ABLE TO RUN THE RADIAL STRIPS SO THAT ALL DETAIL MAY BE IMMEDIATELY TRACED OFF WITHOUT ANY ADJUSTMENT, OR AT LEAST WITH THE ADJUSTMENT REDUCED TO A MINIMUM. THE STRIPS COULD THEN BE PASTED DOWN ON THE PLOTTED MEAN SCALE PROJECTION. UP TO THE PRESENT TIME WE HAVE NOT BEEN ENTIRELY SUCCESSFUL IN ACHIEVING THIS RESULT.

YESTERDAY IT WAS POSSIBLE FOR YOU TO SEE THE INSTRUMENT IN OPERATION AND THE RESULTS WHICH HAVE BEEN OBTAINED WITH IT UP TO THE PRESENT TIME.

PRESIDENT: WOULD ANYONE ELSE CARE TO ASK ANY QUESTIONS ABOUT THIS INSTRUMENT OR ADD ANYTHING TO THE DISCUSSION?

MR. RANNIE: IT SEEMS TO ME THAT IT IS A GREAT SATISFACTION TO EVERY MEMBER OF THIS INSTITUTE TO KNOW THAT WE, IN THIS COUNTRY, HAVE TAKEN SOME LEAD IN WHAT MIGHT BE CALLED THE MOST PRECISE METHODS OF PLOTTING. WE SAW THIS MACHINE AT THE GEOGRAPHICAL SECTION BUILDING YESTERDAY AND IT MADE US REALIZE THE VALUE OF CO-OPERATION WHICH MADE SUCH RESULTS POSSIBLE. I THINK WE SHOULD CONGRATULATE COLONEL BURNS AND MR. FIELD AND THE VARIOUS OTHER OFFICERS WHO HAVE CONTRIBUTED TO THE SUCCESSFUL OPERATION OF THIS MACHINE.

PRESIDENT: I MIGHT SAY A WORD OR TWO IF ONLY TO THANK MR. RANNIE FOR HIS KIND REMARKS ABOUT MYSELF.

SINCE THIS MACHINE WAS ACTUALLY CONSTRUCTED, I HAVE READ A COUPLE OF VERY LONG AND LEARNED REVIEWS OF THE METHODS WHICH ARE GENERALLY KNOWN AS RADIAL LINE METHODS OR SOMETIMES CALLED PRINCIPLE POINT TRIANGULATION OR PLUMB-POINT METHODS--ONE BY A GERMAN EMPLOYED IN LATAVIA AND ANOTHER BY AN ITALIAN: THEY ACKNOWLEDGE WHAT WE KNOW TO BE A FACT, THAT IS, THE RADIAL LINE SYSTEM OF PLOTTING HAS VERY GREAT ADVANTAGES IN THE CONSTRUCTION OF THE SMALLER SCALE MAPS.

WE KNOW ALSO THAT THE MORE ELABORATE TYPES OF STEREOSCOPIC INSTRUMENTS HAVE THE DISADVANTAGE, IN THAT IT TAKES CONSIDERABLE TIME TO ARRANGE THE PHOTOGRAPHS IN THE MACHINE AS WELL AS TO DO THE ACTUAL WORK OF PLANIMETRY AND CONTOUR. THESE INSTRUMENTS ARE SO COSTLY AND THEIR RATE OF OUTPUT SO SMALL THAT THEY CANNOT BE ECONOMICALLY USED ON WHAT WE KNOW AS THE MEDIUM SCALES, SUCH AS THE ONE INCH TO THE MILE MAPS. SO THERE IS STILL A CONSIDERABLE FIELD OF USEFULNESS FOR THE RADIAL LINE METHOD.

AT THE PRESENT TIME THERE ARE FEW OPERATIONS PERFORMED BY THE HUMAN HAND WHICH CANNOT BE SPEEDED UP WITH INCREASE IN ACCURACY WHEN CARRIED OUT MECHANICALLY. IT OCCURRED TO ME THAT A RELATIVELY SIMPLE MACHINE COULD BE MADE TO PERFORM THE OPERATIONS WHICH HAVE BEEN PROVED SO VALUABLE IN THE RADIAL LINE METHOD, AND AT THE SAME TIME CORRECT, OR MINIMIZE, THE ERRORS ARISING FROM THE DEFICIENCIES OF HUMAN VISION, AND OF THE HUMAN HAND IN DRAWING. I THINK THIS MACHINE IS DOING THIS AND THE RESULTS THAT MR. DEMARY HAS EXPLAINED TO YOU SHOW THAT IT IS.

THOSE OF YOU WHO HAVE SEEN THE RADIAL-STEREOPLOTTER WILL APPRECIATE THE REMARKABLE WORKMANSHIP WHICH HAS BEEN PUT INTO IT. IT IS A MACHINE IN WHICH ANGULAR MOVEMENT IS TRANSLATED INTO LINEAR CO-ORDINATE MOTION, AT THE DRAWING, AND SOMETIMES THE MECHANICAL ADVANTAGE OF THE LEVERS TO EFFECT THIS IS VERY SMALL. HOWEVER, SO FAR AS WE CAN TELL, IT WORKS PERFECTLY. THERE IS NO ERROR OF ANY KIND IN ITS MECHANICAL OPERATION AND WHEN YOU THINK IT IS THE FIRST ONE TO BE CONSTRUCTED I THINK IT IS A GREAT FEATURE IN THE CAUSE OF RESEARCH AND I WOULD LIKE HERE TO MENTION THE NAME OF MR. MAY, OF THE NATIONAL RESEARCH COUNCIL INSTRUMENT SHOP, WHO CONSTRUCTED IT. WHETHER IT WILL BE GOOD ENOUGH THAT ANYONE ELSE WILL WANT TO HAVE ONE LIKE IT WE CANNOT TELL, BUT AFTER THIS YEAR'S OPERATION WE SHOULD HAVE A PRETTY GOOD IDEA, AND I WOULD SUGGEST TO OFFICIALS OF OTHER SURVEY BRANCHES, WHO ARE CONCERNED WITH PLOTTING, TO ARRANGE WITH MR. LYON TO SEE IT IN OPERATION, HEAR THE RESULTS OBTAINED AND EXAMINE IT CAREFULLY. THEN, IF IT IS THOUGHT THAT IT IS REALLY FULFILLING A USEFUL PURPOSE, I HOPE IT WILL BE POSSIBLE TO ADOPT, PERHAPS NOT IT, BUT THE NEW MODEL OF THIS MACHINE WHICH YOU HAVE HEARD DESCRIBED BY MR. FIELD, AND WHICH WILL, I THINK BE AN IMPROVEMENT BUT STILL FULFILL MUCH THE SAME PURPOSE.

I WOULD LIKE TO AGAIN THANK MR. FIELD FOR HIS VERY EXCELLENT PAPER AND CONGRATULATE HIM IN THE NAME OF THE INSTITUTE ON THE VERY FINE DESIGN WHICH HE CARRIED OUT BY MAKING MY VAGUE IDEA INTO AN ACTUAL WORKING MACHINE.