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## and design

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## EXPERIENCE - NOT EXPOSURE

This summer there was extraordinary activity for Engineering Graphics professors. At the June summer school of the Engineering Graphics Division at the Air Force Academy, workshops were crowded with graphicists studying analog computer technology. Advanced applications of Graphics in the traditional engineering course context were also studied.

The convention of the ASEE followed the summer school and the Division took a lively part. Through informal conversations as well as formal meetings, it seems evident to me that engineering educators are confused about the direction of education today. As in all educational fields, the vast amount of new knowledge which must be absorbed in our educational endeavor requires us to do a virtually impossible job--to "keep up" and to progress and at the same time to know what and how students should learn for their future.

Professor Betterley in his article on Administration in this issue of the Journal states that we should consider objectives of education for the learner rather than for the teacher. He also emphasizes that we need to consider how to change the student's behavior through experience rather than exposure to course contents.

My view is that engineering design experiences should be provided at the freshman level in graphics courses rather than a rigid prescription of course topics. Exercises in physical dexterity and a collection of disparate subjects do not meet the aims of an engineering education today. Nut and bolt engineering also requires complementary software.

At the Massachusetts Institute of Technology conference on Engineering Design and Graphics in August we had a stimulating view of design taught in Graphics courses and throughout the undergraduate and graduate program within the Mechanical Engineering Department. From some of their students I heard the words "blood and guts engineering" to mean that it is increasingly evident that the aim of engineering education is hardware and software resulting in engineering design.

The Letters-to-the-Editor column has grown in this issue. The reason your ex-editor "Vlad" hasn't responded to your violent reaction to his editorial in the last issue is that although you were violent, you didn't write down your reactions and send them to me. Do so and I'll publish them.

There has been some informal "corridor" talk about splitting or sectionalizing the Division to meet the special interests of its members such as high school and technical institute courses, and advanced graphics research. I have received no written comments on these topics and would publish any articles or letters reviewing the aims of the Division. In considering these matters remember Aesop's fable about togetherness in which sticks are broken if the bundle is separated.

Concerning the publication of the Summer School proceedings, your editor reports that not all the proceedings have been received. When received the publication committee will consider ways and means.

Be sure and come to the Midwinter meeting at Manhattan, Kansas. An unusual fare of formal program and informal corridor talk is being planned by Professor Messenheimer.

Yours truly,

Mary Blade

Mary Blade, Editor


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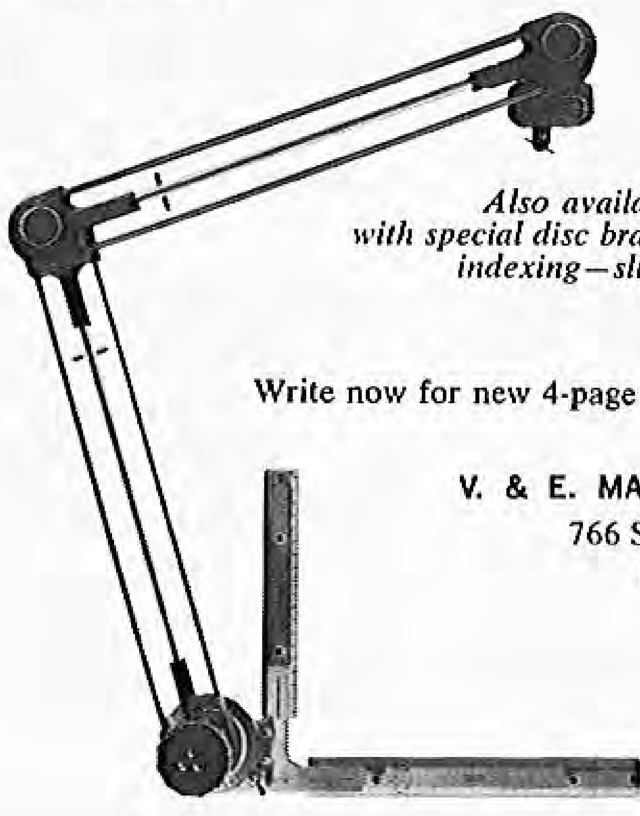

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# Technique of Projective Geometry and Its Application To Engineering Problems

Prof. V. P. Borecky
University of Toronto

INTRODUCTION

In this second article of the series,* I am opening the door to readers who are interested in the application of the technique of projective geometry to engineering problems.

The devices and methods of projective geometry are so manifold that it is impossible to arrange them into a scheme similar to the collection of the principal commandments of the orthographic projection.

For a graphically-minded reader, it is not sufficient to study only the modern mathematical texts on projective geometry, mainly because many authors of the works on synthetic projective geometry are avoiding measurements, so essential to engineers, e.g., Professor H. S. M. Coxeter, Department of Mathematics, University of Toronto, in his "Projective Geometry" says: "In order to encourage truly geometric habits and thoughts, we shall scrupulously avoid the use of coordinates and all metrical ideas except in Chapters 1, 11, 12, and a few of the Exercises. In particular, the only mention of "cross ratio" is in the present sentence."

This statement clearly shows that a synthetic geometer is not interested in magnitudes, in other words, he is not interested in engineering matters. Contrariwise, the engineer is interested in the geometry of action or in the metrical geometry, but not in the geometry of position which is projective geometry.

I agree that the number of axioms and propositions can be considerably reduced when proceeding in the illustratbn of the concepts of synthetic projective geometry in a purely geometrical manner; on the other hand, trivial or obvious problems and statements may prove very difficult to solve or to describe, respectively.

What is a science, even interlaced with the most beautiful and amazing theorems and concepts, when it lacks any practical aspects?

I believe that I found the answer to this question, and also a partial solution to the conflict in my mind between the geometer, the mathematician, and the engineer, when I started to dive to the bottom of the sea bringing this material up to the surface. Next time I shall try to dive even deeper and expect that others will accompany me.

My approach to the exploitation of the technique of the subject is just opposite to that of Professor Coxeter, i.e., it is entirely of a graphical engineering contemplation. Among the experts on projective geometry, there are not many who are aware of the practical, engineering application of the subject.

Professor Coxeter, himself, expert geometer as he is, was quite astonished when I pointed out to him so many practical aspects of the subject and presented an amount of practical applications of the theory regarded by a layman as a sort of "Picassonian art of abstract paintings".

Having concluded my philosophical reasoning, I want to give the reader some useful advice:

If your intention to penetrate deeply into the secrets of the elegant technique of Projective Geometry is serious, then select one field of engineering, e.g., statics, photogrammetry, kinematics, etc., and play with the practical applications on some typical examples collected in my Problem Book (Workship No. 11 at the 1962 Summer School for members of the Division of Engineering Graphics at the U.S.A.F.A.) until they become obvious to you. Then choosing, for example, a series of typical problems in statics (which may be found in any older or recent treatise on statics, mechanics, strength of material), vary the data to the individual problems, i.e., change the given structural frames, find the directions of the applied forces through the critical points of the structure, and decide if the problem can be tackled by applying either the concept of affinity, or collineation, or if such an approach to the construction of the solution by means of projective geometry would be trivial.

When, three years ago, Professor C. A. Wrenshall, University of Toronto, started with the applications of projective geometry to engineering problems, he was much in the same situation you are today. But he took a genuine interest in the subject matter, and he worked hard. Lacking any previous education in the subject, he developed such a judgment in solving two-dimensional problems in statics that at the present time, I may say, there is no problem existing which would cause him any difficulty whatsoever.

This article deals exclusively with the cross-ratio and harmonic cross-ratios (special case) of point ranges and ray pencils, with the affinity, collineation, elation and homotheticity of figures situated in two colocal projective formations (i.e., plane figures), with the affine, and collinear transformations, of a quasi-topological nature, of spatial formations (i.e., quadrics of revolution), and it also deals with two examples of application of the principle of duality, a projective property to the successive steps in construction of nomographical charts. (Note: These two examples have been included in my article by courtesy of Professor A. S. Levens from the University of California at Berkeley, who wrote an outstanding book on Nomography, and who has specialized in the extraordinary applications of the principle of duality to Nomography).

There exists an innumerable supply of problems in each field of engineering which can be solved in an elegant and efficient way by the methods of projective geometry and by the technique illustrated here on ten problems pertaining to the following engineering subjects:

(i) photogrammetry ...Problem 1, Figs. 1a,b, 2 and 3,
(ii) Kinematics ...Problem 2, Figs. 4a, b and 5,
(iii) statics ...Problem 3,4,5, Figs 6,6a, 7,7a,8,8a,
(iv) mapping (affine transformation) ... Problem 6,7,8, Figs. 9,10,11,
(v) radio astronomy (eng.physics) ... Problem 9, Fig. 12,
(vi) nomography ...Problem 10,10a, Figs. 13,13a,14,14a.

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Problem No. 1 - Photogrammetry

Given two corresponding quadrangles: $A_1 B_1 C_1 D_1$ on the map with $A_1B_1 = B_1C_1$ and the angle ABC =90°, and $A^S B^S C^S D^S$ on the photograph. Construct the horizon h, and the station point S of the figure on the photograph.

The solution is illustrated in three steps in Fig. 1a,b, 2 and 3.

Step I Complete the quadrangle $A_1B_1C_1D_1$ to a square $A_1B_1C_1B_1$. By means of "strip paper method", operating with the corresponding ray pencil tetrads (i.e., using the points $A_1'$ and $Q_1$, $A_1''$ and $R_1$), the square $A_1B_1C_1E_1$ from the map (Fig. 1a) is relocated onto the photograph (Fig. 1b); noting that $A^S B^S C^S E^S$ is the perspective projection of the square $A_1B_1C_1E_1$, the join of the intersections of the pairs of its two opposite sides are incident with the horizon h. Observing that these two (vanishing) points are inaccessible, in order to be able to draw the line of the horizon, it is necessary to have recourse to:

Step II affinity, collineation, or homotheticity, the methods of projective geometry based on "Desargues' two-triangle theorem". Since homotheticity is the simplest method in this case, it has been used, as illustrated in Fig. 2.

Step III "Pothenot construction" in conjuction with homotheticity again, is applied to the construction of the station point S' first, which is located at a reduced distance d' from the horizon h'; the corresponding segments of lines on rays forming the pencils with centres S' and S being homothetic, the locus of all station points for the reduced figures, i.e., A'B'CE' is a straight line, and the location of the true S at the true distance d from the true horizon h, is readily obtained. Fig.3.

Problem No. 2 - Kinematics

In Kinematics there is a classical method called "Bobillier" construction which is used for finding the centre of curvature for one point, C, of a rolling system given by a rigid triangle ABC, when the centres of curvature of points A and B, are given; this construction does not apply projective geometry. Using projective geometry, the centre of curvature for the point C can be established by taking advantage of the harmonic property of to colocal projective ranges of points, namely, that the product of the distances of a dyad of two corresponding points from the ideal points of the range is constant. The construction, e.g., for the point A, assuming that the instantaneous pole of rotation S, and the centre of curvature $U_S^A$ for the vanishing point $U_{00}^A$ are given, is due to Mannheim; it is illustrated in Fig. 4b, where $r \equiv r'$; $(AA_s)$ = a dyad; $(T, U_s)$ = vanishing points; S = the invariant point for both ranges. From the construction: $AS : A_sS = SU_s : A_sU_s$ which can be arranged as a proportion: $\frac{AS - SU_s}{SU_s} = \frac{A_sS - A_sU_s}{A_sU_s}$; making $SU_s = ST$, we obtain $\frac{AT}{SU_s} = \frac{SU_s}{A_sU_s}$ or $AT \cdot A_sU_s = (SU_s)^2$, since S = invariant point.

Fig. 4a illustrates the same theory for two perspective point ranges on distant lines, r, r', where ($BB_1$) = a dyad; ($V,U_1$) = vanishing points; $A \equiv A_1$ = the invariant point of the ranges on r and r'. By similar triangles:

$\Delta BSV \sim \Delta SU_1B_1$: $VB.U_1B_1 = SV.$

$SU_1 = VA.\ U_1A_1$ = a constant.

Construction of the solution, Fig. 5

All centres of curvature for the vanishing points of the normals lie on the circle of "reversal". In order to find its centre, the combined "Mannheim" method has been used which results in the location of $U_S^A$, $U_S^B$, the centres of curvature for the points at $\infty$ lying on the normals $n_A$, $n_{B,C}$ through A and B. The circle of reversal cuts $n_C$, the normal through C, in $U_S$. Finally $C_S^C$ the required centre of curvature for C has been constructed by the reversed Mannheim method. Also, having observed that the point L is inaccessible, the concept of homothetic triangles has been used in order to find a line passing through it.

Problems 3,4 and 5 - Statics - Figs. 6, 6a, 7, 7a, 8, 8a.

Principles of collineation and affinity

Problem 3 - Fig. 6a illustrates "Desargues' theorem about perspective triangles" to be applied to the construction of the solution shown in Fig. 6 into which the vector diagram of applied and resulting forces, drawn to scale, has been incorporated.

Statement of the problem.

A three-hinged arch has supports at 2 and 3, and a hinge at 4. The resultants of the loads applied are: P on the left member, and Q on the right member of the structure. Using "Desargues' two-triangle theorem", determine graphically the magnitudes of the reactions at 2, 3 and 4.

Construction of the solution

There are altogether six forces acting on the structure: P, Q, R, $R_2$, $R_3$, $R_4$. In order to find the centres of action of four triads of the same (four possible combinations), and the lines of action for R, $R_2$, $R_3$, $R_4$ such that the conditions of equilibrium be fulfilled, it is necessary to separate the structure, consisting of two members, in two free bodies, first, and then to consider the arch as an entirety, in accordance with the usual procedure in problems of statical mechanics.

The line of action of R (the resultant of P and Q) is readily found, and a vector $\Delta$ containing P, Q and R, can be drawn. Note: The vector diagram (polygon of forces) has been incorporated into the construction of the solution for more clarity, but it may be placed anywhere. One centre of action is in the point S, the centres of action for the other three triads correspond to the points A, B, and C, and the resulting reactions will lie in the directions of the sides of $\Delta$ ABC, i.e., passing through points 2, 3 and 4, as per Fig. 6.

The vertices of $\Delta$ ABC are found by means of a "trial" $\Delta$ A'B'C' which fulfils all the required conditions except one, i.e., A'B' does not pass through point 4. It does, however, pass through a point 1 which is collinear with 2 and 3. This is in agreement with "Desargues' two-triangle theorem" which says: "If two triangles have their corresponding vertices joined by concurrent lines (which may be parallel as we will see in Problem 5) then the intersections of their corresponding sides are collinear."

Thus the mechanical problem became a problem of projective geometry, the centre of projection (perspective collineation) S, and the axis of homology (collineation) 123 are the elements to be properly selected depending on the nature of the problem.

Remarks: The auxiliary device of projective geometry, just discussed, is very elegant and efficient. The reactions are constructed directly without the need of their components. When the diagrams are drawn to larger scales, the solutions are as accurate as those obtained by a lengthy analytical process.

Many of the statical structures (frames) involving, e.g., two members and three hinges (not all three need to be hinges), are basically "three-hinged arches". It is of no consequence if the members joining two hinges (one of which is in the support), are curved or straight, since the resultants of the applied loads always act rectilinearly.

Problem 4 - Figs. 7, 7a

Given: Frame as shown, consisting of two members with hinged supports at 2 and 3, and joined by a hinge at 4; pulley with centre at 5, and a cable attached at 6, carrying a weight W at its end.

Discussion to the solution: The applied forces, weight W and tension T, as well as their resultant R, are concurrent to the centre of action S. The axis of homology (collineation) of the directions of "true" reactions: $R_2$, $R_3$, $R_4$ and the sides of the "trial" triangle A'B'C' which fulfil all the required conditions but one, has been selected again through the hinges in the supports. Laying out the magnitude of the vertical load

W to scale, the polygon of forces shown in Fig. 7a can be readily completed by drawing through the ends of the vector W lines parallel to the direction of reactions, the sides AB, BC and AC of the resulting "true" triangle ABC.

Problem 5 - Figs. 8, 8a

Changing the structure given in the preceding problem such a way that the part of the cable attached at 6 is now parallel to the direction of the load W acting vertically, the centre of action S of W,T and R is shifted to infinity, since these three direct forces are mutually parallel. The axis of homology, in the same place as before, becomes that of affinity in this case. The problem is solved in the manner similar to that of the preceding problem. Despite that the triangles ABC and A'B'C' are of a smaller size, the accuracy of the graphical solution does not suffer.

Note: The axis of affinity need not be parallel to the direction of affinity.

Problems 6,7,8 - Mapping - Affine transformation

These problems belong to the category of the formations of third order (spatial projective geometry), but untuitively are solved in two-dimensional monoplanar projection (or cross-section) of the involved configurations which are, in our case, quadratic surfaces of revolution;the transformation can be extended by a proper selection of the elements of perspective homology, to any quadric, and also to some special warped surfaces; it is of a quasitopological nature.

In topological mapping, we are concerned about geometrical facts that do not even involve the concepts of straight line or plane, but only the continuous connectedness between the points of a figure. The sphere shares all its topological properties with theellipsoid, the cube and the tetrahedron. In the study of projective geometry we may witness phenomena that can be described without any comparison of lengths and angles but that possess nonetheless a precise geometrical character. We may map a part of a sphere onto a plane, a cone, or a cylinder, preserving angles, circles, lengths, or areas, respectively.

By means of the dilatation (the affine, or collinear transformation), we "map" a cube onto a parallelepiped, a sphere onto an ellipsoid, a paraboloid, or a hyperboloid; a right circular cone into an oblique one, etc.

Problem 6 - Fig. 9

This problem deals with the affine transformation of a sphere into an ellipsoid of revolution. It also demonstrates, by means of projective geometry, an extremely useful property, common to all quadratic surfaces of revolution, namely, that any intersection by an oblique plane of both the sphere and the ellipsoid, projects from the respective pole (vertex) onto a plane parallel to the tangent plane through the vertex,as a circle. Since this can readily be proven for the sphere (by a simple proposition of the synthetic high school geometry - one of the fundamental properties of stereographic projection), it can be immediately extended to the ellipsoid, because the circle projected onto the plane related to the sphere remains invariant when this plane, forming a unit with the sphere, is shifted by dilatation in one direction into another plane forming a unit with the ellipsoid. Note: The north poles on the sphere and on the ellipsoid may be regarded as two auxiliary centres of projection.

Problem 7 - Fig. 10

This problem deals with the collinear transformation of a sphere into a paraboloid of revolution. In this case, beside the invariant line (axis of homology), still selected to lie in the equator of the sphere, there are again three centres of projection, but differently located from those in Problem 6, namely: the centre of homology (collineation) is identified with the south pole of the sphere or the real vertex of the paraboloid; the north pole of the sphere (the first auxiliary centre of projection with respect to the formations on the sphere) corresponds to the other vertex of the paraboloid (the second auxiliary centre of projection with respect to the formations on the paraboloid) which lies at infinity.

Remarks: When considering the whole solids instead of their cross-section, then the term axis of homology (collineation) should be substituted by the expression: plane of homology (collineation).

Problem 8 - Fig. 11

Statement of the problem

Construct a conical transition piece (a truncated oblique circular cone) between the given pipes using the property of the affine transformation of a right circular cone into an oblique one. Select such a cone which lies between the right circular cone (inadequate because of the angle of its left outer surface element) and the cone whose intersection with the smaller cylinder would result in a circle, and which could be constructed by the method of "superscribed sphere".

Construction of the solution

The axis of affinity has been selected to pass through the invariant points A and B. The third point C, collinear with A and B, is obtained by the method of "inscribed sphere" to the smaller cylinder and the auxiliary right circular cone, whose centre lies in the intersection of the axes of the cone and the cylinder. The curve of intersection appearing edgewise in the cross-sectional view, passes through C, the third required point on the axis of homology, and any other adequate intersection necessarily passing through C perpendicularly to the plane of the paper, gives the required section on the smaller cylinder. Note that the vertex of the resulting cone lies on a line parallel to the axis of the smaller cylinder, so that the dilatation of the right circular cone is a rectilinear translation of its vertex.

Problem 9 - Radio Astronomy - Fig. 12

Statement of the problem

Electron waves, propagating rectilinearly, emanate from the point source F which is the vertex of a conical envelope with a vertical axis and vertex angle $\alpha$. All wave-rays within the cone are to be reflected horizontally and intercepted by a vertical circular antenna appearing edgewise in the given cross-sectional view. The waves are to be entirely confined to the interior of a wave guide consisting of a conical, a cylindrical, and another surface having the property of reflecting the rays in the horizontal direction. Construct the wave guide, showing its contour lines in the given view. Measure the vertex angle $\alpha$. Scale 1 in. = 3 in.

Construction of the solution

In order to construct the intersecting curve of the cone and the cylinder in the given cross sectional view, a sphere has been inscribed in both (as in the preceding problem). Using the property of the collinear transformation of a sphere into a paraboloid of revolution (see discussion to Problem 7) illustrating the proof for the preservation of circles in projection of the intersection of any plane and the paraboloid into a plane perpendicular to its axis, the third required surface completing the construction of the wave guide, must be such that all its plane intersections lie on the surfaces of homothetic cylinders which are right circular ones when their axes are parallel to the axis of the third surface. This surface cannot be other than a paraboloid of revolution, and one of the homothetic cylinders has its surface elements such that they envelop its elliptic section with the oblique cutting plane and also the circumference of the circular screen.

Problem 10, 10a - Figs. 11-14
Nomography - Principle of Duality

The applications of the principle of duality in a plane, by which lines (points) in one diagram, i.e., in the concurrency graph, are transformed into points in another diagram, i.e., the alignment chart are illustrated by figs. 13, 13a, & Figs. 14, 14a respectively

Fig. 13 shows in orthogonal Cartesian coordinates, x and y, a relationship between two variable quantities, plotted in accord with the data obtained from a series of experiments. It is obvious that the dependence of the corresponding values is non-linear. In order to obtain a simple alignment chart it is necessary to rectify the curve into a straight line, which results in an x'-scale for the quantity plotted along the abscissa. In this case the scale became quadratic, such that the curve is a parabola, i.e., $y = 2x^2$. This parabola has further been transformed into a point, P, in the alignment chart, Fig. 13a, where the variables have been plotted along two parallel lines provided with adequate, arbitrary scales.

In the upper left corner of Fig. 14, the concurrency graph, there is a family of curves (with unknown equations) showing a relationship between two variables, with a different coefficient for each curve. By means of an auxiliary diagram (diametrically opposite to the first), where lines converging to the origin have been drawn, the curves have been rectified by the procedure illustrated in Fig. Then, in order to complete the information necessary for the alignment chart, two additional auxiliary diagrams had to be established. Since it is not the purpose of this exposition to go through the details of the rectifications and other required modifications of the original graph, the reader is referred to 3)

Fig. 14a, the alignment chart, shows the complete transformation of the family of curves from Fig. 14 into a curve, which in this case is a straight line lying between two parallel, arbitrarily chosen scales, the coordinates x' and y'

The quantity $y = \dfrac{R^{1/4}}{G^{7/4}} \times 10^5$, but the physical law relating the variables, is of no importance for the illustration of the principle of duality in Figs. 14 and 14a.

Conclusion

Having been in possession of the scripts and works on practical applications of descriptive-projective geometry by the most renowned European experts in all engineering fields, I was not able to discover any either compact, or individual treatment of the nature this article deals with. I am not a businessman who is offering this material for sale, and I may say that in a way I have been very much disappointed that nobody else tried to fill the gap between the theory and the engineering applications. On the other hand I found very much satisfaction in discovering something which has not been published in any existing text.

This material presented here in a rather concise manner on only a few typical examples can be developed in all directions, it is only necessary to find courageous men who possess a progressive spirit and are not frightened by some extra work which is indispensable to the understanding of the theory of a few principles and concepts of the beautiful science of projective geometry.

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Problems 10, 10a - Nomography --- by Professor A.S. Levens Nomographical charts by the principle of duality.

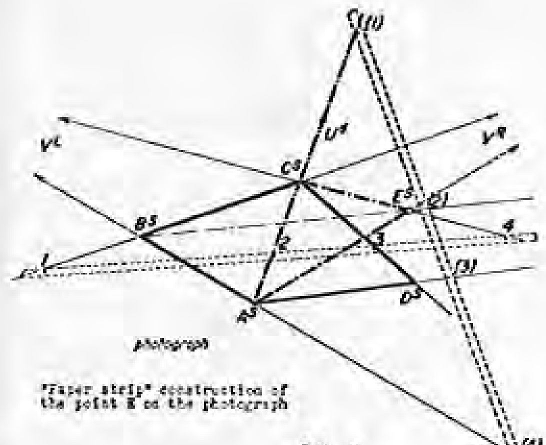



FIG 1b

PROBLEM I

PHOTOGRAMMETRY

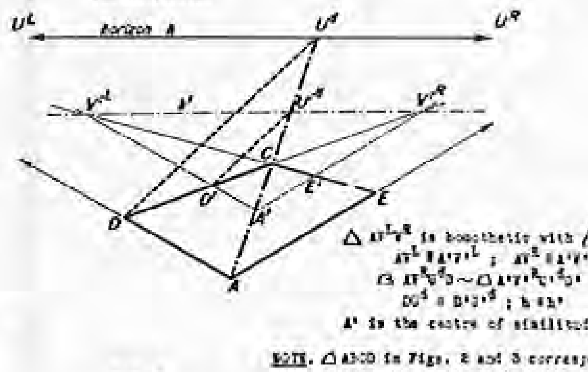
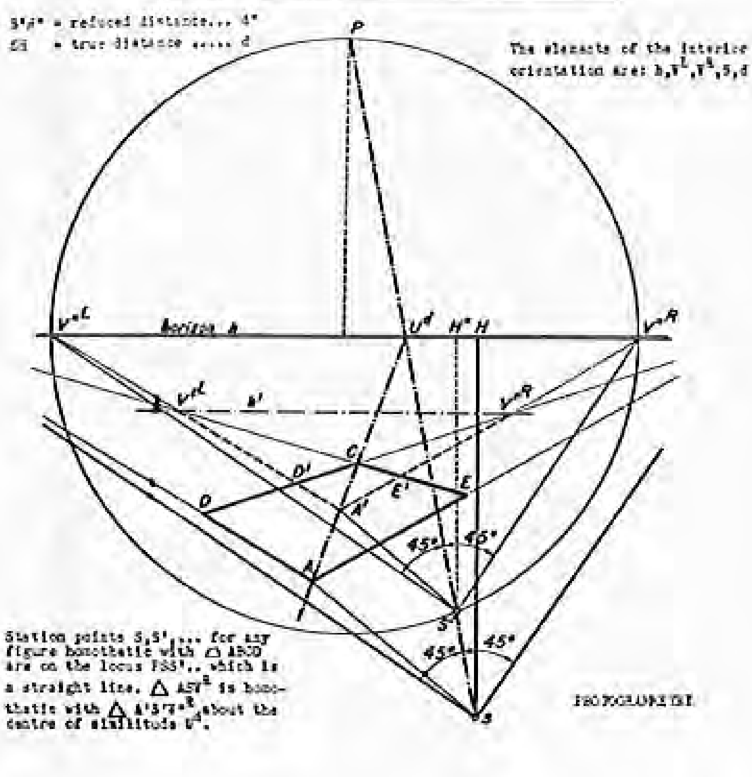



FIG. 2




# *Problems Nos. 1-10*

## *PROBLEM I*

PHOTOGRAMMETRY

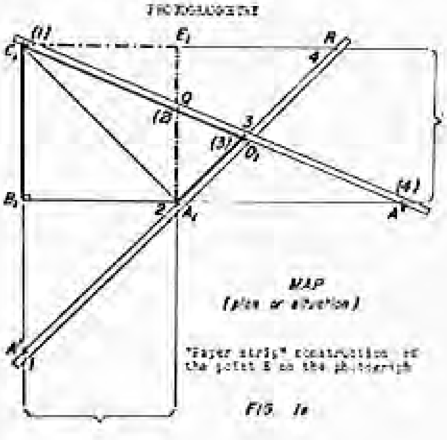



FIG. 1a

## PROBLEM 2

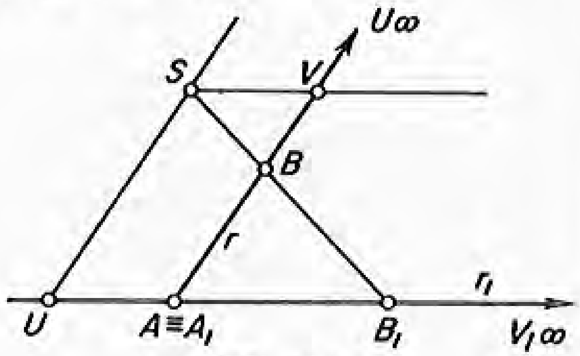
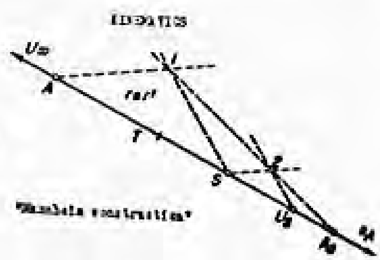



FIG. 4a

FIG. 4B



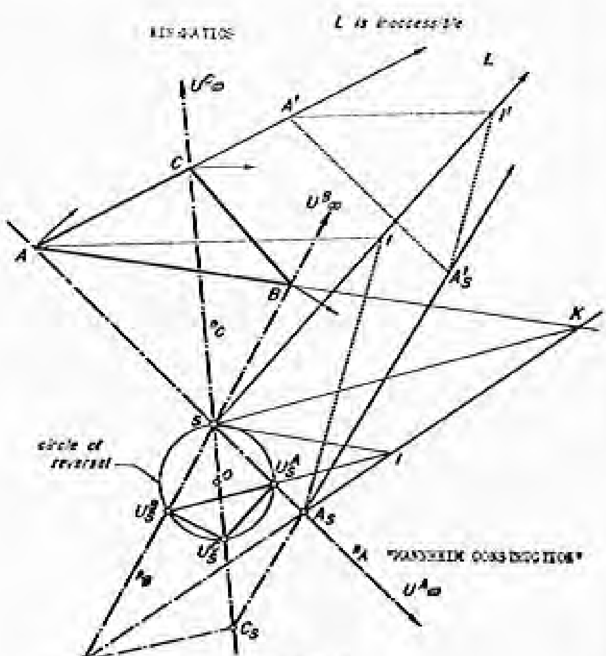




FIG. 5

## PROBLEM 3

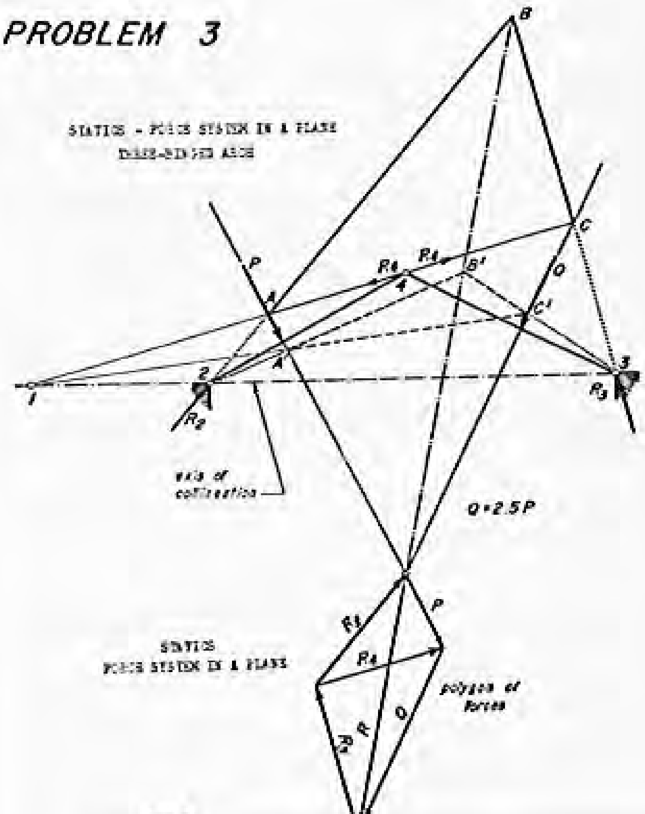



FIG. 6

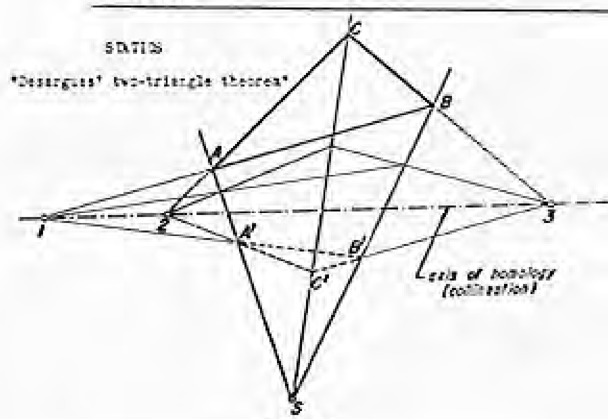



FIG. 6a

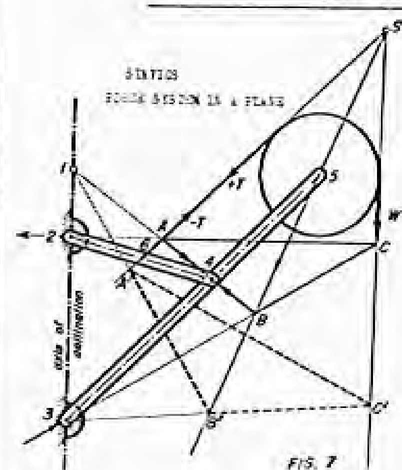



FIG. 7

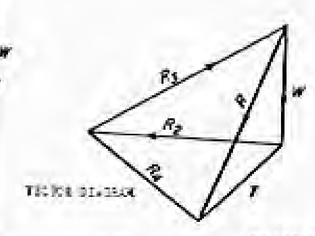



FIG. 7a

## PROBLEM 5

STATICS
FORCE SYSTEM IN A PLANE

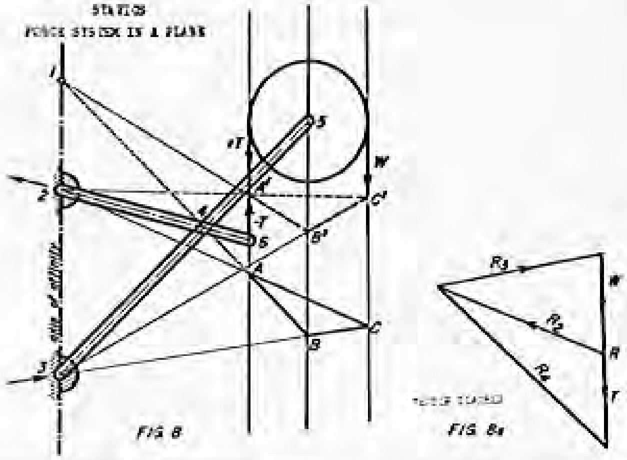
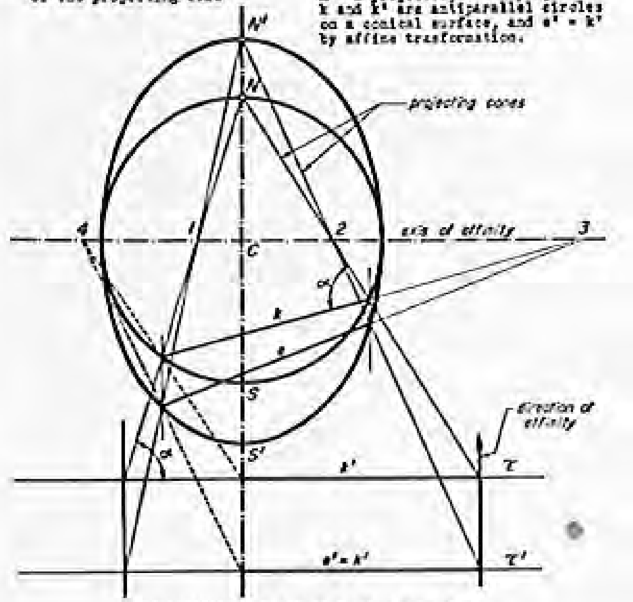



FIG 8 FIG 8a

## PROBLEM 6

k and k' are antiparallel circles, or subcontrary sections on the surface of the projecting cone

k = circle on the sphere
e = ellipse on the ellipsoid
k'= k projected; e'= e projected
k and k' are antiparallel circles on a conical surface, and e' = k' by affine trasformation.




STEREOGRAPHIC PROJECTION OF THE SURFACE OF A SPHERE AND AFFINE TRANSFORMATION OF THE SPHERE INTO AN ELLIPSOID

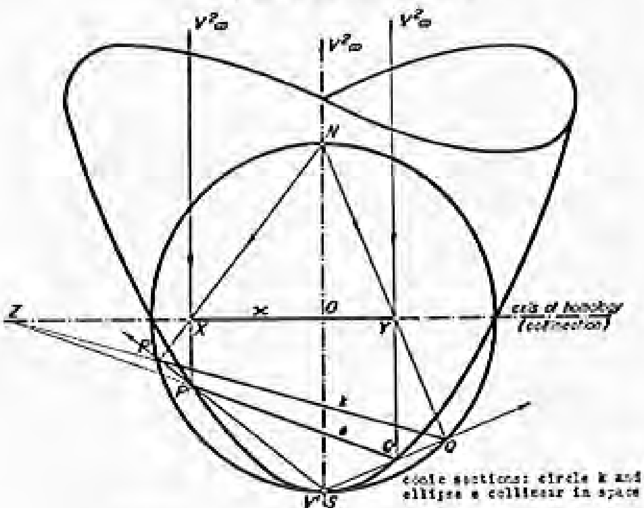
AFFINITY IN THE CROSS-SECTIONAL PLANE

FIG. 9

## PROBLEM 7

COLLINEAR TRANSFORMATION OF THE SURFACE OF A SPHERE INTO THE SURFACE OF A PARABOLOID

Concept: All sections of a paraboloid of revolution project onto a plane ⊥ its axis as circles



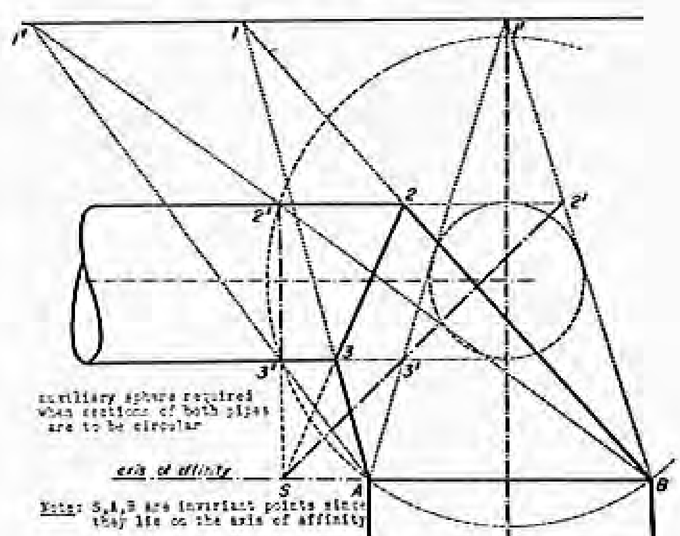

COLLINEATION IN THE CROSS-SECTIONAL PLANE

FIG. 10

## PROBLEM 8

TRANSITION PIECE BETWEEN TWO PIPES
PIPE TRANSITION

Observe the linear transformation, i.e. the translation of the apex of the cone



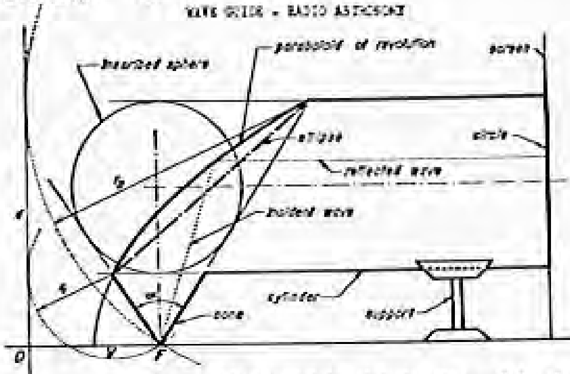

See Grant: Fig. 506 c), page 880

AFFINITY IN THE CROSS-SECTIONAL PLANE

FIG. 11

## PROBLEM 9

WAVE GUIDE - RADIO ASTRONOMY




Suggested by the Division of Engineering Graphics and constructed by the Department of Engineering Physics at U. of T.

FIG. 12

continued on page 59

# *Engineering Graphics for the "Philosopher" or the "Plumber"*

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## CURRENT TRENDS

The current trend in engineering education appears to be toward preparation for specialization with emphasis on teamwork. Such specialization requires more and more complete communication instead of less, and directs much attention to professional ethics. The engineering student of today must be guided into a pattern of thinking whereby he will be able to correlate tomorrow the fundamental rules of scientific principles and the engineering art. As someone has said, "We must have proper programs of education for both our 'plumbers' and our 'philosophers' or neither our pipes nor our ideas will hold water."

It is only through the educational development of the individual that his value to employer and society may be increased. Students must acquire the knowledge, attitudes, and skills which they will need to cope with the wide variety of problems which they must solve as practicing engineers. They must not only be encouraged to high individual attainment, but they must also be prepared to participate as a productive member of the engineering team.

The Engineering Graphics Division of ASEE is confronted with a three-fold question: How is the scientific specialization and teamwork required going to affect drafting courses; how can a proper program of education in engineering graphics be designed for all areas of specialization in engineering and science; and how can the student acquire adequate skills in graphical communication and basic design ability? The engineer, scientist, technician, and craftsman must understand each other. The final proof of adequate education for each will be determined by their collective performance.

## PROGRAM OBJECTIVES

A positive program in engineering graphics will have clean-cut and clearly defined objectives. The engineering student should-

1. Acquire sufficient knowledge and practice in engineering drawing that he may be prepared for further studies in engineering science and design.
2. Be provided with classroom and laboratory experience in combining the theoretical with practical applications needed for successful completion of future work assignments expected in the field.
3. Have training and practive in the use of engineering graphics needed by professional engineers who are expected to have concepts of an experimental approach beyond that of engineering formulas.
4. Develop in ability to perform progressively difficult assignments in engineering and accept increasing civic and job responsibility.
5. Develop in ability to exercise initiative and sound judgment, to appreciate the importance of aesthetics, to communicate ideas clearly and accurately, and
6. Develop his creative talents by improved analysis and synthesis with the methodology involved in performing the design function.

## ENGINEERING GRAPHICS AS A CATALYSTIC AGENT TO ENGINEERING AND SCIENCE

The student need not be required to take courses in engineering graphics just to "exercise the mind." But as long as engineering drawing remains the universal language of the engineer, all engineering students should be required to master its techniques.

Engineering drawing, enthusiastically taught by competent teachers, will go far toward developing graduate engineers who will display a high level of native creativity and inventiveness. There is no ceiling on the ultimate accomplishment expected of our students, except their individual talents, opportunities offered to them, and their own initiative.

Engineering graphics may well be the catalyst that will show the student how to integrate or synthesize his scientific knowledge Graphical communication provides a means of clear understanding. A beginning student with little background in engineering and scientific information may be hopelessly lost with only the oral or written explanation and needs a pictorial aid to acquiring accurate concepts. Effective learning is closely related to the meaningfulness of the terminology used and the interest and willingness of the student to learn. Terminology should be kept in the language of the student's former experience and new material should be well illustrated by pictorial concepts, such as design layouts, sketches, detail drawings, mock-ups, actual parts, exploded assembly drawing, and photographs.

## COURSES AND TEACHING

New techniques of teaching and instructional devices may be used to advantage. Exhibits of commercial drawings may be used as a means of instruction to demonstrate methods of design procedures. They often arouse interest and inspire the students to higher attainment.

Emphasis should be on projection principles, dimensioning, and production processes required for interchangeability. General drafting techniques in all the basic courses of engineering science will undoubtedly aid the student to a clear understanding of more advanced problem assignments.

## SYNTHESIS AND CREATIVITY

Students of science and engineering should be taught that nearly all solutions of engineering problems are at best only close approximations. Perceptive ability, imagination, stability, the capacity and willingness to collect necessary data, and the ability to assimilate facts must be developed in the student.

Facts serve as a starting point for new ways of doing things. Creative and inductive thinking takes existing facts and rearranges them in new combinations by applied imagination. Engineering drawing provides an accepted technique of displaying this new arrangement in physical mass or motion which we call design. As Professor Douglas P. Adams[1] puts it, "Graphics is the handmaiden of the sciences," and "Graphics gives appearance to mathematics, materials, physical reactions, and many other characteristics of scientific facts through lines and symbols."

The engineer usually wishes to convey visual concepts. Engineering graphics assists the engineer to first build up a complete pictorial image of a design or problem solution in his own mind. Then it serves the practical utility of recording his thinking as well as giving accurate instruction to those who are assigned the task of production or fabrication of his design.

Engineering graphics courses must therefore continue to provide the student with practice in systematic organization of productive ideas. These ideas may be expressed in good quality drawings which clearly convey his thinking to those who work with him.

The student must acquire the ability to converse in this language to successfully analyze and synthesize the combination of problems which will challenge him in both science and engineering. He must be in a position to convey his ideas and solutions to others before his designs or solutions are of ultimate value to mankind.

## NEW PROCEDURES

Engineers are often concerned with mock-up models. Models may also be used for instructional purposes. In fact, changes are often explored in the model stage to save expensive materials. Drawing changes are finalized after the model has been perfected Photographs are used for copying the model and are marked and noted for final specifications. The computer is also getting its share of attention as a means of graphical production. Time saving is the ultimate objective and therefore modeling, photography, drawings and other methods are combined.

## PROGRESS AND RESPONSIBILITIES

Individual progress is due largely to improvement in ability to assimilate and select items of knowledge, changes in responsibility, job experience, and environmental influences. The student will be unprepared to accept job responsibilities if he is hemmed in by narrow percepts due to teachers who place thumbscrews on the lid of new ideas and new ways of doing things. The student should not be directed down narrow paths of learning which may tend to limit his potential capacity. Not knowing the advantages of graphical methods used for computation and communication employed by engineers may severely handicap the student and shorten his ability on the job.

## FUNDAMENTALS VERSUS OBSOLESCENCE

A strong positive program in engineering graphics begins with a thorough knowledge of basic fundamentals. Fundamentals should not be replaced by frivolities. Nor should courses lead the student into areas of obsolescence except for historical background.

There are definite dangers of obsolescence in overspecialization at the undergraduate level; technologies change. Extreme specialization without first acquiring the basic principles may make the engineer or scientist immediately useful, but such specialization shortchanges the student in that it may hasten the obsolescence of his learning.

R. W. Olson[2] emphasizes the usefulness of knowledge in "making, selling, and intelligently using products as an economic activity." The engineer must understand the newer sciences. The old handbook and slide-rule is no longer adequate. Team efforts are necessary, and complete communication is required for good teamwork. The uses of new equipment often requires new graphical concepts for complete communication.

The endless stream of knowledge must be faithfully examined with each new develop-

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ment to detect significant fundamentals. Unless we have been grossly negligent in years past, a sizable amount of subject matter in our present-day curriculum is absolutely essential and cannot be discarded without woefully harming the student's future progress.

FUTURE DEVELOPMENTS

We can expect changes. No one can logically deny the inevitable. Consistency may be admirable, but not at the cost of making expensive mistakes. Only the mediocre are sure beyond a doubt. Therefore, we must test each new innovation as it is proposed in the light of what will it do for the student's progress and the future of mankind. The progressive teacher, like the engineer, must be able to grasp the implication of each new scientific advancement and put it to work in the classroom and laboratory.

*footnotes.*

1. Adams, Douglas P. (Massachusetts Institute of Technology). "Graphics--the Cursive Writing of Science": ASEE Anual Conference, Pennsylvania State University, 1955.

2. Olson, R. W. (Vice President of Texas Instrument Company). "Needs in the Electronic Field": ASEE Annual Conference, Purdue University, 1960.

GRAPHIC ODDS & ENDS

GRAPHIC TANTALIZER

Space can be divided in two by one plane, and can be divided in four by two planes, and into eight by three planes. How is space divided by four planes? By five, etc.? Send your graphic solution to your editor, Mary Blade.

# Graphical Method in Error Analysis of the Photogrammetric Problem

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Princeton University

## Introduction

Photogrammetry is the science of making measurements from photography, as its name implies. These measurements can be made from a single photograph, a pair of photographs, or a whole group of photographs. This paper will be limited to considering the case in which a pair of photographs is used. That case is analogous to the problem of human vision, and involves stereoscopy. An appreciation of the physical relationships in stereoscopy will provide and understanding of this type of photogrammetry.

Photogrammetry is basically dependent upon the relationships of geometric optics. Straight lines of sight (or rays) issue from the nodal points (or the lens center, practically speaking) of the camera lens, both towards the object space and towards the image space. These nodal points, furthermore, are the points of origin for central point projections. Thus, truly three-dimensional arrays are established as in stereoscopy. With two uniquely identifiable and oriented projection centers, the composite ray pattern in the object space singularly defines the three-dimensional location of object points. This is the goal of stereoscopic photogrammetry.

A further limitation in this presentation will be to consider the normal case in aerial photogrammetry. Aerial photogrammetry, as applied to map making, is unquestionably the type of photogrammetry in greatest use today. Map making can also be carried out on the ground, and is, to a much lesser degree. Other uses of photogrammetry include investigation of deformations where extensive and/or instantaneous records of deformations are needed, both in the laboratory and in the field. The normal case of photogrammetry requires the image planes of the pair of photographs to be coplanar. This simplifies much of the geometry, but it is an idealized case. In actuality, in aerial photogrammetry a completely free system with three translational degrees of freedom and three rotational degrees of freedom is encountered. In other uses of photogrammetry more restrictive systems can be and are used

## The Physical System

The normal case of photogrammetry, in which the landscape is photographed, is shown in Fig. 1. The lines of sight are projected from the lens centers onto the coplanar image planes in the image space. These image planes can be seen to have image points transposed right to left as happens with a simple lens. For analysis, however, the images are invariably transposed an equal distance about the lens centers into the object space as is also shown in Fig. 1.

There are two fundamental geometrical relationships in photogrammetry on which everything depends. One of these states that for a given point the y-coordinates

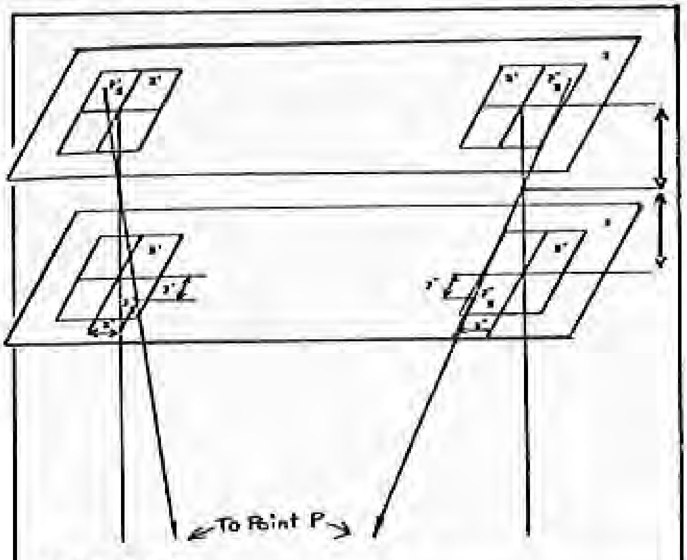


FIGURE 1

of the two image points must be the same. The other states that, for a given camera (focal length, f, known), the vertical distance from the airplane to a ground point is directly proportional to the distance between the two camera stations, and inversely proportional to the difference in the x-coordinates of the two image points. These important fundamental relationships are developed in the appendix.

In order to facilitate solution of the aerial photogrammetric problem, auxiliary information regarding the camera location and orientation is sometimes used. For the direct determination of these necessary values, Shoran, Doppler navigation, the statoscope for precise barometric height differences, and, more recently, inertial devices are used. For the indirect determination of these values, ground surveys of photogrammetric control points are carried out. This includes the determination of the latitude and departure and/or elevation of the prescribed points. Thus is the physical system completely defined.

## Error Sources

Photogrammetry is a relatively simple system as described above. However, many factors work against the theoretical solution of the photogrammetric problem. The two main classes of errors are 1) those which are related to the ray paths, and 2) those which are related to the camera orientation problem.

The ray path errors can be further subdivided. In the camera object space, a straight line of sight in a cartesian coordinate system is assumed as was shown in Fig. 1. In actuality, the ray is bent by the varying density of the atmosphere as it proceeds toward the earth, and the object points, furthermore, are located in a spherical coordinate system. As for the camera image space, the camera lens introduces a certain distortion, both radial and tangential. The image plane is theoretically flat and perpendicular to the optical axis; however, in practice, such an assumption cannot be made. The stability of the photographic emulsion from the instant of exposure to the time of analysis must be taken into account. Positional changes here will unquestionably effect the results. The ray path problems of the camera system will be present in the data reduction devices also. Flatness of photographic emulsion and projection lens distortions are paramount in this situation.

The orientation errors in photogrammetry are those which involve first the relative orientation of one image plane with respect to the other image plane for the proper stereoscopic relationship, and, second, the absolute orientation of the stereoscopic pair with respect to the desired coordinate frame of reference.

In the first case, the y-coordinate relationship of image points as mentioned above is used. Each of the three possible rotational movements, and each of the three possible translational movements, except that in the x direction, will produce differences in the y-coordinate values. Any inability to eliminate these differences will therefore provide errors in the relative orientation. The direct determination of the camera orientation and position differences by electronic, inertial and similar devices will also introduce errors which will affect the relative orientation.

For absolute orientation, ground positions computed from the stereoscopic pair of photographs can be compared with measured ground positions from the ground surveys. In this manner, absolute orientation can be accomplished. However, any final difference in the computed and measured values will be an indication of absolute orientation errors. As in the case of relative orientation, other auxiliary information can be used to carry out absolute orientation, with similar error problems introduced.

Examination of the error sources mentioned above will show that ray path errors are non-independent in nature and therefore tend to reinforce each other. Furthermore, these errors are primarily systematic in effect. With regard to orientation errors, they are independent in nature and tend to be additive. Also, these errors are primarily accidental.

## Error Problems

The relationship of the error sources mentioned above to the solution of the photogrammetric problem can be analyzed in the same sequences. The state of the art will now be considered.

The ray path in the camera object space remains a difficult problem. Fortunately, the errors caused by the use of a cartesian coordinate frame of reference for a spherical coordinate object space tends to cancel the effects of a line of sight which is curved by air which becomes constantly denser as it goes from camera to object. Furthermore, the method of absolute orientation mentioned above in which computed and measured ground points are compared, tends to eliminate this particular problem by forcing an adequate solution.

The error problems of the camera image space have been taken care of, to date, by constantly improving lens performance requirements and image plane flatness specifications. Film emulsions and their supporting base have also continually improved, so that these are less of a problem than previously. The data reduction system has also experienced steadily tightened specifications. Thus, the three foregoing errors have achieved a level of performance satisfactory for the usual mapping problem, and can be momentarily forgotten.

The use of auxiliary information for the solution of the relative orientation problem has not been at all satisfactory to date. The y-coordinate relationship, however, is used, and a fifth degree equation is solved. There is one indeterminate case which may be of interest and is whown in Fig. 2. If the camera and the ground points define a circle or approximately so, the rotation of the camera about the x-axis cannot be determined from the y-coordinate relationship.

For absolute orientation, the use of auxiliary information from electronic, inertial and similar devices has also been unsatisfactory to date. Resectioning, by comparing measured and computed ground positions, has been the normal approach to solving the absolute orientation problem.

An interesting adjunct to the orientation problem is as follows. Theoretically, once absolute orientation has been accomplished for a single stereoscopic pair, by the successive use of relative orientation procedures in which a new photograph is related stereoscopically to an existing one, a new, absolutely oriented stereoscopic pair will be defined. However, errors accumulate in this operation, which is known as bridging. The extent to which bridging can be carried out, furthermore, depends on the magnitude of all of the error problems discussed above. Failing a satisfactory solution by successive bridging, absolute orientation of individual stereoscopic pairs of photographs must be performed often enough to satisfy accuracy requirements.

Error Solutions

The methods of solving the photogrammetric problem and their limitations are next investigated. The two major elements to be considered are the basic physical system involved, and the orientation problem.

First, consider the orientation problem. The relative orientation relationship discussed above involves the y-coordinates of 5 points. Consequently, a direct solution for only these 5 points can be guaranteed. Due to ray path errors, which exist to a greater or lesser degree throughout the area of concern, both in the camera, and the data reduction system, errors of some magnitude are certain to be present in the relative orientation solution for all other points. The same can be said for the absolute orientation procedure. The x, y, and z coordinates of only three points can be properly determined in an absolutely oriented system. However, all other points will experience errors due to the ray path errors and the relative orientation errors just described.

To analyze the physical system, its elements must be known. First of these is the proper definition of the model which includes the object, the object space ray path, the camera, the photographic film, the available positional information, and the data reduction system. Next, the data input to each of these elements must be understood. Finally, the significance (or the order of magnitude) of each of the date inputs must be comprehended. With these three elements adequately defined quantitatively, a precise solution of the error system can be made at any point desired.

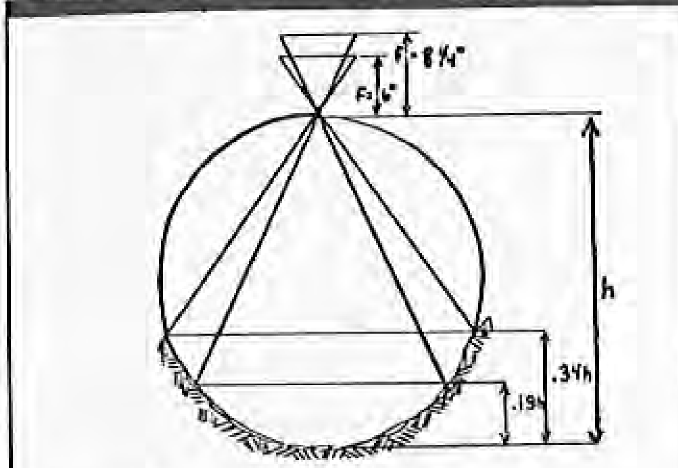

FIGURE 2

The data reduction system has not yet been mentioned. It is in order to give some idea of the methods used in carrying out this work. The simplest, accurate system is basically an optical analog computer as exemplified by the Balplex and Kelsh plotters. The entire original optical system is scaled down so that it reproduces for the operator, at the desired scale, a model of the original scene. A more accurate system is that represented by the Wild A 7 or the Zeiss Stereoplanigraph C 8 which is basically an optical-mechanical analog computer with mechanical linkages for the ray paths from the plotter lens. A final high-accuracy system worthy of mention is the stereocomparator in which photographic coordinates of points viewed stereoscopically are precisely measured from the photographic plates. These values are then inserted into mathematical expressions for the precise determination of ground coordinates.

## Magnitudes

In order to obtain a moderate perspective of some of the factors involved in aerial photogrammetry, the following are cited. The usual positional accuracy for a point on a map is 1/40" at map scale, this being considered as fine as one can normally use a map. A vertical accuracy of 1/2 contour interval for 90% of the map area and not more than a full contour interval for the remaining 10% is normally used. The flying height varies from 1500 ft. to 36,000 ft. depending on the scale and mapping system used. A rough method relating the contour interval to the flying height is through "C factor" which gives a ratio between these two values, and is dependent primarily on the date reduction system used. It runs from 800 conservatively for the optical plotter to possibly 2400 for the best optical-mechanical system. The camera is a precision 9" x 9" with a lens cone of approximately 95°. Shutter speeds vary from 1/200 to 1/800 sec. In order to carry out adequately the mapping work, end overlap between successive exposures is approximately 60% and side overlap is about 20%.

Considerable research and investigation has been done on the nature of the ray path in the image space of the aerial camera. Quantitative information is quite well known in this regard. Practically no information is known, however, about the ray path in the object space of the photogrammetric system.

The optical type analog data reduction system is good for solving the relative orientation problem, but cannot be used effectively for bridging. The optical-mechanical analog system can be used successfully for relative orientation and the bridging of a few stereoscopic models for absolute orientation. However, if absolute orientation is to be projected through an extensive system, the stereocomparator with an analytical solution is required.

## Photogrammetric Needs

The most significant need in photogrammetry at this time is the checking out of the photogrammetric model in order to determine the sensitive elements of the system. Following this, an analysis of the quality of the data input at the various points is necessary. Mapping, in the mathematical sense, could be a means of appreciating at various points the effect of errors in the original data input. Finally, help could be used on the significance problem. The resulting effect of a round-off error at some previous point needs to be demonstrated. By the solution of any or all of these problems, photogrammetry will be able to design its systems more intelligently in the future.

Another important and challenging, but less complex area of concern, is that of dealing with composite known errors. Along the ray path, the individual components of the errors of the image space are well known. However, the effect of combinations of these errors is not as well known as desired. These could appropriately be mapped also.

The problems along the ray path in the object space have been mentioned previously. Some method is needed to appreciate the magnitude of the bending of the optical rays and the errors in projecting a spherical coordinate system onto a cartesian coordinate system.

Graphical analysis of the errors encountered in relative and absolute orientation have been pursued to a modest degree, but much more needs to be done here. The various relative orientation errors need to be combined in order to obtain the total error picture.

## Conclusions

The photogrammetric system which has been discussed above can be seen to be basically a three-dimensional, graphical system using a central point projection. The basic problem, however, in the accurate use of the photogrammetric system is an appreciation of the errors encountered in it. Mathematical mapping of the effects of errors at various points in the system would be most helpful. However, the introduction at the proper point of some of these errors and the follow through to the final topographic map for their effects, in true systems analysis fashion, is the greatest need of photogrammetry. It would solve a great many of photogrammetry's major problems.

At the present time, the tendency is to look for mathematical solutions of these problems. But these solutions are cold, and actually do not give one a clear feeling for the validity of the results.

For the three-dimensional projective relationship that is met in photogrammetry, there would seem to be apriori evidence that graphical methods are possible in the error analysis of the photogrammetric problem. And because of this there should be a most fruitful area of research.

## Appendix (see Fig.3)

Proof of y parallax relationship

For $\Delta$'s $L'o'w'$ & $L'O'W$ and $\Delta$'s $L'w'p'$ & $L'WP$

$$\frac{L'o'}{L'O'} = \frac{L'w'}{L'W} = \frac{o'w'}{O'W} \quad (1)$$

$$\frac{L'w'}{L'W} = \frac{w'p'}{WP} \quad (2)$$

Then $\frac{L'o'}{L'O'} = \frac{w'p'}{W\,P}$ and $\frac{L'o'}{L'O'} = \frac{f}{H-h}$,

$$\frac{w'p'}{W\,P} = \frac{y'}{Y}$$

and $y' = \frac{fY}{H-h} \quad (3)$

Similarly for $\Delta$'s $L''o''w''$ & $L''O''W''$ and $\Delta$'s $L''w''p''$ & $L''WP$

$$\frac{L''o''}{L''O''} = \frac{L''w''}{L''W} = \frac{o''w''}{O''W} \quad (4)$$

$$\frac{L''w''}{L''W''} = \frac{w''p''}{W\,P} \quad (5)$$

then $\frac{L''o''}{L''O''} = \frac{w''p''}{W\,P}$ and $\frac{L''o''}{L''O''} = \frac{f}{H-h}$,

$$\frac{w''p''}{W\,P} = \frac{y''}{Y}$$

$$y'' = \frac{fY}{H-h} \quad (6)$$

Therefore, $y' = y''$ q.e.d. (7)

Proof of x parallax relationship

Construct $L'w_1'$ parallel to $L''w''$.

Then $w_1'o' = w''o'' = x''$

$$\Delta L'w_1'w' \sim \Delta L'L''W$$

$$\frac{w_1'w'}{L'o'} = \frac{L'L''}{L'O'} \quad (8)$$

but $w_1'w' = x' + x'' = p =$ difference in x coordinate

$$H-h = \frac{fB}{p} \quad (9)$$

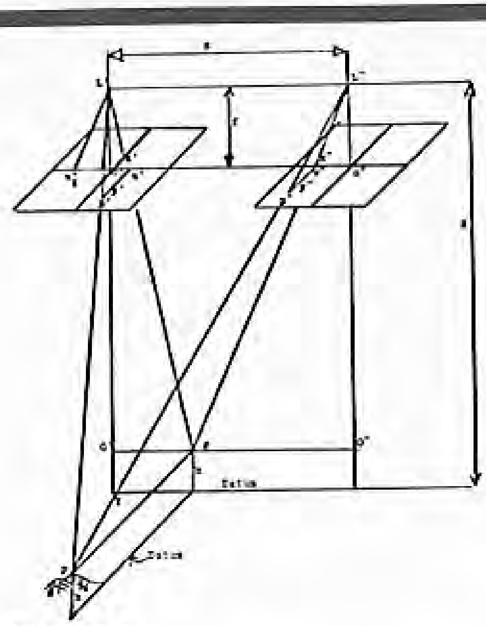

FIGURE 3


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Hallert, Bertil - Photogrammetry, New York, N.Y. McGraw-Hill Book Co., 1960

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# Nomograph for $xy = z$

Dr. D. Mazkewitsch
University of Cincinnati, Ohio

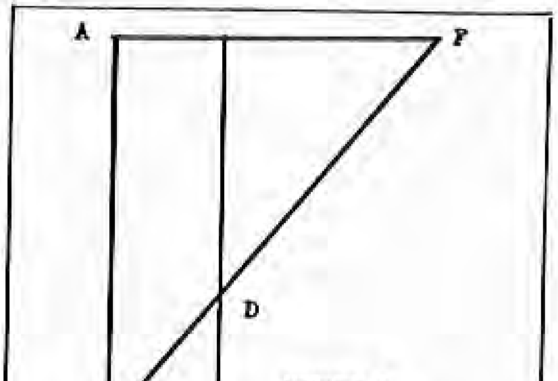



FIGURE 1

From figure we have: $CD = AB.BC.\frac{1}{AF}$, that is, CD is the reciprocal of AF with modulus AB.BC. The above equation may also be written: $CD.AF = AB.BC$

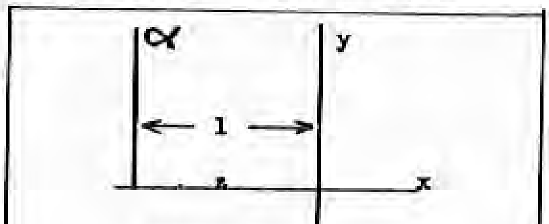



FIGURE 2

Now, on Ax (fig.2) lay off to any scale 1,2,3,... On Ab⊥Ax, to any scale, lay off AB = a = 10. Through 1 on the x-scale pass 1C // AB. Connect B with 1,2,3,... Then the points of intersection of these lines with 1C give the reciprocal values of 2,3,... with modulus a.1, and solutions of the equations xy = a.. If in the same diagram we pass parallels to AB through 2,3,...we obtain on these parrallels solutions of the equations xy=2a, xy=3a...

The multiplication table by Pouchet is well known*. But the drawing of the table requires the construction of equilateral hyperbolas, Moreover, if the product does not lie on one of the hyperbolas drawn, an interpolation by sight must be made.

By virtue of what has been said in the beginning, the product xy=z may be found by using the coordinate system xAB as in Fig. 2 without additional lines: Connect B with the number on Ax representing x; a horizontal tjrpigj u.
a horizontal through y. read on AB, intersects Bx at the point representing the product xy, read to the scale of x times 10 (length of AB). For example, for 3.8x4.5 we find in the chart 17.1 (The lines Bx do not need to be drawn, as the index lines in aligment charts are not drawn).

* See: R. Soreau: Nomographie ou Traité des Abaques, p. 45, Paris 1921
or: W. Meyer zur Capellen: Leitfaden der Nomographie, p.32, 1953

# Nomograms for $z = \frac{uv}{w-v}$

Consider two rectangular coordinate systems u,w and z,v; superpose them so that the u- and z-, and the w- and v-axes coincide respectively.

The condition that the triples of points 1) (-u,w), (0,v), (z,0), 2) (-u,-w),(0,-v),(z,0), (3) (u,w), (0,v), (-z,0), 4) (-u,-w), (0,-v), (-z,0) lie in one line is

$$\begin{vmatrix} -u & w & 1 \\ 0 & v & 1 \\ z & 0 & 1 \end{vmatrix} = 0.$$

The development of the determinant yields

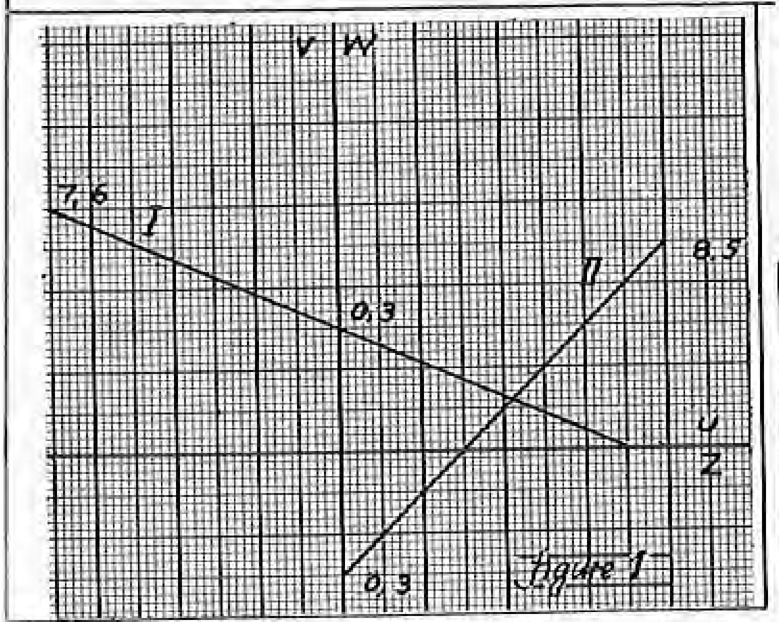
$$-uv + zw - zv = 0.$$

This equation is the title equation.

Hence a chart, in which the u- and z-axes and the w- and v-axes have respectively the same moduli, solves the title equation. Example: u = 7, v = 3, w = 6, z = 7 (Line I in the diagram). Note that in the derivation of the chart for the title equation the given value of u is positive, i.e., if the given value of us is negative, this value is to be plotted on the positive u-axis.

The condition for the triples of points 1) (-u,w),(-z,0),(0,-v), 2) (u,w),(z,0),(0,-v), 3) (u,-w), (z,0), (0,v), 4) (-u,-w), (-z,0),(0,-v), to lie in one line is

$$\begin{vmatrix} -u & w & 1 \\ 0 & -v & 1 \\ -z & 0 & 1 \end{vmatrix} = uv - wz - vz = 0$$




$$\therefore \quad z = \frac{uv}{w + v} \ .$$

The same chart is used. In using the chart for this formula it has to be kept in mind that v is to be plotted with sign opposite to the given sign.

Example: w = 5, u = 8, v = 3, z = 3, (Line II in the diagram.)

To solve the title equation by means of a nomogram, we transform the equation as follows:

$$z = \frac{uv}{w - v} = \frac{u}{\frac{w}{v} + 1}$$

$$\therefore \quad \frac{w}{v} - 1 = \frac{u}{z} = \alpha \ ,$$

being the auxiliary variable. To present

$$(1) \ \frac{u}{z} = \alpha \qquad \text{or} \qquad \frac{u}{z} - \alpha = 0$$

in a rectangular coordinate system xy, put

$$(2) \ x = u; \ y = -\alpha \qquad \text{or (3)} \ x - u = 0;$$

$$y + \alpha = 0.$$

Substituting (2) into (1):

$$\frac{x}{z} + y = 0 \qquad \text{or (4)} \ x + zy = 0.$$

From (3) and (4) we form the determinant

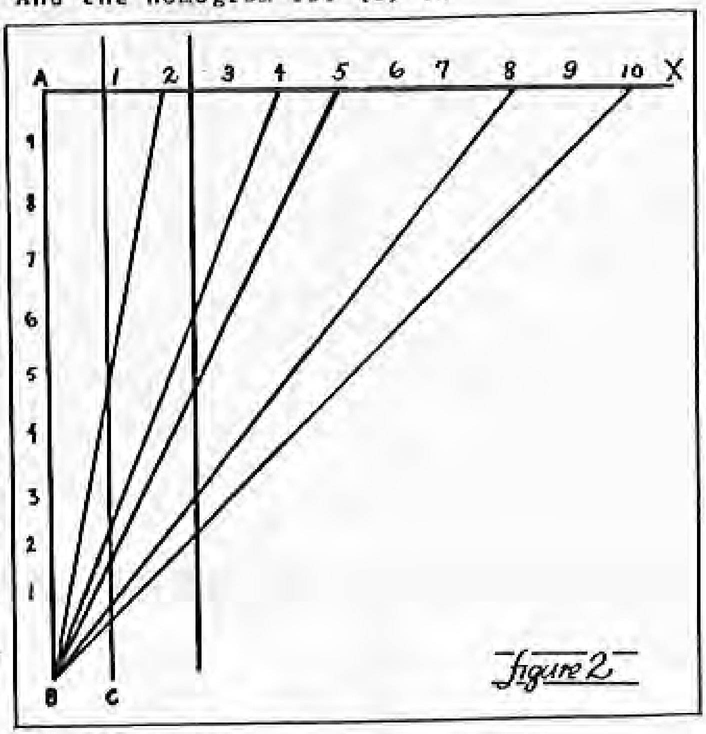
$$\begin{vmatrix} 1 & 0 & -u \\ 0 & 1 & \alpha \\ 1 & z & 0 \end{vmatrix} = \begin{vmatrix} 1 & 0 & -u \\ 1 & 1 & \\ 1-z & z & 0 \end{vmatrix} = \begin{vmatrix} 0 & -u & 1 \\ -1 & \alpha & 1 \\ \frac{-z}{1+} & z0 & 1 \end{vmatrix} = 0.$$

From the desgin determinant we obtain the equations of the

u - scale: $x = 0, \ y = -u$
" $x = -1, \ y = \alpha$

z - scale: $x = \frac{z}{z+1}, \ y = 0.$

And the nomogram for (1) is




To: represent

$$(5) \ \frac{w}{v} - 1 = \alpha \qquad \text{or} \qquad \frac{w}{v} - 1 - \alpha = 0$$

in a rectangular coordinate system xy, we put $x = w, = -\alpha$ or (6) $x - w = 0, \ y + \alpha = 0.$

Substituting (6) into (5):

$$\frac{x}{v} + y - 1 = 0 \quad \text{or (7)} \ x + vy - v = 0.$$

From (6) and (7) we form the determinant

$$\begin{vmatrix} 1 & 0 & -w \\ 0 & 1 & \alpha \\ 1 & v & -v \end{vmatrix} = \begin{vmatrix} 1 & -w & 1 \\ 0 & & 1 \\ \frac{1}{1+v} & \frac{-v}{1+v} & 1 \end{vmatrix} = 0$$

∴ Equation of w-scale: $x = 1, \ y = -w$
" $\alpha$ " : $x = 0, \ y = \alpha$
" v- " : $x = \frac{1}{1+v}, \ y = -\frac{v}{1+v}$ .

Eliminating from the equation for the v-scale the parameter v, we obtain v, we obtain as equation of the v-scale: $y = x - 1$. Hence for $x = 0$: $y = -1$, and for $y = 0$: $x = 1$.

continued on page 58

# The Challenge of Multidimensional Parallel-Axis Projection

Forrest M. Woodworth
University of Detroit

Recently there has been a revived interest in Projective Geometry, which is certainly a neglected phase of Theoretical Graphics.[1] An article appearing in this journal was devoted to the topic,[2] and a workshop on the subject was held at the recent Graphics Division Summer School in Colorado[3]. A second article deals with a related topic.[4] One intriguing outgrowth of Projective Geometry might be termed "parallel-axis projection", because it involves dual (point-line) coordinate systems of more than two dimensions. This article will simply review a few basic principles, and ask some questions. No attempt will be made to provide answers.

The two dimensional case stems directly from projective constructions. The latter subject is expertly presented in a current Engineering Graphics text.[5] The dualizing of points and lines is in reality a kind of graphic transform, and in this article dualize and transform will be used interchangeably.

The point $p(x_0,y_0)$ in Fig. 1 is part of a two dimensional coordinate line (convergent-axis) system. Note that this point is dualized (transformed) to a line in the two dimensional coordinate point (parallel-axis) system of Fig. 2. This implies the following transform theorem.

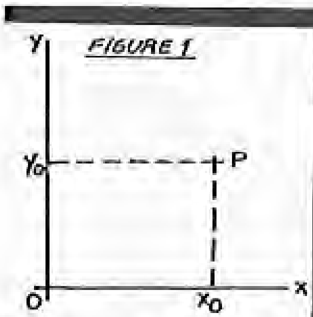



FIGURE 1

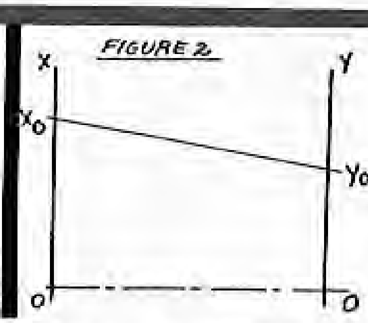



FIGURE 2

<u>Theorem I. A point (x,y) on a convergent-axis plane transforms to a line xy on the corresponding parallel-axis plane.</u>
The inverse transform principle follows as a corollary.

Any plotted line, such as that of Fig. 3, can be described by two points $(x_1,y_1)$ and

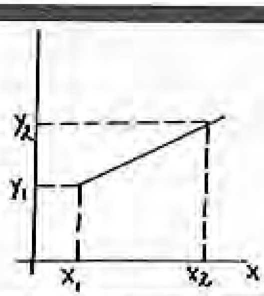



FIGURE 3

$(x_2,y_2)$. In the coordinate point system, this line becomes the intersection of the lines $x_1y_1$ and $x_2y_2$. The transformed line has been identified as the point (x,y) of Fig.4. A second theorem may now be stated.

<u>Theorem II. A line on a convergent-axis plane described by two points $(x_1,y_1)$ and $(x_2,y_2)$ transforms to a point (x,y) on the corresponding parallel-axis plane.</u>

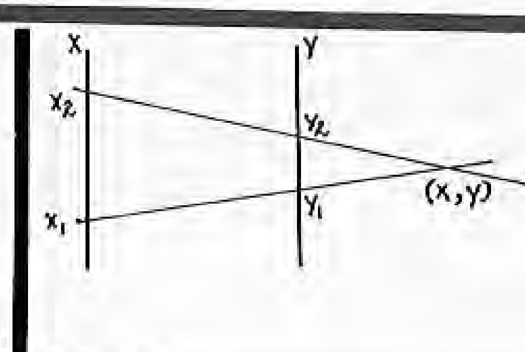



FIGURE 4

A rather obvious question might be raised: how can the length of a transformed line segment be measured? Granted the question is academic because applications of Projective Geometry are not ordinarily concerned with such things, it nevertheless could lead to some interesting speculation.

Enough information has been presented to solve a simple "coplanar" parallel-axis problem. Given two non-parallel coplanar lines described by the pairs of points $(x_{11},y_{11})$, $(x_{12},y_{12})$ and $(x_{21},y_{21})$, $(x_{22},y_{22})$; determine their intersection $(x_{00},y_{00})$ by using a dualized system.

The solution is shown in Fig. 5. The points $(x_1,y_1)$ and $(x_2,y_2)$ are the transforms of the given lines. These two points determine the line $x_{00}y_{00}$, and the intersections of this line with the two axes must be the required points for evaluating the coordinates of the intersection.

More stimulating is a problem using a three dimensional transform. Assume that the defining coordinates of an orthogonal line are $(x_1,y_1,z_1)$ and $(x_2,y_2,z_2)$. What will a parallel-axis plot of this line look like, and,

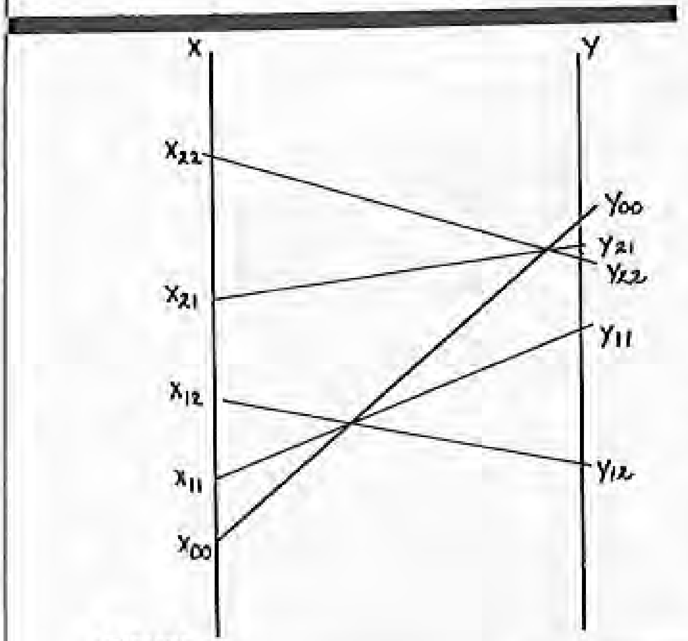



*FIGURE 5*

given one coordinate of an intermediate (third) point on the line, how can the other two coordinates be found?

The answer to both questions will be found in Fig. 6. The given orthogonal points are represented by triangles, and the parallel-axis points (x,y), y,z), and (z,x) are the three principal coplanar projections of the given orthogonal line. Note that these three points all lie on the same straight line: This suggests the question of whether a theorem is possible to the effect that in higher spaces of multiple dimensions all such points would also line up. The theorem could be proved or disproved. Another question might involve the parallel-axis representation for the intersection of a line and a plane.

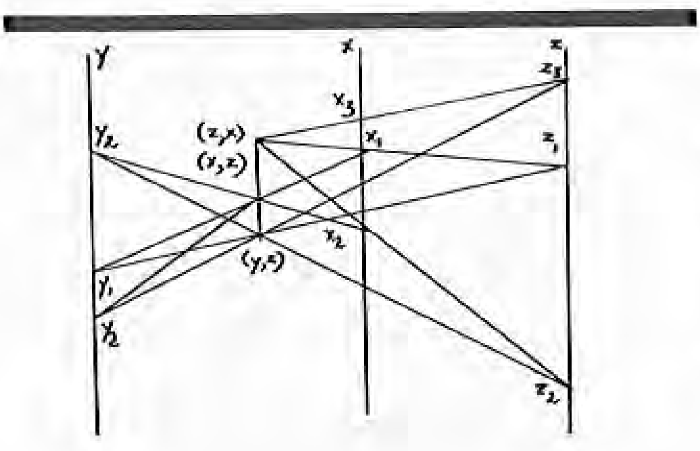



*FIGURE 6*

Returning to the problem at hand, it will be assumed that the intermediate coordinate $x_3$ is known (Fig. 6). To obtain the corresponding y and z coordinates, first draw a line through $x_3$ and (z,x), and extend this line to the z axis, thereby determining $z_3$. Next draw a line through $z_3$ and (y,z); the intersection of this line with the y axis will be $y_3$. As a check, the points $x_3$, (x,y), and $y_3$ should all lie on the same straight line.

Admittedly, the pursuit of such problems can appear to be pointless. Nevertheless, if from such mental gymnastics creative thought evolves, the effort must be considered worthwhile.

## *footnotes*

[1] There may be some question as to the advisability of calling Projective Geometry a branch of Theoretical Graphics. The inference here is that it cannot be Applied Graphics unless frequently used, which it is not.

[2] V. P. Borecky, "Relationship Between Projective and Descriptive Geometry", Journal of Engineering Graphics, Vol. 26, No. 1, February, 1962, Pages 8-11.

[3] Professor Borecky was the leader of this workshop.

[4] L. I. Epstein, "On the Non-Projective Transformations of a Nomogram", Journal of Engineering Graphics, Vol. 25, No. 3, November, 1961, Pages 15-18.

[5] Rule, J. T., and Coons, S. A., GRAPHICS, New York; McGraw-Hill Book Co., 1961, Chapters 18 and 24.

## From Your Chairman
M. McNeary, University of Maine

Annual meetings such as the one last June at the Air Force Academy are refreshing experiences for me. I am always impressed with the high calibre of my colleagues. I rejoice in their successes on their home campuses, share with them their frustrations in local academic skirmishes, and resolve to put their experiences to use in my own situation.

This year's meeting, preceded by the Engineering Graphics Division Summer School, was outstanding. Ed Griswold and all those who contributed to the program deserve congratulations for a well-organized series of conferences on topics of high interest. Those who provided leadership for the Summer School merit particular praise for their enthusiasm and hard work.

Those at the meeting in June were concerned, as always, about trends in engineering education and their possible effect on the teaching of Engineering Graphics. Indeed, trends are a concern of all teachers of engineering subjects at all levels in the curriculum. My personal opinion is that the renewed interest of educational administrators and degree-granting departments in the teaching of design offers us a rare opportunity to make engineering graphics a vital force, vitally needed, in the future curriculum. We are in a favorable position to contribute for two reasons (1) Graphics is a primary tool for the expression of the conceptual phase of design, and (2) our work in the first year of the engineering curriculum with impressionable beginners is a good place to start design-oriented thinking.

Perhaps the work "conceptual" need some explanation. Design has tow main phases: the conceptual and the analytical. We first fix our concept of a new idea or device on paper using the traditional methods of engineering drawing, and then the new idea of device is analysed using mathematics and the laws of the physical sciences to determine whether it meets criteria for performance and economy. These two phases are re-iterated, or repeated, perhaps many times until optimum design is reached. For many simple devices analysis is not need and in some cases it is impossible. Since analysis is taught in depth in upperclass courses, it seems to me that work for beginning students should consist of problems that require originality in concept with a minimum of analysis.

The foregoing is my observation of a trend that I find challenging and suited to my personal tastes. Many of you will have other interests that you feel are more worthy of emphasis. As our good friend Jasper Gerardi, whom we honored at our last annual meeting, said so well, "The outstanding characteristic of the Graphics Division is its capability of making good personal friends of people who differ widely with each other on matters of educational principles." May it ever be so.

Professor Matthew McNeary,
Head, Dept. of Engineering Graphics
University of Maine

Some Remarks by the Past Chairman
Edward M. Griswold

Professor Edward Griswold,
Dept. of Mechanical Engineering
The Cooper Union

Design is an important field which offers fertile ground for teaching material in Engineering Graphics. In my opinion design is the primary function of the engineer. The word design can apply to the most complex of systems right down to the highly important hardware which makes it possible for the system to perform its function.

Out recent Summer School set the stage for the use of design concepts in Engineering Graphics. Design must begin with the basic concepts of Descriptive Geometry and Engineering Drawing. I do not see how any branch of engineering which engages in the design of any type of three dimensional object can possibly arrive at a satisfactory solution without making some kind of sketches or drawings. The Summer School presented the principles behind graphical solutions to the mathematical problems of design. The graphical method often offers the best solution of the problem and requires skill in the manipulation of drawing instruments to get an acceptable answer. The computer is another important design tool when iterative processes are involved in the solution.

It seems to me that we can rightly and properly enter the field of design and begin the process of developing this largely uncultivated territory in the minds of the students. We can start early to make our candidates for engineering degrees of any kind design oriented. It can begin with almost the first drawing room problem if a little imagination is used. Open ended problems create interest and provide motivation in the classroom.

Let us continue to study, reevaluate, and improve the teaching of that which is basic. Let us keep our minds open to new ideas and new ways of doing things which may be developed into something that is superior to what we now have. So long as we continue to do these things Engineering Graphics will have an important place in engineering education.

The reins of the Division have been passed into the capable hands of Professor McNeary, your chairman. I am looking forward to a great year under his leadership.

It has been both an honor and a pleasure to have served as Chairman of the Division of Engineering Graphics during the past year. I would like to take this opportunity to thank the members of the Division for their support and their participation in the work and activities of the Division.

Edward M. Griswold

# Decimalized Measure Versus The Metric System

The age-old contest contines between the advocates of the metric system and the advocates of the English-inch system of measurement. The complications and growth of technology today has caused many leaders of industry to take a critical look at communication systems and drawing delineation standards in dimensioning.

The advocates of the metric system claim that both industry and science would profit by using the metric system of dimensioning and measurement. But the majority of industrial representatives insist that the metric system of measuring has many disadvantages. The metric system has the drawback of requiring a "rounding off" or adjustment in size dimensions which creates difficult isolated problems in engineering rather than solve the total problem. Extremely close measurement is difficult by the metric system where function and interchangeability are integrated into mass production processes of manufacturing.

The proponents of the metric system claim that the U.S. must change over to the metric system in the near future for urgent national security reasons. But they forget that if the metric system were adopted to replace the English-inch system, and if a national emergency should occur during the changeover period (and no one visualizes an overnight transition), our defense efforts could be seriously handicapped by the confusion that would surely exist.[1]

The metric system advocates point out the difficulties of translating the English fraction of an inch to decimals and the trouble machinists have in "rounding off" decimal equivalents. They forget that even though the metric system has the advantage of units advancing by tens, it also involves the problem of multiple "rounding offs" where an assembly requires extremely close tolerances to secure proper fit between mating parts.

Those against changing to the metric system point out that "the millimeter is an unfortunate size in terms of the resolving power of the human eye. The millimeter is about .040 inch which is about twice too large to be suitable as the smallest graduation on a scale; but .1 mm or .2 mm would be too small. This has resulted, in countries where the metric system is used, in the practice of rounding off any measurement smaller than one millimeter into the nearest half millimeter-expressing the result as .5 mm. Whenever this needs to be divided by two, it has the awkward result of either adding an additional digit - .25 -- or causing a second "rounding off."[2]

Already industry in the main has converted to a decimalized inch system which avoids the pitfalls of "rounding off" and also advances in units of tens.

Decimal arithmetic is no longer the monopoly of the metric system. The inch has been decimalized in a majority of manufacturing and mass production industries. Arithmetic computations have been simplified, and time and effort has been greatly reduced. The need for conversion of fractions to decimals (or vice versa) with its resultant problems has been eliminated by the decimal inch system. Scales have been simplified. They are easier to use in making layouts and measurements by engineering, manufacturing, and inspection personnel.

The decimal-inch system uses infinitesimal units in a dynamic and logical manner which is compatable with the requirements of modern industry or science. The thousandth and ten thousandth of an inch are common increments of measure in the machine shop. And the calibrating laboratories readily check precise inch measurements, using the millionth for the increment of measure.

The decimal inch system is easy to learn and understand. It provides a single unit of linear measurement which has been standardized by the Bureau of Standards at Washington, D.C. so that one inch equels 2.54 centimeters and can be easily and directly converted to the metric system.

History documents the fact that both the metric and the English-inch systems have undergone revisions to facilitate design and fabrication. Innovations have been adopted in both systems when a change in technology required new considerations and concepts.

The cost of complete conversion to the metric system seems to be the major difficulty. It has been conservatively estimated that it would cost American industry 75 billion dollars to adopt the metric system. Estimates for the time required to make the conversion varies from five to thirty years. Nearly all of the existing tools will require recalibrating. Cost of this alone would be inconceivable. All of the blueprints using English-inch dimensions would be obsolete, and all working drawings would have to be replaced for any part yet in use. The cost of this change alone is estimated as approximately 25 to 30 per cent of the original engineering time for the original drawings.[3]

Proponents for the metric system assert that simplicty would be gained through compatability between industry, science, and the rest of the world. They argue that the elimination of frequent conversion between engineering and science laboratories would offset somewhat the cost of complete conversion.

The anti-metric advocates point out that it will take not only time but expensive training programs to re-educate the machinists, inspectors, etc., who would be involved with the change. And others visualize a training program which involves their customers in everyday living. Our whole lives have been adjusted to the English system of measurement.

Textbooks must be revised for elementary school mathematics, technical drafting, and shop courses as well as these same courses in engineering and technical schools. Instruction in the classroom will also be affected by both standards of measure--metric or decimal inch.

Automation and computer controlled machining developments are also making the problem of conversion more complex. Programming is usually done in decimal notation which uses the 10-base numerical system. The decimal inch eliminates the common fraction and gives many of the advantages of the metric system without severe penalty.

In 1959 a suggestion was made to the ASA Mechanical Standards Board urging greater use of decimalization in the standards under the scope and jurisdiction of the Board. At the same time the American Society of Tool and Manufacturing Engineers introduced a resolution into the ASA Council proposing the development of an American Standard for the definition and use of the decimal inch.

The council resolution was referred to the Mechanical Standards Board which approved the project on March 9, 1960. Accordingly the ASA Standards Committee B-87 Decimal Inch was formed by appointment of representatives from those industrial, scientific, and other organizations interested in the project from both the United States and Canada. Twenty-two organizations appointed twenty-eight[4] members and alternates to the Committee.

Mr. Roy P. Trowbridge, Director of General Motors Engineering Standards, was appointed chairman of the new committee. The first meeting was held in Detroit, Michigan on February 3, 1961. At this meeting the objective and scope of the Committee was defined and sub-committees were appointed with sub-committee chairmen who were to constitute the Executive Sub-Committee.

The various sub-committees were assigned to prepare definition and proposals for the areas of:

1. Terminology for subdivisions and multiples of the inch -- R. Hastings, Industrial Truck Association.
2. Investigating the desirability and feasibility of decimalization of the circle -- A. Duggar, Jr., American Gear Manufacturing Association.
3. Interpretation of limits and tolerances where given -- Earl D. Black, American Society for Engineering Education.
4. Prepare a Foreword for the Standard -- Roy P. Trowbridge, Automobile Manufacturers Association.
5. Recommend wording for purpose, scope, and definitions as required, I.H. Fullmer, The American Society of Mechanical Engineers.
6. Preferred systems; square measure; volumetric measure; use of systems in combination; and conversion of common fractions to decimals -- C. H. Bayer, National Electrical Manufacturing Association.

These sub-committees set to work and their proposals were reviewed by the Sectional Committee in New York City on May 18, 1961. The results was a complete revision to include suggested changes to avoid complications and add new considerations which seemed to be a logical part of any standard on the use of the decimal inch.

On October 6, 1961 the Executive Sub-Committee met at the ASTME headquarters in Detroit, to prepare a draft proposal to be circulated to the Sectional Committee prior to its next meeting. All letters, reports, and proposed revisions were considered. It was also agreed that the Executive Sub-committee should recommend that one thousand copies of the finalized proposed standards on the Decimal Inch be printed and circulated to selected industrial representatives for comment.

The ASA Sectional Committee B-87 was called together in Detroit, Michigan on January 18, 1962 to review the revised first draft of the proposed standard. The scope and responsibility of this Committee was enlarged to include not only standards for linear measure, but also angular and volumetric measure. Therefore, it was considered wise to change the title of the B-87 Committee from "The Use of the Decimalized Inch" to "Decimalized Measure." Furthermore, it was decided that the Sectional Committee B-87 on Decimalized Measure be non-classified, as it is composed[5] of a non-commercial, scientific group.

However, due to the urgency and need of standards on the decimal inch, it was decided that the first standard proposal should be confined to the "Decimal Inch."

The Executive Sub-committee was instructed to prepare a second draft of the proposed standard incorporating revisions and additions as selected by the Executive Sub-committee. The printing of 1,000 copies of the revised second draft was also authorized for wide distribution to industry.

It was agreed that very close coordination should be had between ASA Sectional Committees B-87, B-89, and Z-75. Many of the ASA sectional committees are undoubtedly going to be affected by the work of the B-87 Committee. The work of this committee on the Decimal Inch standards will include information on:

1. Scope
2. Purpose (objective)
3. Definitions and Terminology

4. Preferred System
5. Tolerances and Limits
6. Commercial Tool and Stock Sizes
7. Existing Parts
8. Decimal Equivalents, and
   Appendix
  I. Rounding off (during transition)
 II. Advantages of Using Decimals Instead of Common Fractions.
III. A tentative Proposal for a More Complete System of Decimalized Measure.

The date of the next ASA Sectional Committee B-87 was set tentatively after Labor Day, 1962.

The work of this ASA Sectional Committee is restricted as to distribution until it is finalized and accepted. However, I expect to have many discussions with members of the American Society for Engineering Education, and should you receive a copy of the proposed standards on the Decimal Inch, please send your remarks and constructive criticism to your representative, Earl D. Black, Head of Engineering Drawing, Product Engineering Department, General Motors Institute, Flint 2, Michigan.

NOTE: Further reports will be made as the Committee progresses in developing proposed standards on Decimalized Measure.

Progress report ASA Sectional Committee B-87 Decimalized Measure by Earl D. Black, General Motors Institute.

By Earl D. Black
General Motors Institute

[1] John W. Greve. The Tool and Manufacturing Engineer: Editorial, April 1962.

[2] Russell Hastings, Clark Equipment Copany, Industrial Truck Division, Battle Creek, Michigan.

[3] Product Engineering: October 2, 1961 (Should the U.S. Go Metric?)

[4] ASA Standards Committee B-87 Decimal Inch, Proposed ASA Standards, Decimal Inch 1962.

[5] ASA Sectional Committee B-87 Decimalized Measure, January 18, 1962 -- Leslie S. Fletcher, Secretary.

# Midwinter Meeting

ASEE DIVISION OF ENGINEERING GRAPHICS

Midwinter Meeting

Dates: Jan. 23, 24, and 25, 1963

Where: Kansas State University
Manhattan, Kansas

Contact: Professor A. E. Messenheimer
Department of Mechanical Engineering

Come one - Come all

AN EXPLORATION OF PROCESSES USED IN SOLVING PROBLEMS IN ENGINEERING DRAWING

By
Lois B. Greenfield
Assistant Professor, Engineering Education
and
Fred O. Leidel
Professor, Drawing and Descriptive Geometry
College of Engineering
University of Wisconsin
Madison, Wisconsin

This report describes a pilot program exploring the problem solving processes used by students in a first semester engineering drawing course. The students attempted to solve problems taken from a test covering their knowledge of orthographic projection. Students were asked to "think aloud" as they solved the problems. Their verbalizations as well as their reactions to the problem situation were tape recorded for this analysis.

Purpose

This study was undertaken to gain insight into the problems some engineering freshmen experience in the introductory course in drawing. The course arouses in some students feelings of utter hopelessness, discouraging some to the point of abandoning the course. While certain students might be expected to experience more difficulty in a drawing course than others, as a result of previous training, differential aptitude, etc., it is generally felt that students capable of college work in traditional academic areas should be able to complete a drawing course.

Through the pilot study, it was hoped to clarify the manner in which students handled various drawing concepts, and the methods by which they attacked problems, so that teaching methods might be varied and remedial efforts redirected.

Background

The method of "thinking aloud" as an exploratory tool has been used with problems of a verbal nature to study the problem solving processes of college students (1, 2) as well as of younger children (3) by the senior researcher. This study attempts to find out whether the methods of attack described for verbal problems are similar to and can be applied to problems more visual in nature.

Previous research on problem solving with human subjects has been more frequently concerned with the products of thought than the processes. Although it is sometimes possible to infer from the product the process which preceded it, it appears more reasonable to try to study process directly.

The writers have examined the process of solving problems in orthographic projection by asking subjects to "think aloud." This verbalization is recognized as being a representation, rather than the actual thought process. The differences in method of attack which are found are regarded as clues to the complete process, and inferences are made therefrom. Evidence supporting this assumption is found in studies (1, 2, 3) showing that methods of attack on problems may be learned, and changed, and that remediation may be effected.

Earlier Studies

In earlier studies (1, 2, 3) of problems almost entirely verbal in nature, a check list of problem solving characteristics was developed, which differentiated the characteristics of good and poor or successful and non-successful problem solvers as defined by performances on objective tests.

This check list analyzed the problem solving characteristics into four major areas.

I. Understanding the requirements of the problem.

II. Understanding the ideas contained in the problem.

III. General approach to the solution of problems.

IV. Personal factors in the solution of problems.

I. Understanding the requirements of the problem.

Understanding the requirements of the problem meant comprehension of directions and the statement of the problem. The successful and non-successful problem solvers differed in their ability to understand what they were asked to do, and to keep the directions in mind as they worked toward a solution.

The successful students were better able to determine what was involved in the problem and had an easier time beginning a problem than the non-successful students. The non-successful students did not always read the directions, or after they read the directions, they did not understand how to start the problem nor what was expected of them. The non-successful students did more reading of the directions and statement of the problem than did the successful students, seemingly in an effort to increase their comprehension by this means. The non-successful students would, more often than the successful students, attack a problem different from that intended by the examiner as a result of misinterpreting a term in the directions or failing to keep the directions in mind as they worked toward a solution.

II. Understanding the ideas contained in the problem.

Understanding the ideas contained in the problem meant possession of basic information necessary to solve a problem as well as the ability to bring this knowledge to bear in a solution. The successful problems solvers did, in general, have more information. However, the major difference between the two groups of problem solvers was not that the successful students possessed more or even more pertinent information than the non-successful students, but rather that the successful students were better able to bring the knowledge they possessed to bear on the problem they were attacking. For them the knowledge they possessed could be manipulated, translated, and related to the questions being asked, while for the non-successful students information they possessed remained in huge unwieldy blocks which could be used only in the form in which they had learned it.

III. General approach to the solution of problems.

General approach to the solution of problems meant the procedure used by the student during his attack on a problem. The successful and non-successful problem solvers differed in the extent of thought about a problem, i. e., the successful students took a more active approach while the non-successful problem solvers were more passive; they differed in the care and system in thinking about a problem, i. e., the successful problem solvers attempted a reorganization of the material to make it more meaningful and were careful in considering pertinent details; and they differed in the ability to follow through on a process of reasoning, i. e., the successful problem solvers elaborated criteria or set up a plan for the solution and then carried through to apply this reasoning to the selection of the final answer.

IV. Personal factors in the solution of problems.

Personal factors in the solution of problems meant the emotions, values and prejudices of the problem solver as they influenced the attack on a problem. The successful and non-successful problem solvers differed in their attitude toward reasoning, i. e., non-successful problem solvers took the attitude that reasoning was of little value, for one either knows the answer or one does not; in their confidence in their ability to solve problems, i. e., the non-successful problem solvers did not try as many problems and did not try as hard to solve a problem as the successful problem solvers because they lacked confidence; and in their introduction of personal or external considerations into problem solving, i. e., the non-successful problem solvers were likely to introduce irrelevancies into their problem solving.

The description above summarizes differences in method of attack between successful and non-successful problem solvers which were identified in earlier studies of verbal problems. No student always resembled the model successful problem solver. Any discussion of methods is based on the hypothetical successful or non-successful model student. In the earlier analyses, a deviation from this model was considered significant only when it was repeated frequently.

## Present Study

Subjects: The subjects chosen for this study were two groups of three freshmen each, matched on scores on the College Qualification Tests, the Pre-Engineering Ability Test, and high school centile rank. The matched individuals differed on the scores achieved on the first test on orthographic projection given after two weeks of instruction in the introductory course in drawing, one student of each pair making a high score, and the other a low score. All subjects were taught by the same instructor. Data used for matching students are presented below.

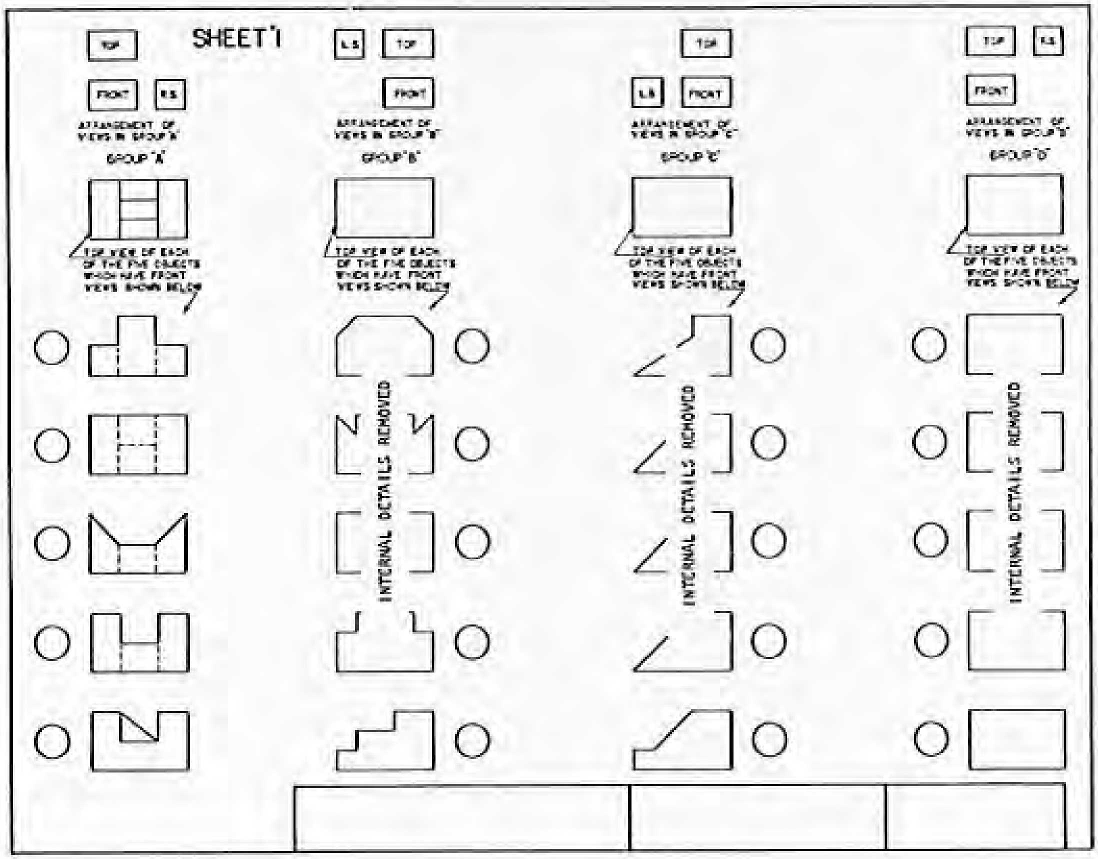
Subjects' Achievement on Aptitude Tests, HSCR, and on First Drawing Test

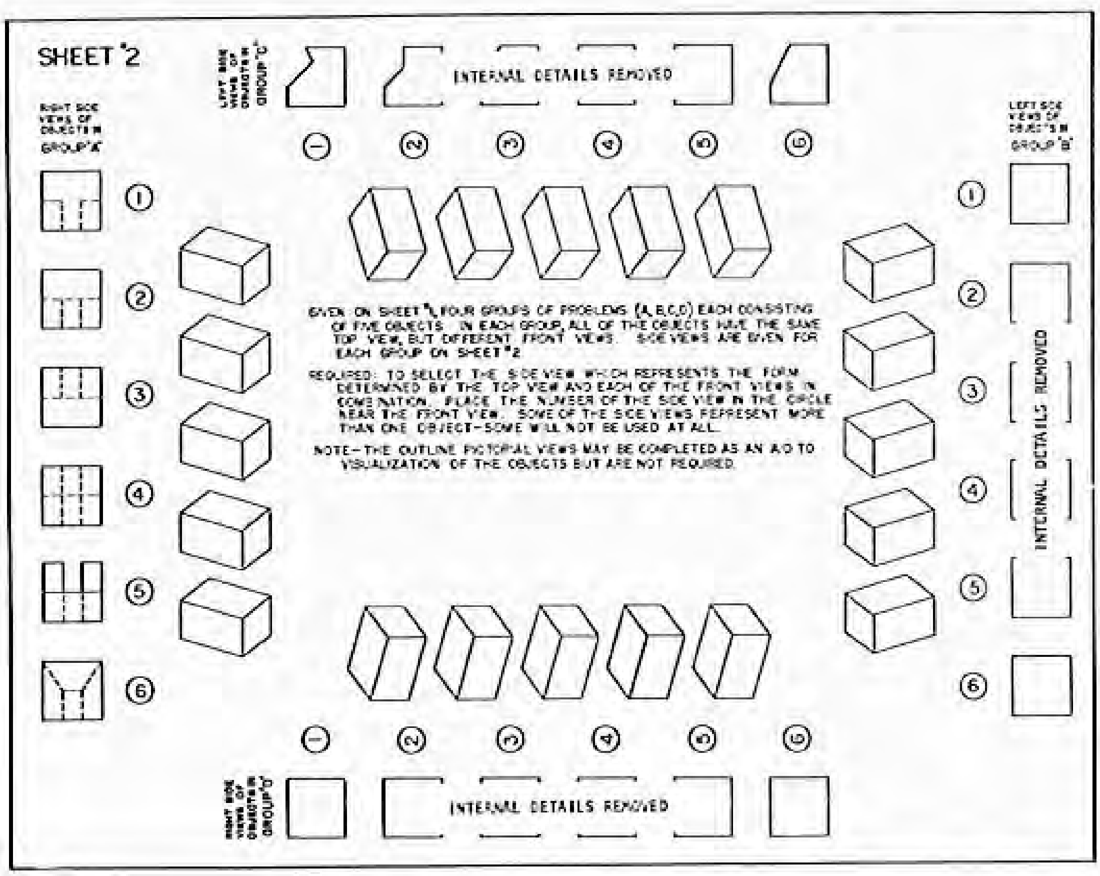
| | CQT Verb. | CQT Num. | CQT Sci. | CQT Soc. St. | CQT Tot. | Pre-Engr. | HSCR | Score on first test |
|---|---|---|---|---|---|---|---|---|
| High Group | | | | | | | | |
| MEA (Ia) | 64 | 47 | 21 | 24 | 167 | 64 | 90 | 100 |
| HDW (IIa) | 35 | 44 | 24 | 23 | 126 | 52 | 80 | 100 |
| ELS (IIIa) | 68 | 49 | 35 | 32 | 184 | 68 | 97 | 95 |
| Low Group | | | | | | | | |
| ICH (Ib) | 53 | 50 | 34 | 27 | 164 | 65 | 96 | 45 |
| DRL (IIb) | 38 | 45 | 25 | 23 | 131 | -- | 85 | 65 |
| ELR (IIIb) | 67 | 48 | 36 | 32 | 183 | 55 | 69 | 65 |

Problems: An alternate form of the test on which the subjects made the high or low scores which differentiated them as subjects supplied the problems. The test was presented on two sheets, the first of which gave the top view of an object with five different front views. (See cut.) The task was to choose the side view from the second sheet "which represents the form determined by the top view and each of the front views in combination." Directions were on the second sheet. A place on which students might outline pictorial views was available on the second sheet, but such views were not required. Choice of side views, either right or left, and/or projected from the top or front view varied the task. In each problem, six possible side views were presented to match with five front views. Directions included the statement that "Some of the side views represent more than one object - some will not be used at all."

Procedure: The instructor submitted a list of names of students with highest scores and lowest scores on the first test, from which the list of matched subjects was drawn. The purpose of the study, i. e., to find out more about how students solve drawing problems, the difficulties they experience, and the kinds of methods they use, was explained to the subjects, and their voluntary participation was requested. Subjects were informed that participation in the study would in no way influence grades in the drawing course.

When the subject appeared for his appointment, the purpose of the study was described again. Subjects were told that the method would be that of "thinking aloud." The subjects were presented with several simple arithmetic problems, and given some practice in this technique. When they were at ease in the experimental


SHEET 1
TOP
FRONT
R.S.
ARRANGEMENT OF VIEWS IN GROUP "A"
GROUP "A"
L.S.
TOP
FRONT
ARRANGEMENT OF VIEWS IN GROUP "B"
GROUP "B"
TOP
L.S.
FRONT
ARRANGEMENT OF VIEWS IN GROUP "C"
GROUP "C"
TOP
R.S.
FRONT
ARRANGEMENT OF VIEWS IN GROUP "D"
GROUP "D"
TOP VIEW OF EACH OF THE FIVE OBJECTS WHICH HAVE FRONT VIEWS SHOWN BELOW
INTERNAL DETAILS REMOVED


SHEET 2
LEFT SIDE VIEWS OF OBJECTS IN GROUP "C"
INTERNAL DETAILS REMOVED
RIGHT SIDE VIEWS OF OBJECTS IN GROUP "A"
LEFT SIDE VIEWS OF OBJECTS IN GROUP "B"
1
2
3
4
5
6
GIVEN ON SHEET 1, FOUR GROUPS OF PROBLEMS (A,B,C,D) EACH CONSISTING OF FIVE OBJECTS. IN EACH GROUP, ALL OF THE OBJECTS HAVE THE SAME TOP VIEW, BUT DIFFERENT FRONT VIEWS. SIDE VIEWS ARE GIVEN FOR EACH GROUP ON SHEET 2
REQUIRED: TO SELECT THE SIDE VIEW WHICH REPRESENTS THE FORM DETERMINED BY THE TOP VIEW AND EACH OF THE FRONT VIEWS IN COMBINATION. PLACE THE NUMBER OF THE SIDE VIEW IN THE CIRCLE NEAR THE FRONT VIEW. SOME OF THE SIDE VIEWS REPRESENT MORE THAN ONE OBJECT—SOME WILL NOT BE USED AT ALL.
NOTE—THE OUTLINE PICTORIAL VIEWS MAY BE COMPLETED AS AN AID TO VISUALIZATION OF THE OBJECTS BUT ARE NOT REQUIRED.
INTERNAL DETAILS REMOVED
RIGHT SIDE VIEWS OF OBJECTS IN GROUP "D"
INTERNAL DETAILS REMOVED

situation, the recorder was started, and the problems were presented. It was emphasized that the experimenters were less concerned with the correctness of response than with completeness of the record of the problem solving methods used. If a silence lasted for more than approximately five seconds, subjects were reminded to think aloud and were asked what they were doing. The subjects were extremely cooperative, and after a few minutes of work on the first problem they seemed to perform the strange task of thinking aloud with little difficulty.

Where subjects asked about the correctness of their answers, they were told this information would be made available at the end of the session. Where they asked for clarification of procedure, they were informed that they were to think of this as a test situation and that they should proceed as they would in a regular test.

Analysis of Data: Analysis of the data is limited by the recognition that the protocols obtained do differ from the actual thought processes. Putting thought processes into words, when the thought may take place faster than it can be put into words, distorts the record. The clues obtained from the protocols, therefore, are considered as indications of the underlying process, closer to the real process, however, than a study of the thought product (i. e., the answer to the problem) alone would be.

The experimental situation also differs from a test situation in that the subjects were divorced from pressure of time. They were scheduled for an hour interview, but if they had not finished the four problems in that time, they were allowed to continue. All subjects commented that they felt that solving the problems while thinking aloud took more time than solving the same problems in the usual manner, but that otherwise their verbalizations did not differ in kind from their usual problem solving behavior.

Results: Using the checklist as a base (see above), the taped records of solutions were analyzed to differentiate characteristics of successful and non-successful matched problem solvers on problems of orthographic projection. Problem solving processes of students who had scored high on the first test were contrasted with the processes of students who had scored low on the first test. These differences and similarities are described below. Included are comments on differences resulting from differences in the nature of the problems used, i. e., spatial problems as differentiated from the primarily verbal problems used in the earlier studies. The small number of records analyzed and the lack of diversity of problems requires that differences noted be regarded as clues to areas of profitable future research rather than as exact conclusions.

I. Understanding the requirements of the problem.

The directions to the problems were:

> Given: On Sheet #1, four groups of problems (A, B, C, D) each consisting of five objects. In each group, all of the objects have the same top view, but different front views. Side views are given for each group on Sheet #2.
>
> Required: To select the side view which represents the form determined by the top view and each of the front views in combination. Place the number of the side view in the circle near the front view. Some of the side views represent more than one object - some will not be used at all.
>
> Note: The outline pictorial views may be completed as an aid to visualization of the objects but are not required.

On Sheet 1, where the problems were presented, a shorter statement of the problem could be found, indicating the arrangement of the views, i. e., right or left side projected from top or front view, for each of the four problems. Perhaps because the earlier similar examination had been taken so recently, only one of the students, ELS, a high scorer, read the directions. The type of difficulty encountered by a low scorer, DRL, who did not read the directions, is illustrated by this quotation from his initial attack on the test.

> Does not read directions, but does read statement of the problem. Reads "Top view of each of the five objects which have front views shown below." "Line up A with A. We have top view, given, and a right, a right, a right side view given. Trying to find __________." (Examiner asks what is happening.) "Forgot what I'm supposed to know. Right side view of objects in Group A and top view, and want to get right front view so have to line up that right side view with the front views and see which would fit best and the top view is the same in each case so you take number 1 and see how we'd fit that in. Got invisible line. __________ (pause) front view, find side view, take number 1. First one (pause)" Rereads "Top view of each of the five objects which have front views shown below." "Have side view, top view and want to find front view, is that right?" (Examiner gives correct directions.)

DRL then tried to match each front view with the top view and side views, rather than trying to find the side view resulting from considering the top and front together. Another of the low scorers did this same thing, i. e., fitting the side views to the front and considering each side view as a possible solution with each front view. ELR, DRL and ICH, all low scorers, asked in the protocol if they could use a side view more than once. They would have known this if they had read the directions. Where the students assumed they could not use a side view more than once, their chances for obtaining an incorrect answer were increased. The high scorers, too, were disturbed by this situation, as

> KDW: "Yes, I'm just checking now. When I put down two of the same number 1 always go back to check to see that there wasn't a mistake in one of them and that both of them fit the views."

Since the problems chosen for study had only one set of directions, and since these directions were identical to those used earlier, comparison with findings from the analysis of verbal problems is limited. For the verbal problems, a distinction in understanding the requirements of the problem was made between ability to start the problem, i. e., comprehension of directions, and ability to understand the specific problem, i. e., solving a problem different from the one intended, skipping a problem, etc. This distinction was less clear in the limited sample chosen for study. However, it can be seen that DRL changed the problem from the one intended by the examiner, i. e., finding the right side view projected from the front view to finding the front view, despite the fact that he correctly read the problem statement at least twice.

Comment:

I. Understanding the requirements of the problem.

It is clear that, either because they assumed they understood the directions or because they failed to read them, the low scoring students had trouble with the problems because they were confused about such relatively clear-cut matters as whether they were to choose a front or side view, or whether the alternatives offered could be used more than once. Failure here did not reflect lack of information about orthographic projection, but rather failure to understand the requirements of the problem.

Simple changes in the format of the test might clarify these points for the students. A cautionary note on Sheet 1 to read directions on Sheet 2 would appear to be helpful, or better yet, directions could appear on Sheet 1. Underlining the part of the directions telling that alternative side views might be used more than once might help increase student awareness of this. Unless the opposite is specifically called to their attention, students seem to have a preconception that once an alternative is chosen, it ceases to exist as a possible answer.

II. Understanding the ideas contained in the problem.

The distinctions between problem solving processes of high and low scorers supported the earlier findings relevant to verbal problems. The high scorers were more likely to use accurate and precise terminology in referring to the drawings than were the low scores. For example, ELS, a high scorer, referred to hidden lines in the drawings, while his counterpart, ELR, referred to dotted lines. Another low scorer, DRL, referred to invisible lines.

In a different area related to terminology, ICH, a low scorer, referred to vertical lines in the drawings as horizontal. He also spoke of inside lines, areas which stuck in or stuck out, jutted in or out, etc. This would seem to be an instance where improper or incorrect terminology hampers problem solving processes.

A major difficulty of the subjects was the inability to work with the problem in the form presented. The subjects were generally less able to work with a view adjacent to the top view, and worked as if the view had been made adjacent to the front view. They then rotated it in order to choose the correct side view. Several of the subjects worked by actually rotating the test form. Low scorers were more likely to do this than high scorers. HDW, a high scorer, worked by combining a top and a side view to determine the front view where he was unable to proceed in the traditional manner. Here, however, the student seemed to be proceeding with an alternate method of attack where the traditional one did not work. The subject's comments indicated that this was what he was doing.

The test form provided a place where a pictorial view might be sketched if the subject desired to use this as an aid to solution. The high scorers sketched less often than the low scorers, seemingly better able to visualize the views in space without resorting to paper and pencil. Where the high scorers experienced difficulty, they did sketch the pictorial view. The low scorers sketched more often, seemingly using drawings of the orthographic views to suggest ideas. One student, ELR, redrew the views already presented on the test form, but attached the views to each other.

Comment:

The low scoring students were less likely to know and use terminology appropriate to the problem solving they were asked to do. Stress placed on learning the language of engineering drawing (orthographic projection) might be helpful to such students in clarifying their thinking. Here the language appropriate to the task would seem to be an additional tool. For example, the term "hidden line" is more usefully descriptive than "dotted line," while "hidden edge" might be even more useful.

The difficulties apparent in manipulation of the views, the necessity for transforming problems to side views adjacent to the front, would seem to be an area subject to remedial teaching. If the class work consistently utilizes varied views, the students will have greater facility in working with them.

III. General approach to the solution of problems.

In contrast to the low scoring subjects, the high scoring subjects were more active in their approach to problem solving, were more precise in considering details relevant to the solution of problems, reorganized material to make it more meaningful, and were more likely to check their solutions. Sample protocols from the problem solving of a high scorer illustrate some of these points.

HDW. Did not read directions but did read the problem statement. "First project up and see if all the views kind of fit together. All the front views fit with the top. (pause) Then I kind of work the sheet, the second sheet, around to see if I can find a view to fit with the first one plus the top view and the possibilities of first one with the top view would be (pause) These are end view (pause) little awkward doing it out loud. On these I'd try to picture how the end view would look according to the two views given and I see that the first one has a notch in it and dotted lines coming down from the notch which would indicate a hidden part behind and (pause) or it could mean the center of the top view would be hollow and I'd look for a view on Sheet 2 where the center would be indicated as hollow plus a notch and I see that could be view 3 and also, no, the only possible one I see is view 3, I think. Yes."

> HDW. "This one is again a little complicated, again trying to put the top view with the end view and seeing how they would fit together. Ah. I see that so far they would fit together and picturing it again from the side I would see _____ The top has a straight line, bottom has a straight line and there would be a hidden line going horizontally across and also a diagonal which would not be hidden from one-third of the way down to the top (pause) and looking at the views I see that there's only one view which has two lines in it that would possibly fit with a horizontal which is a hidden and a diagonal which is not hidden and that's number 6."

The subject described with precision the criteria the solution must meet, and then proceeded to examine the alternative side views to see whether this choice was provided. This was similar to the procedures followed by successful problem solvers working with verbal multiple-choice problems in previous studies. The low scorers would not define what they were looking for, or would define it with less precision, and were more likely to be misled into choosing an incorrect alternative because they depended upon the alternatives supplied by the examiner for clues. For example,

> DRL. (Looking at alternative side views.) "I'm trying to pick off one that would suit. Would have to be 5 or 6 from the way the lines are slanting. No, they wouldn't. The hidden lines would not be hidden lines in the side view probably, so I'd say that (pause) should be only one line (pause) I'll try number 2."

> DRL. "Put the right side view next to the front. Trying that for each one as I go along. Take one side, take one front view and try a side view until I find something I think looks right. (Draws front view with side view connected.) Drew front, try to add top. Should be able to figure out proper side view. Trying to find the most logical side view."

The high scorers were more apt to carefully check their problem solving. Where they were unsure as to the correctness of their answers, they would return to check the problem. One of the high scorers discovered an error in the test when he realized there was no possible answer which fit the given facts.

Low scorers were more likely to be careless in observing minor details. For example, DRL said that alternative 6 would fit the fourth problem (a correct choice) but he wrote down alternative 4 in the space provided for an answer.

Subjects would neglect clues afforded by the problem or by their own reasoning. For example, they failed to define hidden lines, direction of slant, etc., apparent in the 2 views given. In one instance, MEA, a high scorer, defined impreciseIy what he thought the criteria for an answer should be before looking at the choices. Such a choice was not available, and he returned to reconsider the problem. In this one instance MEA was trapped by the alternatives offered into making an incorrect choice. He had been on the track of the right answer, but neglected correct clues supplied by his own reasoning.

Evidence of lack of system in problem solving was seen when two of the low scorers were observed to start a problem, get partially through it, begin another, return to the first, solve it, and then go on to another, working several dissimilar problems simultaneously, which resulted in confusion.

<u>Comments</u>:

> Protocols from the problems would seem to demonstrate wide variation among the subjects in their general approach to the solution of problems. The findings generally substantiate the earlier studies of processes used in verbal problem solving. The high scoring subjects contrasted to the low scoring subjects, seem to do more thinking, i. e., they define the characteristics of an answer before looking at the choices supplied, and in this process fully utilize the clues provided in the problem and by their own reasoning; they are more careful and systematic in their thinking, i. e., they reorganize the problem material to increase their understanding they check their work where they are in doubt about an answer they have chosen; and they are able to follow through on a process of reasoning, sticking to a plan of action.
>
> Similarities between this and the earlier studies in which remedial problem solving methods were taught suggest that a similar effort might be made with spatial problems. An effort to teach methods related to active rather than passive attacks on problems, care and system in approach, systematic checks on work completed, etc., might be demonstrated in the classroom. A study of the processes employed by a student experiencing difficulties with drawing might reveal the source of the difficulty and open an avenue for clarification and/or remediation.

IV. <u>Personal factors in the solution of problems.</u>

Only one type of problem was presented to the subjects for solution. Thus, the chance to observe personal factors in the solution of problems was limited. There were, however, some differences between high and low scorers in their attitude toward reasoning. The high scorers were more likely to take the attitude that the problem solutions could be reasoned out. The low scorers were more likely to use such phrases as "I'm looking to see which one it could be," "This <u>seems</u> to correspond ," "I'm trying to pick off which one would suit," and "I'm trying that until I find something I think works, something I think looks right," giving the impression that problems were solved on the basis of vague feelings, intuitions and hunches.

Subjects commented as they worked, to indicate their confidence in their answers. For example, ELR said, after arriving at an answer, "Usually on tests like this they tell you two may match up, may or may not be true." He erased his first answer, refigured the problem, got the same answer, and wrote it down, adding "I hope that's it." ELR volunteered an estimate of his total score as between 65 and 70; his score was actually 90. Such unrealistic lack of confidence might have a depressing effect on the problem solving performance of a student.

Subjects indicated that problems seemed harder in one form than another, a circumstance unrelated to the actual problem. One student asked whether the test was the same as the one he had taken earlier, and remembered "the answer he had given before." Actually, the test was similar in form, but the problems were different.

Differences between high and low scorers were less evident in this area than in those discussed above.

Conclusions and Implications

This study points out that the technique of "thinking aloud" is useful in studying the processes involved in solving drawing problems, as well as in offering hints to instructors about difficulties and misconceptions of students. It is also useful in checking on the efficacy of testing devices.

A difficulty in using this technique is the great expenditure of time involved. Judicious selection of fewer problems would serve to minimize this difficulty.

Instruction: Asking students to think aloud as they solve problems may give the instructor some insight into the students' difficulties and the reasons for such difficulties. If steps in the method of solution are elaborated by the instructor when problems are demonstrated to students, it would be possible for them to learn systematic and effective methods of procedure for various types of visual and graphic problems.

Remedial instruction: All teachers have been faced with the blank face of the student who states, "I just don't get it!" yet is unable to state what it is that he doesn't get. By requesting that such a student try to solve a problem orally, with the instructor observing, it should be possible for the instructor to get some clues as to the source of difficulty. Does the student not understand the attack on the problem, has he made a careless error which made the problem senseless - these are questions which may be answered through use of oral problem solving. Once the difficulty has become apparent, it is easier to supply and apply remedial techniques.

Test construction: Examiners cannot be sure just why a student made an incorrect response to a question: whether the student did not have the requisite information, whether he misread the question, whether he was so puzzled by the directions he was unable to attack the problem, or in fact did not read the directions. Using a variation of "thinking aloud" examiners may pre-test their questions (4), directions, problems, to determine whether they are testing the students on the material and in the manner in which they think they are testing them.

Understanding of mental processes: Although no one would argue that "thinking aloud" is an exact replica of the complete process of problem solving, it does provide valuable clues to the process. By emphasizing the process of thought rather than the end product, new information about the process of problem solving may be obtained. The information gleaned from visual or spatial problems differs from that obtained from verbal problems. Similarities exist in solving the two types of problems. The effective use of the similarities and differences may be used to enhance teaching.

Understanding of personal characteristics: The personal characteristics of an individual are hinted at by problem solving performances since the record of "thinking aloud" provides an observable sample of behavior. For example, one student, MZA, had a score on the experimental problems that was lower than one would predict from his test scores. Observation and analysis of the tape indicated that he was over-confident to the point of making obvious errors in thinking, not questioning his answers, nor checking his work. While this attitude may have been a result of his knowledge that the study would not affect his course grade, this course grade was lower than it should have been because of a similar lack of concern in situations that did count. A problem solving approach might be useful as an additional technique in exploring the effect of personal characteristics on performance.

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# Inter-Disciplinary Challenges for Graphics

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The theme of the 1962 annual A.S.E.E. meeting at the Air Force Academy was "Inter-Disciplinary Challenges in Engineering Education". This annual meeting offered a great opportunity to participate in close the cooperation between the various departments and disciplines which exist in the field of engineering education.

As part of the annual program, the Civil Engineering Division scheduled a joint conference with the Engineering Graphics Division and Professor Sumner Irish of the Civil Engineering Department of Princeton University presented a paper which is printed in this issue of the Journal.

A number of activities have taken place during the past year which are inter-discipline oriented. For example, a series of three Engineering Graphics Seminars have been held at Princeton this past school year for engineering faculty, graduate and undergraduate students, industrial and research personnel, and engineering graphics faculty outside of Princeton University. We have attracted to the seminars, Professors from Pennsylvania State University, Cooper Union, Lafayette College, Swarthmore College, Rutgers University, and the Newark College of Engineering. Each seminar paper has been published by the Department of Graphics and Engineering Drawing of Princeton University and has been given a wide circulation throughout the country. The seminar reports are issued as part of a technical report series and are catalogued in the Princeton University Engineering Library. In addition, copies of these reports have been sent to Princeton Engineering School faculty with the purpose of developing a closer inter-disciplinary contact with these departments. The following three technical seminar series reports were presented this past year:

"On Graphical Solution of First Order Differential Equations" by Professor Woodworth of the University of Detroit.

"On N-Dimensional Descriptive Geometry and Multivariable Functions" by Professor Steven Anson Coons of the Massachusetts Institute of Technology.

"The Tangent Line Alignment" by Mr. John H. Fasal, Assistant Chief Engineer, "KUDA" Division, Walter Kidde & Company, Clifton, New Jersey

In addition to the seminar activities of the Department of Graphics and Engineering Drawing in Princeton University, we have kept in contact with the different departments in the School of Engineering through periodic informational memoranda describing some of the activities of our department and describing the changes that are taking place in our courses. One major recent change in the presentation of Engineering Graphics at Princeton has taken place and our courses have become elective courses. We have attempted to meet the challenge which has been placed before us by changing the format of our courses radically and they are now lecture courses with outside homework and with no regularly scheduled drawing laboratories. The course format is being organized so that it has a more inter-disciplinary flavor than it has had in the past.

This past year, an extensive report was made to the engineering faculty at the Pennsylvania State University by Professor Ernest Weidhaas. The objectives and the course content of the engineering graphics courses at Penn State were fully documented to keep the faculties of the various engineering departments informed as to the orientation and activities of the engineering graphics department.

Most of us are aware of the fact that a two-year course content development study in engineering graphics, which is inter-disciplinary in scope, was initiated last October at the University of Detroit. The Director of this project is Paul Reinhard who in addition to heading up the entire project also covers the central region of the United States. The Eastern Region is headed up by Professor Frank Heacock who is an associate director of the project while the Western Region is covered by Professor Alexander Levens who is also an associate director of the project. On May 7 and 8 a National Science Foundation Seminar was held at Princeton University to discuss the reports of the developmental aspects of the National Science Foundation supported course content study.

The Department of Graphics and Engineering Drawing at Princeton University has proposed to the National Science Foundation an International Conference on Space Geometry. This Conference, if financial support is obtained from the National Science Foundation, will be held in Princeton in August of 1963 and will also be inter-disciplinary in scope since the participants invited to this Conference from abroad represent the major countries of the world, include fields of graphics, geometry, mathematics, various fields of engineering, and in addition the American participants backgrounds are basically graphically oriented but inter-disciplinary in nature.

It is my feeling that we in the field of engineering graphics must continue to be inter-disciplinary minded since in the final analysis if one looks for a common denominator in engineering one would readily see that this common denominator is engineering graphics. Because of its nature it naturally crosses all lines of engineering. Therefore the teachers of engineering graphics must continue to expand their outlook as well as to learn about the other fields.

I would like to suggest a possibility of a Division of Engineering Graphics sponsored study which could be proposed to the National Science Foundation or the Office of Education related to the spatial relations ability of students vs. engineering talent. A number of interesting papers over the years have appeared on this subject. One appeared in the Psychological Monograph published by the American Psychological Association Inc. This article was entitled "Increase in Spatial Visualization Test Scores During Engineering Study" by Mary F. Blade and Walter S. Watson. This was published in 1955. (no. 307, vol. 69, no. 12). In April 1960 Professor Bigelow of Princeton and myself completed a study dealing with the "predictive Value of Engineering Graphics as to Later Achievement in Engineering Studies" and this study indicated that spatial relations ability was an important factor in engineering. A few years ago, a professional psychological testing concern came to Princeton to attempt to determine what made good engineering students. The preliminary report from this company (Johnson O'Connor Company in New York) indicated that those students who had engineering ability had one common trait and that was that they had a developed spatial relations ability. Therefore, the type of project, I propose, can have a significant influence on how and where engineering graphics will go in the future.

I would also strongly urge the creation of Advisory Councils to Engineering Graphics Departments throughout the country such as we have at Princeton. Our Advisory Council, for example, is truly inter-disciplinary, having members from industry that represent the major fields of engineering. This Council meets, at least once a year, with our graphics faculty to discuss the work we are doing and to supply a stimulus to our thinking. The Advisory Council formally reports its reactions to the President of Princeton University and the Dean of Engineering. In addition, plans are in the works to have our Advisory Council meet with the Advisory Councils of the other departments to further promote the concept of inter-disciplinary education in engineering.

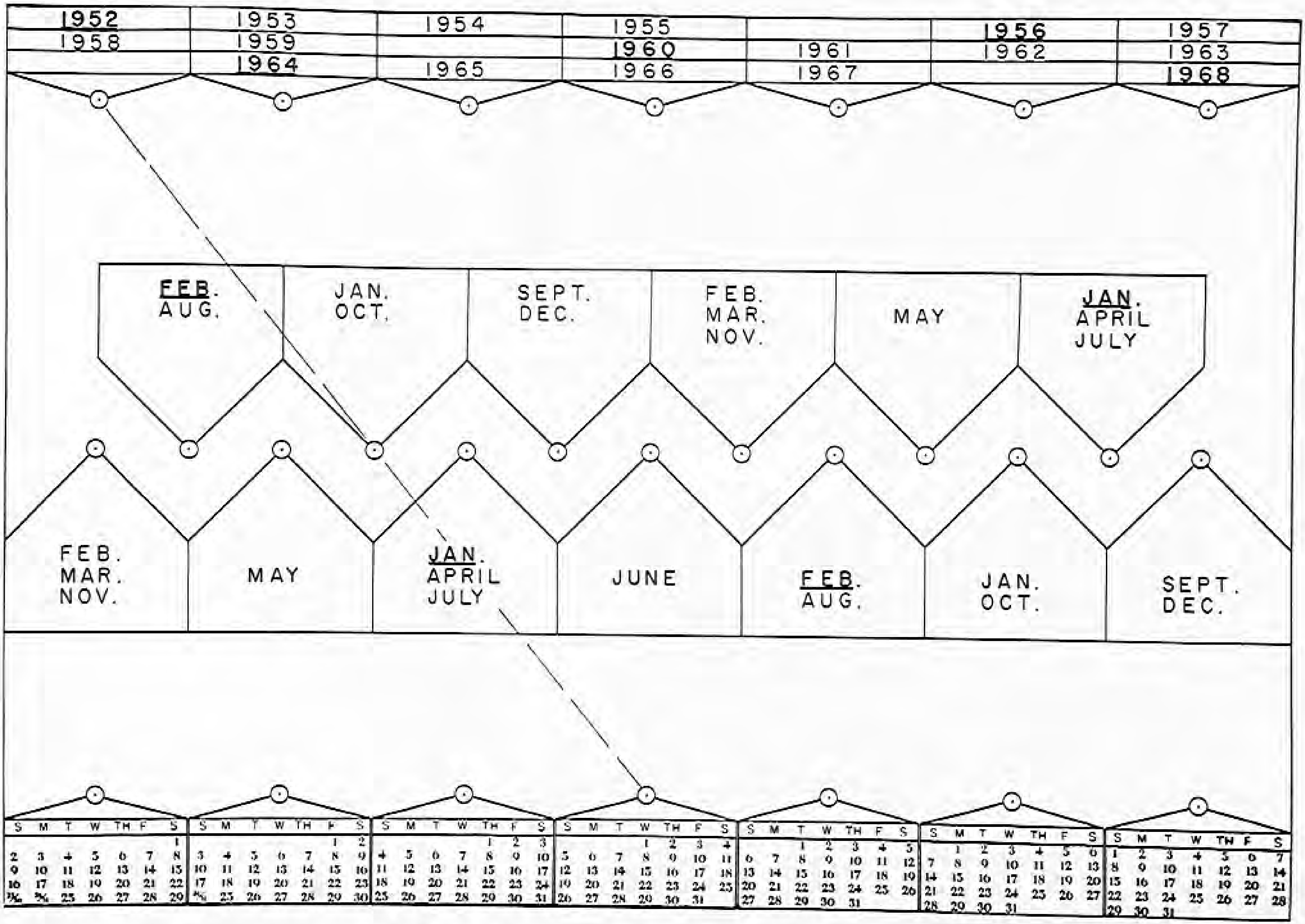
In addition I recommend that every Engineering graphics Department attempt to conduct technical seminars of the type that are held at Princeton. This seminar activity offers great inter-disciplinary opportunities and becomes a two-way street where people in each discipline can learn from each other.

The field for action in the inter-disciplinary areas is wide open and I feel that Engineering Graphics educators, without question, should be leading in this action.

GRAPHIC ODDS & ENDS

*Please Note:*

Provocative articles solited by your editor. Deadline for the February issue, December 15, 1962. They must be typed, all illustrations in ink ready for offset, and all lettering at least 1/8".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SEPT. DEC.

# A Calendar Nomograph

Melvin L. Betterley

Prof. and Head, Dept. of Engineering Drawing
The State University of Iowa

The calendar nomograph was originally designed at the request of an official of the Rock Island railroad. In various hearings and legal matters it was frequently necessary for the railroad officer to relate certain events, as known by the date, to the day of the week.

The nomograph was designed by noting that there are seven calendars--each beginning on a different day of the week (seven days in a week). Therefore, the twelve months of the year may be placed in seven groups--each group having a different day of the week as a beginning. Leap year now enters into the grouping and results in a shift of January from it's normal grouping with October to the April-July group, and February shifts from the March-November group to a bracket with August.

In examining the beginning of each yearly calendar note that the days of the week progress one day per year (except when following a leap year and then the progression is two days). Therefore a normal chronological progression of years may be established for seven spaces (then the same progression is folded again and again). Notice that this normal alignment involves four years in four units and then a unit (space) is "leaped"--because the upcoming year is a "leap year". The leap or blank unit, along with the re-grouping of January and February, maintains the one-day shift. On the calendar following a leap year the re-adjusted January and February produce the two-day change.

Thus the nomograph was designed as a Z chart--with the top scale a normal seven-unit progression of years and the bottom scale a seven-unit progression of calendars --arranged inversely. The center scale is a folded scale involving the seven monthly groupings previously mentioned. Mathematically speaking, the nomograph is a relatively simple device for the addition or subtraction of a known unit with a second known unit, the result being a sum (or difference) which represents the desired answer.

The railroad official wished to know on what day of the week was October 24, 1952. The dashed line illustrates the manner in which 1952 (year) and October (month) are aligned, using the "bullseyes". Thus the correct calendar is found for that year and month. October 24, 1952 was on a Friday.

Other questions that you might try answering on the nomograph are as follows:

1. What months will begin on Thursday in 1963?
2. Your birthday occurs on Sunday in what year?
3. If a birthday occured on Thanksgiving day in 1961, when will it again fall on Thanksgiving day? (Thanksgiving day being the fourth Thursday in Nov.)
4. When will Memorial day provide a three day problem for safety officials by again falling on a Monday or a Friday? (and a three day holiday for us)
5. For any leap year, what other months have the same calendar as January?

There are many other interesting and valuable answers you can find by applying a straight-edge to the nomograph. The nomograph was designed to retrogress eleven years and to advance five years--but the folded scale of years can be labeled or counted to cover any period by following the same system forward or backward.

GRAPHIC ODDS & ENDS

GRAPHIC TANTALIZER

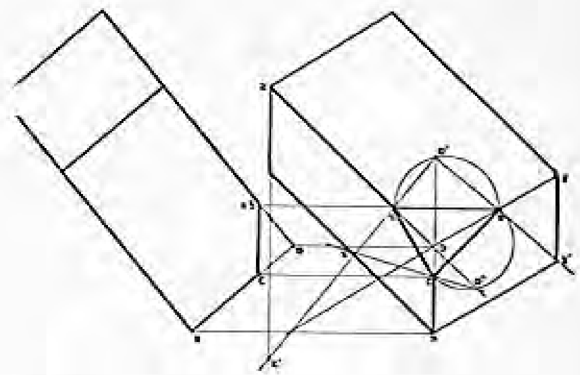
Could you fill space with regular tetrahedrons? Send graphic "ideal" solution to your editor, Mary Blade.

## GRAPHIC TANTALIZERS

The May 1962 Journal published a Descriptive Geometry Problem. Since the methods of solution illustrate different approaches, all solutions which were submitted are published. First to be received was a note from Professional Engineer Irving Gordon of the Bronx, New York. He made an analytical solution which was not cricket for a graphician in the Journal of Engineering Graphics!
The first Graphic solution came from Prof. Kevin B. O'Callahan of the University of Buffalo.

<u>FRONT VIEW</u>

Layout oblique surface ABC true shape.
Draw a perpendicular to each side thru the opposite corner which locates O.
OA, OB and OC are the axes for the view.
Draw semicircle AO'B
From O' along O'B layoff 6" to Y'
Project Y' to Y parallel to OO'.
This locates one corner of block.
From O' along O'A layoff 10" to Z'
Project Z' to Z parallel to OO' which locates corner Z.
Follow similar construction on BC to locate corner X.
View can be completed by drawing the parallel edges.

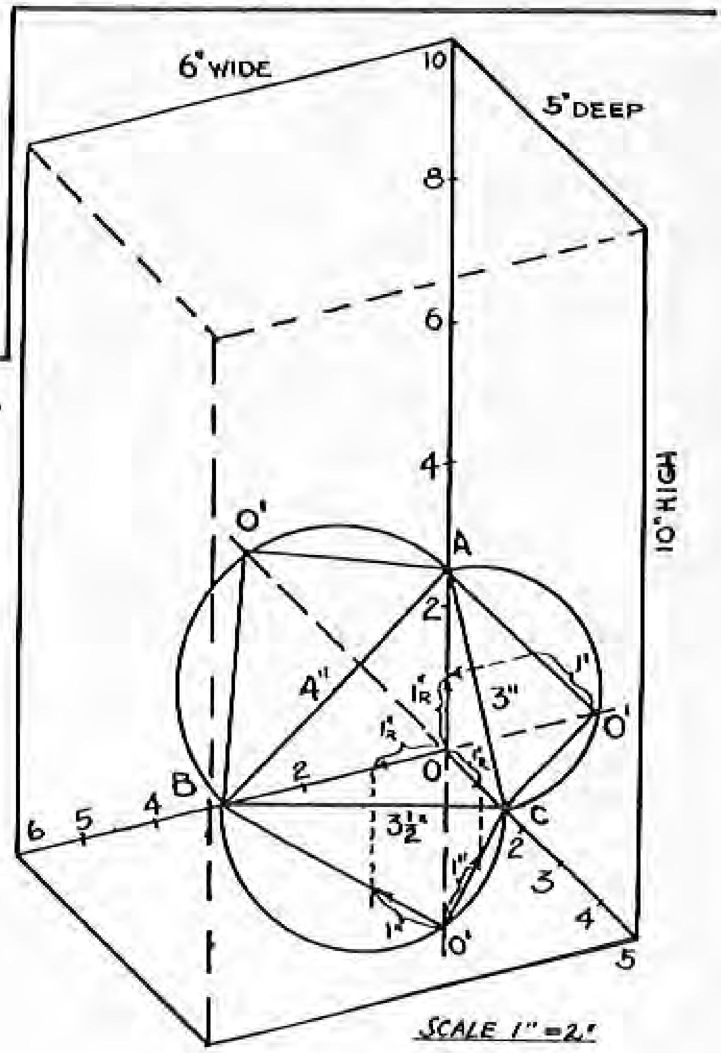


<u>SIDE VIEW</u>

Project points C and AB to get edge view of oblique surface.
With radius X'C strike arc with C as a center and cutting the projector from X.
XC extended to projection of O.
OAB will be at right anges to OCX.
View may be completed by projection from the front view.
Drawn one half size.

The second solution came from Prof. H. W. Blakeslee, Drexel Institute of Technology, Philadelphia.

1. Draw ABC-4"x3-1/2"x3" BC is horizontal.
2. Thru each vertex draw A⊥ to the opposite side. These are axes & intersect at O.
3. Find true shape of OBC by rotating O to O' on semi-circle.
4. Same for OAC.
5. Measure 1"(full size) from O' towards B.
6. Project this inch to OB. Use 6 of them for 6" width.
7. Measure 1" from O' towards C & project to OC. Use 5 of these for 5" depth.
8. Measure 1" from O' towards A. Project to OA & use 10 for 10" height.
   Adjacent view not necessary.




*SCALE 1" = 2'*

At the end of the summer came another solution. This was by Prof. W. W. Preston of the University of Alberta, Edmonton, Alberta, Canada.

Dear Colleague

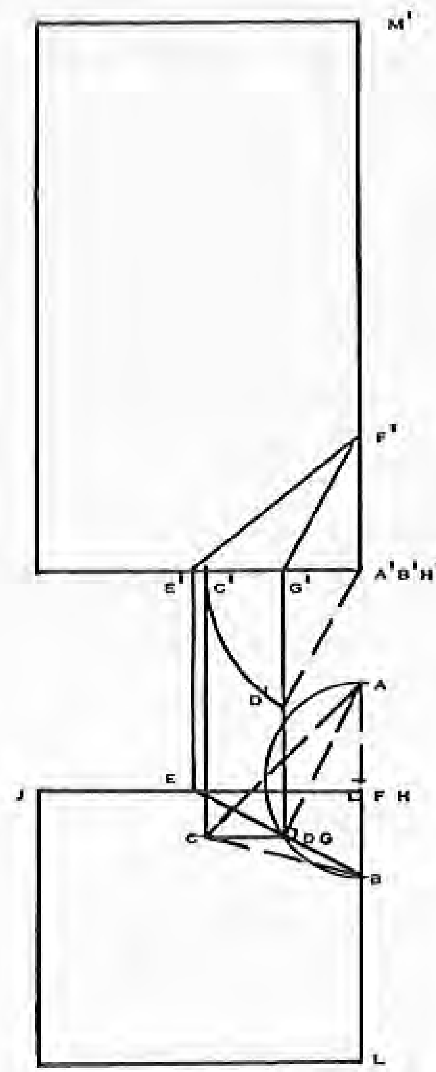
Re Problem in Descriptive Geometry in May 62 issue J.E.G.

Obviously this is not an attempt to submit the first solution to your problem, nor the last, though it may qualify as such. I write in the hope that my after-holiday solution may qualify as the "Best Received" and be "Honorably mentioned". I assume that "best" includes orienting the block as described in your data with a minimum number of views.

I also write to express the hope the you will continue to publish graphical tantalizers.

Solution submitted.-
Plot the bottom view of the level, three and a half inch edge of the notch in the preliminary position AB. With AB as base plot the true view of the triangular area bounded by the given edges of the notch. AC as four inches and BC as three inches.
Revolve C about AB to position D where projection ADB equals ninety degrees.
Plot the altitude of the notch D'G' perpendicular to A'B'C'.
Now flip over the bottom view of triangle ABD, keeping B fixed: A goes to E on BD entended and D goes to F on BA. Thus H'F' equals D'G'.
The join of FEBF is the perimeter of the notch. Plot the overall extended distances HEJ as six inches, HBL as five inches HBL as five inches and H'F'M' as ten inches. Finally add the remaining edges shown.

W.W.Preston,
Assoc. Prof.in charge of Graphics
University of Alberta
Edmonton, Alberta, Canada




The Graphic Tantalizer for this issue is as follows: Have your newspaper library find the photographic illustration in the Sunday supplement "This Week Magazine" September 23, 1962, page 7. Professor K. E. Lofgren of Cooper Union thinks he knows how Mark Wilson floats, by applying principles of Descriptive Geometry. Write your editor if you think you have solved the problem.

## Nominations for 1963-64

(a) The Nominating Committee to be appointed in June at the annual meeting shall be composed of five persons, three of whom shall be the last three past Chairmen of the Division who are present at the annual meeting (not including the retiring chairman) and two others, who are present, to be appointed by the Vice-Chairman in office with the approval of the Executive Committee. The latter two appointees shall not hold any office at the time of their appointment. The senior past Chairman of the Division shall act as Chairman.

(b) The Nominating Committee shall prepare a slate containing, for each office to be filled, two names of eligible candidates who have expressed a willingness to accept nomination and to serve if elected. The slate as prepared by the Nominating Committee shall be published in the November issue of the Journal.

(c) A properly prepared petition nominating a member for any office that bears ten (10) signatures of members of the Division and Society shall require the Nominating Committee to place the name on the ballot.

(d) The nomination period must be considered as being closed at the end of the last conference session of the mid-winter meeting. A petition for nomination received after the close of the mid-winter meeting cannot be accepted. A conference session is herein defined as a regularly scheduled meeting at which papers are presented for discussion.

(e) On March 1, and returnable before April 1, the Secretary shall mail to each member of the Division an election ballot bearing the slate prepared by the Nominating Committee.

(f) Any holder of an elective office whose term extends beyond the current year shall not be eligible for nomination to another office.

The Nominating Committee of the Division of Engineering Graphics met at the Air Force Academy, Colorado Springs, Colorado, and selected the following candidates for the office indicated.

| | |
|---|---|
| Vice-Chairman | Robert H. Hammond, U.S. Military Academy<br>A.P. McDonald, The Rice Institute |
| Secretary | Earl D. Black, General Motors Institute<br>Robert D. LaRue, Colorado State University |
| Director - Executive Committee | Raymond A. Kliphardt, Northwestern University<br>Alfred J. Philby, Ohio State University |
| Advertising Manager - Journal of Engineering Graphics: | Myron G. Mochel, Clarkson College of Technology<br>R. Wallace Reynolds, California State Polytechnic College |
| Division Editor | Charles J. Baer, University of Kansas<br>Arthur C. Risser, University of Wichita |

Additional candidates may be nominated by petition as outlined under paragraphs (c) and (d) of the rules. The candidate must have expressed his willingness to serve if elected. Such petitions for nominations should be presented to the chairman of the Nominating Committee by the end of the last conference of the 1963 mid-winter meeting. See rule (d).

The Nominating Committee - J. S. Rising, Chairman; W. J. Luzadder, I. Wladaver, K. B. O'Callahan, A. S. Palmerlee

## NEWS OF THE DIVISION

### THE DISTINGUISHED SERVICE AWARD

DIVISION OF ENGINEERING GRAPHICS - ASEE
AIR FORCE ACADEMY, June 16, 1962

Dean Jasper Gerardi has had a distinguished career as a practicing engineer, as a teacher in the field of Engineering Graphics, and as an administrator in the College of Engineering at the University of Detroit.

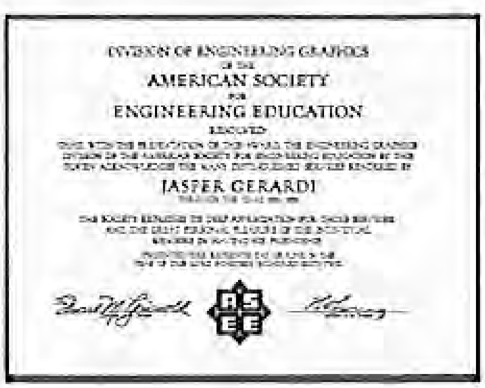
Before completing his undergraduate work at Detroit, Jasper Gerardi had already tasted teaching as a student assistant and found it to his liking. During the period from 1929 to 1947, he successively served as Instructor, Assistant Professor, and Professor of Engineering Drawing. He completed the work for a Master's degree in Structural Engineering at the University of Michigan in 1935. In 1947 Professor Gerardi was made Assistant Dean of Engineering at the University of Detroit.

During each summer period before 1943, Jasper Gerardi held industrial positions in the Detroit area sa civil engineer, structural engineer, and chief draftsman. From 1943 through 1945 he was on leave of absence from the University to accept his responsibility in the war effort as a stress analyst on a research project involving metal blades for helicopters. More recently he has acted as a consultant on engineering standards for a leading company. Also, he is a registered Professional Engineer in the State of Michigan.

This distinguished member has been a leader in the Engineering Graphics Division, enthusiastically supporting all progressive phases of graphics. He has been regular in attendance; participated in discussion; and served the Division in most of its offices since becoming a member of ASEE in 1929. He was Editor of the T-square page in the Journal of Engineering Education; the first vice-chairman of the Division, having been appointed by the executive committee; chairman of the Division; and representative of Engineering Graphics on the ASEE General Council. In addition, he has served actively on many committees.

Dean Gerardi is a prolific writer. He has had some twenty articles published in the Journal of Engineering Graphics, Product Machinery, Product Engineering, S.A.E. Journal, and the Jesuit Quarterly. He is listed in Who's Who in Engineering and holds memberships in the American Society of Civil Engineers, American Society for Engineering Education, Standards Engineers Society, Tau Beta Pi, and Chi Epsilon Fraternity. His many other activities include the SAE Auto-Aero Drafting Standards Executive Committee, and the Defense Drawing Practice Industry Advisory Committee of the United States Department of Defense. He is also on the citizens' advisory committee of the Detroit Board of Education on Equal Education Opportunities, and a consultant and member of the steering committee of the National Science Foundation Course Content Development Study in Engineering Graphics.

Jasper Gerardi is held in high esteem by his students, his colleagues and his friends. He is nationally recognized for his ability and for his sincerity and devotion to his chosen field.


DIVISION OF ENGINEERING GRAPHICS

AMERICAN SOCIETY

ENGINEERING EDUCATION

JASPER GERARDI

Distinguished Service Award Committee
Division of Engineering Graphics, ASEE
Irwin Wladaver
Al Jorgensen
Jim Rising, Chairman

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[redacted]

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## Nomography Award

The Annual Nomography prize was awarded to Harry W. Smith Jr. of Harry W. Smith Inc. The prize winning article "Nomograms for Press Fits using $MoS_2$ Lubricant" was published in Design News March 13, 1961. Professor Richard G. Huzarski, chairman of the Nomography committee announced the prize of $100 was donated by Teaching Machines, Inc. of Albuquerque, New Mexico. Members of the Division are encouraged by Professor Huzarski to send him papers from the literature for this year's nomograph paper contest.

## DESCRIPTIVE GEOMETRY AWARD

No winner of the Division's Descriptive Geometry Award for 1960-61 was announced. The Gramercy Award will be made for the present year. Readers of the Journal should bring worthy articles to the attention of the chairman of the committee, Professor I.L.Hill
Director of Technical Drawing
Illinois Dept. of Technology

# Trigonometric Truss

An Introductory Teaching Aid for Trigonometry

By Dr. Werner F. Vogel[1] and Klaus E. Kroner[2]

In explaining and deriving trigonometric functions for students, mathematics instructors have to make use of algebraic transformations. The following discussion, based on an original treatise published thirty-three years ago[3], deals with a geometric framework which graphically illustrates the relationships between the trigonometric functions of any angle and also shows the exact expressions for the functions of the angle. Furthermore, by expanding the "Trigonometric Truss", as this geometric framework has been named, it is possible to show all integral powers of all functions simply by lines of certain lengths.

The fact that all functions of an angle, all their integral exponents, and the functions of the double angle appear in one and the same figure as lines, has the additional important advantage of giving the observer a graphical comparison between the scalar lengths of the individual functions.

The caption of Figure 1 explains the speedy establishment of a special truss, in which all vertical and horizontal bars are perpendicular to the "lower" and "upper" girder, respectively. From the left-hand part of the truss (solid lines) we can read:

| | |
|---|---|
| $CD = 1$ | $DF_1 = \sin a \cos a$ |
| $AD = \cot a$ | $CK_1 = \sin^2 a$ |
| $CE_1 = \sin a$ | $DK_1 = \cos^2 a$ |
| $DE_1 = \cos a$ | |

then: $CK_1 + DK_1 = CD$ from which follows

that: $\sin^2 a + \cos^2 a = 1$

Furthermore, the following PRINCIPLES can be set down for the truss in Figure 1 (using the nomenclature of its caption):

1. Each vertical and diagonal bar is equal to the next bar to its right multiplied by cos a,
2. Each section of the upper girder (AC) is equal to the adjoining vertical bar on its right multiplied by sin a,
3. Each horizontal section is equal to the diagonal bar above it multiplied by sin a,
4. Any bar of any panel is equal to the corresponding bar of its right-hand adjoining panel multiplied by $\cos^2 a$.

From principles 1 and 4, it follows that: The vertical and diagonal bars (solid lines) in Fig. 1 represent in direct succession all positive integral exponents of the function cos a from the exponents 0 to $+\infty$; and furthermore, the vertical bars correspond to the functions with even exponents (i.e., the functions $\cos^0 a = 1$, $\cos^2 a$, $\cos^4 a$, etc.) while the diagonal bars correspond to those with odd exponents ($\cos a$, $\cos^3 a$, $\cos^5 a$, etc.). The negative integral powers of the function cos a, which are identical to the positive integral powers of the function sec a, are represented by the broken lines.

Principles 2 and 4 yield the values given to the sections of the "upper" and "lower girder", respectively:

Figure 2 is developed similarly as Figure 1 only that now the angle a is placed on the vertical line CD (where again CD = 1).

In Figure 2 then:

| | |
|---|---|
| $CD = 1$ | $DF_2 = \sin a \cdot \cos a$ |
| $BD = \tan a$ | $DK_2 = E_2F_2 = \sin^2 a$ |
| $DE_2 = \sin a$ | $CK_2 = \cos^2 a$ |
| $CE_2 = \cos a$ | |

Of course here also $CK_2 + DK_2 = CD$ or

$\cos^2 a + \sin^2 a = 1$.

Principles 1 and 4 can also be referred to Figure 2 as long as the functions mentioned in them are replaced by the corresponding cofunctions (and read "left" instead of "right").

In particular the following is true about principle Number 4:

Any bar of any panel in Figure 2 is equal to the corresponding bar of its left-hand adjoining panel multiplied by $\sin^2 a$.

The (solid) vertical and diagonal bars in Figure 2 represent in direct succession all positive integral powers of the function sin a; the negative integral powers of sin a (which are identical to the positive integral powers of sec a) are represented by the broken vertical and diagonal bars of Figure 2.

By combining Figures 1 and 2 the "Trigonometric Truss" is developed as shown in Figure 3. Triangle ACD corresponds to triangle ACD in Figure 1, and triangle BCD to triangle BCD in Figure 2. Observation of Figures 1 and 2 leads to the realization that $\sin^2 a + \cos^2 a = 1$. One could of course also obtain the same result from Figure 3 by noting that

$$CK_1 + DK_1 = CD$$

or

$$\sin^2 a + \cos^2 a = 1.$$

In the same manner one can derive the following relationships from Figure 3:

$$AD \cdot BD = CD^2 \text{ or } \cot a \cdot \tan a = 1$$

(because the altitude of the right triangle is the mean proportional of both hypotenuse segments).

The diagonal within the rectangle $CE_1DE_2$ is $E_1E_2 = CD = 1$.

Furthermore angle $DE_1E_2 = a$ and therefore angle $F_1E_1E_2 = 2a$.

One can also draw the horizontal line $E_2K_2J$ to form the cross-hatched right triangle, whose acute angle is 2a and whose hypotenuse is 1.

It follows that $\sin 2a = JE_2 = F_1F_2$.

The distance $F_1F_2$, however, is the addition of the parts $F_1D$ and $DF_2$ whose values we already know, from Figures 1 and 2, as being sin a cos a. It is therefore obvious that $\sin 2a = \sin a \cos a + \sin a \cos a = 2 \cdot \sin a \cos a$.

Similarly it follows that $\cos 2a = E_1J = E_1F_1 - E_2F_2 = \cos^2 a - \sin^2 a$.

From Figure 3 it can also be seen that $BM_1 = BL_1 + L_1M_1$ or $\frac{1}{\cos^2 a} = 1 + \tan^2 a$,

also $AM_2 = AL_2 + L_2M_2$ or $\frac{1}{\sin^2 a} = 1 + \cot^2 a$.

The simplicity of the derivation of these formulae has already been mentioned inthe introduction. Even those who have learned the derivation of formulae differently, may find an interesting confirmation and deepening of their perception in the above demonstration. The introduction of the "Trigonometric Truss" in the teaching of trigonometry may be very well suited to exercise and reiterates the concept of the individual functions.

The "Trigonometric Truss" can also be used to illustrate in the simplest manner how an infinite series leads to a finite limit; and, in addition, how six formulae can be derived which may have direct practical value and whose inclusion in handbooks for applied mathematics and mechanics is recommended.

Let AD in Figue 1 represent, first a whole distance from A to D and secondly, the sum of the altitudes of the trapezoids, then:

$\cot a = \sin a \cdot \cos a + \sin a \cdot \cos^3 a + \sin a \cdot \cos^5 a + \ldots\ldots\ldots\ldots$ or (after dividing both sides of the equation by $\sin a \cdot \cos a$):

$$\frac{1}{\sin^2 a} = 1 + \cos^2 a + \cos^4 a \ \ldots\ldots\ldots \quad (1)$$

Repeating this procedure with line BD in Figure 2, we get:

$\tan a = \sin a \cdot \cos a + \sin^3 a \cdot \cos a + \sin^5 a \cdot \cos a + \ldots\ldots\ldots\ldots$ or (after dividing both sides of the equation by $\sin a \cdot \cos a$):

$$\frac{1}{\cos^2 a} = 1 + \sin^2 a + \sin^4 a + \ldots\ldots\ldots \quad (2)$$

Geometrically, equation 1 states:

The sum of all vertical bars within the triangle ACD (Figure 3) is equal to the first vertical exterior bar $AM_2$ (dotted lineon left of Figure 3). Equation 2 can be similarly interpreted to be:

The sum of all vertical bars within the triangle BCD (Figure 2 or 3) is equal to the first vertical exterior bar on the right ($BM_1$ in Figure 3).

The right side of equation 1 represents an infinite geometric series with the ratio $\cos^2 a$, that of equation 2 one with the ratio $\sin^2 a$. The purely arithmetic evaluation of the known summation of formula leads of course to the value already derived on the left side of the respective equation. The two different types of derivations of the formulae, once strictly graphically from the diagram and then strictly by arithmetic, should be of particular pedagogical value, such as the geometrical interpretation of the end result. Inserting the relations derived above, $\frac{1}{\sin^2 a} = 1 + \cot^2 a$ and $\frac{1}{\cos^2 a} = 1 + \tan^2 a$, into equations 1 and 2 respectively, it follows that:

$$\cot^2 a = \cos^2 a + \cos^4 a + \ldots\ldots\ldots\ldots \quad (3)$$

and
$$\tan^2 a = \sin^2 a + \sin^4 a + \ldots\ldots\ldots\ldots \quad (4)$$

These relations can also be derived from the trigonometric truss.

From the interesting regularities of equations 1 to 4 simple relations for $\sin^2 a$ and $\cos^2 a$ could also be expected. Such relations are indeed obtained through geometric summation with the ratios $(-\tan^2 a)$ and $(-\cot^2 a)$ respectively and are shown in the following equations 5 and 6. For reasons of clarity, equations 1 and 4 are listed again, but in such a manner that the six newly-derived equations are listed in order of the functions.

$$\sin^2 a = \tan^2 a - \tan^4 a + \tan^6 a - \ldots\ldots\ldots\ldots \quad (5)$$

$$\cos^2 a = 1 - \tan^2 a + \tan^4 a - \ldots\ldots\ldots\ldots + \ldots\ldots\ldots\ldots \quad (6)$$

$$\tan^2 a = \sin^2 a + \sin^4 a + \ldots\ldots\ldots\ldots \quad (4)$$

$$\cot^2 a = \cos^2 a + \cos^4 a + \ldots\ldots\ldots\ldots \quad (3)$$

$$\sec^2 a = \frac{1}{\cos^2 a} = 1 + \tan^2 a = 1 + \sin^2 a + \sin^4 a + \ldots \quad (2)$$

$$\text{cosec}^2 a = \frac{1}{\sin^2 a} = 1 + \cot^2 a = 1 + \cos^2 a + \cos^4 a + \dots\dots\dots \quad (1)$$

Whereas equations 1 to 4, which were derived from the trigonometric truss, are valid for any angle, equations 5 and 6, which were not derived from it, are limited in this respect. Equation 5 is valid only for angles of $a < 45°$, equation 6 is valid only for angles of $a > 45°$.

It can also easily be shown that the sin and cos functions of 3a and 4a appear as certain lines in the "Trigonometric Truss". In Figure 4 a horizontal line has been extended from $E_1$ to meet a vertical line from $E_2$ at $E_{11}$. Diagonal $JE_{11} = E_1E_2 = 1$. Point M is found by drawing a line from J perpendicular to CB and have this line intersect with a line drawn from $E_{11}$ parallel to CB, thus forming a right angle at M. As shown, angle $JE_{11}E_2 = 3a$. Point N is located by drawing a line from J perpendicular to $E_1E_2$ to intersect at right angles with a line from $E_2$ which is parallel to $E_1E_2$. $NE_{11}$, being parallel to $E_1E_2$, makes an angle of 2a with a vertical. Therefore, angle $NE_{11}J = 180° - 4a$. For this reason a minus sign appears on the scene. It now is apparent that in Figue 4:

$JM = \sin 3a$

$E_{11}M = \cos 3a$

$JN = \sin (180° - 4a) = \sin 4a$

$E_{11}N = \cos (180° - 4a) = -\cos 4a$

It appears, similarly, in Figure 5 that all of the higher exponents of the functions of the angle 2a can be represented by lines, again being dependent on the originally-chosen unit. They form the sides of the new truss $E_2PQ$ with the vertex angle 2a at Q, which, interestingly enough, grows out of the original "Trigonometric Truss" ABC. It is needless to go into the details at this stage, as all of the regularities which were shown to exist in the case of the original "Trigonometric Truss" logically are valid for this new truss also. Of particular interest is the fact that the easily proven construction of sin 4a and (- cos 4a) in Figure 4, shown above, appears in Figure 5 as a matter of course, but is revealed only on the basis of awareness of the deeper relationships brought out in Figure 5.

This, however, as viewed from a higher plane, is perhaps the most interesting revelation about the "Trigonometric Truss", namely that the complicity of many relations between the individual trigonometric functions seem to appear as necessary so that all the separate laws follow the most simple geometric order of fitting into a universal projective system of presentation.

Figure 6 shows additional geometric and arithmetic relationships. The partial truss appearing in the upper right-hand corner of the illustration shows not only all integral powers of tan a in consecutive order but also indicates that all similar links in adjacent rectangular areas follow the law which states that any link is equal to the same link in the respective neighboring area to the left multiplied by $\tan^2 a$. Furthermore, two new geometric series appear in this figure, namely:

$$1/2 \tan 2a = \tan a + \tan^3 a + \tan^5 a + \dots\dots\dots \quad (7)$$

for $a < 45°$, and

$$1/2 \tan 2a \cdot \tan a = \tan^2 a + \tan^4 a + \tan^6 a + \dots\dots\dots \quad (8)$$

for $a > 45°$.

Multiplying equation 7 by 2, we get

$$\tan 2a = 2 (\tan a + \tan^3 a + \tan^5 a + \dots\dots), \text{ and then}$$

$$\tan a = 2 (\tan \tfrac{a}{2} + \tan^3 \tfrac{a}{2} + \tan^5 \tfrac{a}{2} + \dots\dots).$$

In conclusion it should be pointed out that all of the integral powers of tan a and cot a can be shown in the trigonometric truss. In the expanded truss shown in Fig 7, the original triangle ABC is shown in reduced size. Its altitude however is here also a unit value. The integral powers of the functions tan a and cot a are represented by the stair-like configurations to the right and left of C, whose construction is obtained without difficulty from Figure 6, and which can of course be extended indefinitely into either direction

footnotes

1\.
Dr. Werner F. Vogel, Professor of Engineering Mechanics at Wayne State University, Detroit, Michigan; formerly of Berlin, Germany

2\.
Klaus E. Kroner, Assistant Professor, Department of Mechanical Engineering, University of Massachusetts, Amherst, Massachusetts.

3\.
Das Trigonometrische Fachwerk, W. Vogel, Oesterreichische Paedagogische Warte, Vienna, vol.24 - No.11-1929 and Vol.25 - No. 1-1930.

continued (figures 1-7) next page →

# THE OBJECTIVES AND CONTENT OF ENGINEERING GRAPHICS COURSES

Melvin L. Betterley
The State University of Iowa

## Introduction

There comes a time in the life of an administrator of Engineering Graphics when it becomes necessary to analyze and re-organize course offerings. This, to a minor degree is a continual process--or should be, but what I refer to at this time is the major over haul that occurs when engineering curricula in general are revised.

This may happen somewhat in the following manner: After an inspection visit by the E.C.P.D., the dean and the curriculum committee hold a series of conferences in order to implement the recommended changes. During these conferences-emphasis, credits, changes, and time are all examined. Courses are suggested, examined, discarded, re-shuffled, etc. This generally results in a great many "growing pains"--not only for graphics but for all subject fields directly related to any major changes. Maybe the meaning of the words "growing pains" is a misnomer--perhaps the meaning is inverse, since much of this reorganization, on the basis of E.C.P.D. recommendations, results in less time for graphics. In many schools, civil and mechanical engineering students have been cut to two semesters of four or five credit hours, with the electrical and chemical engineering students required to take one semester of two or three credit hours. Such a change calls for serious and studied revision on the part of the graphics administrator and his staff. He will therefore call his staff together and establish a reorganization procedure. This procedure should be aimed at classroom output and student learning of basic required knowledge and skills in a minimum amount of time and with maximum efficiency. Believe me! -- This is not an easy task. This is a task for which no one has the perfect answers. This is a task which requires working and reworking all the facets of teaching:-objectives, content, learning experiences, and testing.

Related to these is the matter of texts, worksheets, and references. Then there is the big bugaboo! time-- or rather the lack of it. Time is requireed to change behavior patterns - if too much material is attempted in a given amount of time,-little is accomplished in the way of behavioral change and precious time may actually have been wasted.

While this reorganizational procedure may take several weeks or months--with the administrator and staff meeting regularly--I have attempted to condense the procedure, demonstrating the steps necessary to reorganize the curricula.

I suggest a procedure somewhat as follows:

1. Determine and state the objectives for each course or for the department.
2. Analyze possible course content in the light of the objective.
3. Select, modernize, emphasize, discard certain of the possible content. (In actual practice, this may require several conferences with the faculty who teach related subjects in the degree-granting departments.)
4. Select learning experiences within each content category.
5. Select and prepare lecture, text, worksheets, and test material relative to the learning experiences previously isolated.
6. From the above material, develop a course to occupy the given amount of time.

## I. The Objectives of a course in Engineering Graphics

When discussing and deciding upon objectives for a course in graphics, one may select objectives for the teacher or for the learner. Any objectives selected for the teacher involve what he is to do--how he is to do it--and when he is to do it. Such objectives are secondary--but are directly related to the objectives that affect the learner. We are primarily interested in objectives, the end product of our efforts as teachers. Thus objectives should be stated as changes which will take place in the student's behavior, his attitude, and his interests. Objectives are ends to be achieved by learning experiences.

From the above statements it is to be seen that objectives are not a statement of course content nor a statement with any reference to content headings. At the mid-winter meeting of the Division at Lincoln, Nebraska in 1958, I listened for two hours to a panel discussion of what the panel members considered objectives of Engineering Drawing at that time During the session such things as sectioning, threads and fasteners, pictorial sketching, and the whole array of course content headings were mentioned. The panel concluded with no objectives which clearly and specifically stated desired changes in student behavior, attitude, and interests.

As a result of a clear understanding of what a teaching objective must accomplish for the learner, we become aware of the fact that whil the objective is the end product, it must be stated before and used to plan all other features of the course. In other words, the objectives are necessary before teaching and learning can take place--because they determine what course content and learning experiences shall be used.

To get down to the business of actually selecting objectives, it might be well to use as a screen a certain amount of basic philosophy and psychology, remembering at all times that objectives are ends to be achieved by learning--that learning is achieved by doing--that doing involves day by day specific assignments and learning experiences, and that, fortunately, most learning experiences actually produce multiple outcomes. Remember that an objective is best stated when it identifies both the kind of behavior to be developed in the student and the area in which this behavior is to operate.

SOME POSSIBLE OBJECTIVES OF AN ENGINEERING GRAPHICS COURSE

To understand the theory of projection
To develop a reasonable amount of drafting skill
To comprehend the reasons for, the place for, and the use of drawings in industry.
To analyze problems graphically.
To design by means of graphics.
To acquire professional ethics.
To synthesize by means of graphics.
To synthesize profession and society as an accepted social order.
To use profession to improve the society in which one lives.
To use graphics as a vehicle for communication.
To understand graphics as a bridge between ideas and the process or finished product.
To appreciate and apply standard graphical practice and skill.
To desire insight into new developments, materials, and techniques of representation.
To perceive spatially.
To understand engineering nomenclature, fabrication, and machine processes in relationship to engineering graphics.
To develop and read schematic and symbolic representation.
To think creatively.
To solve mathematical problems by graphic methods.
To develop self-realization through expression in graphics.
To appreciate engineering as a discipline.
---etc.

OBJECTIVES WHICH MIGHT ENCOMPASS THESE STATEMENTS ARE AS FOLLOWS:

Objective No. 1:
To understand the role of graphics in contemporary engineering in regard to analysis, design, and communication.

Objective No. 2:
To apply, in contemporary engineering, the techniques of graphical representation and computation.

II. Course Content Selected on the Basis of Learner Objectives

There are several methods by which course content may be selected in terms of learner objectives. One method--using graphics to do the job--would be to chart the behavioral aspects against the content aspects, as follows:

BEHAVIORAL ASPECTS

1. To understand the role of graphics in contemporary engineering in regard to analysis, design, and communication.

2. To apply in contemporary engineering, the techniques of graphic representation and computation.

CONTENT ASPECTS

| | 1. | 2. |
|---|---|---|
| A. Basic Topics: | | |
| 1. Instrument Technique | | X |
| 2. Freehand Technique | | X |
| 3. Lettering | | X |
| B. Graphic Representation | | |
| 1. Pict. Draw. and Sketch. | X | |
| 2. Orthographic proj. | X | |
| 3. Aux. views | X | |
| 4. Sections and conv. | X | |
| 5. Intersections and Dev. | X | |
| 6. Shop processes | X | |
| 7. Dimensioning | X | |

## A DIVISION OF ENGINEERING GRAPHICS AND DESIGN

Dear Editor:

At the 1962 ASEE meeting, Professor Myron Mochel formally proposed what I feel is an excellent idea. He asks that the name of our division be changed to The Division of Engineering Graphics and Design. I believe that this name would be much more descriptive of the total activity of the division, and therefore that Professor Mochel's suggestion merits serious consideration.

Many individual Graphics departments have learned that by teaching a variety of Engineering fundamentals, rather than traditional material, they have been able to stop recent incroachments on their allotted curriculum time. If we can make the name of the division more inclusive, I believe the prestige of the division would be greatly enhanced. Many who are uncertain as to the true meaning of the word "Graphics" claim to clearly understand what "design" means.

Respectfully submitted,

F.M. Woodworth
Dept. of Engineering Graphics
University of Detroit

## DRAWING - GRAPHICS AND ENGINEERING

Dear Editor:

At a discussion session of the 1962 Engineering Graphics Summer School, it became evident that there still is confusion over the proper use of the terms Mechanical Drawing, Engineering Drawing, and Engineering Graphics. The following brief history is presented in the hope that the present meanings of these words will be clarified.

Prior to the end of the first decade of this century, "Drafting," or "Mechanical Drawing" was taught. This term implied the making of drawings by instrumental or mechanical means rather than freehand, and, in view of the state of engineering practice at that time, it was adequate. With the publication in 1911 of "Engineering Drawing" by Thomas E. French, a new name was introduced and widely accepted by colleges and universities throughout the country. Professor French thought that more than the mechanical manipulation of instruments was being taught, and that the adjective "Engineering" was more descriptive. Because of the rapid evolution of engineering since the two World Wars, and the subsequent change in subject matter, there was considerable sentiment to settle on a name which would more nearly convey a proper understanding of true objectives, that is, graphic communication and problem-solving in all its aspects, freehand as well as instrumental, and the use of the analytical power of graphic methods in creative design. Progressive colleges and universities adopted the title Engineering Graphics by 1950 (some schools much earlier).

Textbooks appeared:

| | |
|---|---|
| Engineering Graphics<br>Rule & Watts, M.I.T. | 1951 |
| Graphic Aids in Engineering<br>Computation - Hoelscher,<br>University of Illinois | 1952 |
| Engineering Graphics<br>Rising & Almfeldt, Iowa State | 1953,1959 |
| Graphics<br>Levens, California at Berkeley | 1954,1962 |
| Engineering Geometry & Graphics<br>Shupe & Machovina, Ohio State | 1956 |
| Graphics for Engineers, Basic<br>Graphics - Luzadder, Purdue | 1957,1962 |
| Introductory Graphics<br>Arnold, Purdue | 1958 |
| Fundamentals of Engineering<br>Graphics - Mochel, Clarkson | 1960 |
| Graphics<br>Rule & Coons, M.I.T. | 1961 |
| Engineering Graphics<br>Svensen & Street, Texas A & M | 1962 |

Finally, even French appeared revised and expanded under the title "Graphic Science" in September 1960.

In June, 1958, the Engineering Drawing Division of the American Society for Engineering Education by a two-thirds vote of the membership present at the Berkeley midwinter meeting officially changed its name to the Engineering Graphics Division.

The term "Engineering Graphics" is now almost universally accepted since it characterizes more accurately the scope of this work: that is, sketching, drawing, illustration, charts and graphs, descriptive geometry, graphical mathematics, nomography, projective geometry, etc.

Sincerely

Ernest R. Weidhaas
Associate Professor in Charge,
Engineering Graphics
The Pennsylvania State University

THE BIG SQUEEZE

Dear Editor:

I've been getting letters from book publishers saying that they are advocating and writing books for a condensed course of one semester for Engineering Drawing and Descriptive Geometry. As all good Engineering Drawing teachers know, that is just too much for a three-hour, one-semester course and we Engineering Graphics people should not let our subjects be squeezed out by others who would enlarge their fields at the expense of ours. It is high time we of Engineering Graphics did something about it.

Sincerely yours,

James Bignell
University of Tampa

COLLEGE VERSUS HIGH-SCHOOL TEACHERS

Editor's note:

For background of the letter see the Letters pages in the February and May 1962 issues of the Journal.

Dear Professor Carlson,

Thank you for your letter of March 16 and the copy of your comments.

Before I discuss your comments, let me remind you that Professor Blade suggested this be a lead article in a series of such discussions. It, therefore, reflects two things. One, this is a new responsibility for me and offers the analysis of one with a fresh but intermit contact with graphic problems and second, I tried to be provocative for the benefit of the series.

In reviewing your comments, I find we are in substantial agreement. I would have suspected that one with your excellent background and experience in graphics would be a little more critical of my position. I also realize it could involve some charity on your part.

I note you take strong exception to my "flip" comment about "glorified high school teachers". This phrase is not without some merit, because I think there is a difference between high school teaching and professional teaching to the more mature college student. However, that is not what bothers me. Your feeling that I spoke in a derogatory manner with regard to high school teachers does. It was not intended that this should in any way insult my many very close friends in the high schools. I believe that the development and maturity of the student at the college demands a different approach, one that some college people have not developed. In rereading my article, certainly one could have taken it as you did and I am sorry for this.

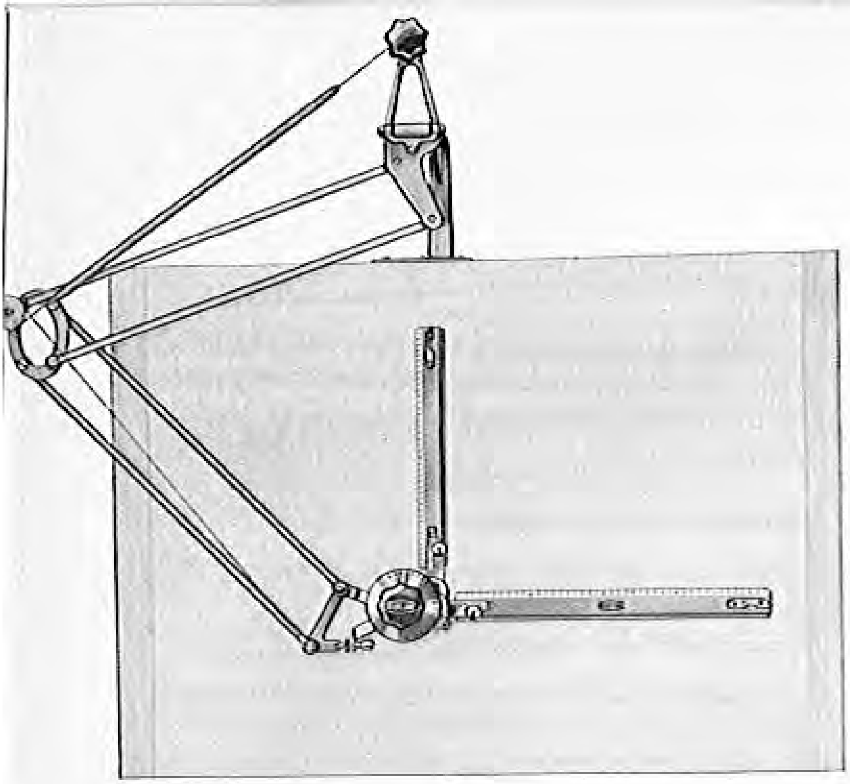
Your comment with respect to college professors who are unable to hold their own in industry is well taken. However, I feel that we are in a minority in feeling this way today. The youth who is most successful is the one who ignores or seemingly ignores any industrial responsibility and dabbles in "way out" research and publishes his results. This is the accepted success story in our profession today. For myself, and I gather you may agree, I feel that every man on my staff should be able to pick up an offer from industry and receive substantial increase in salary. The men I hope to staff my department with are those who are dedicated teachers and truly professional engineers, and the offers from industry just flatter this type professor.

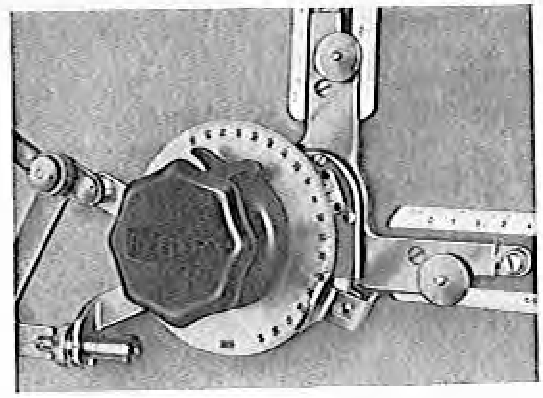
You discussed my suggestion of combining graphics with one of the other professional engineering departments. You state that you think this combination has merit if the school does not have a department of General Engineering. I find here again I would have to agree with you. A department of Basic or General Engineering as they are called, does seem to be the logical place for graphics which is a science to all engineering.

I want to close by thanking you sincerely for your comments and your well wishes for my success in incorporating the graphics division into the mechanical engineering department. I hope to have the pleasure of meeting you personally at one of the future ASEE meetings.

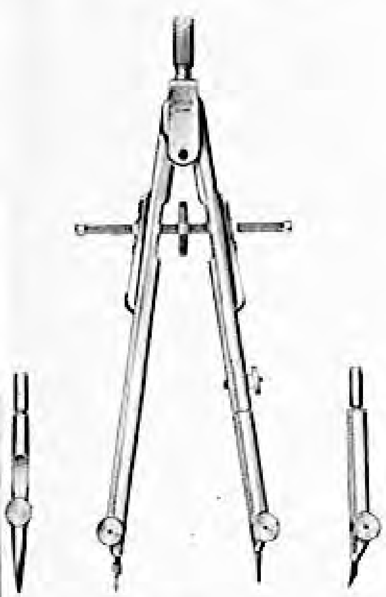
Yours truly,

John H. Fernandes
Head, Mechanical Engineering Department
Manhattan College, N. Y.





RIEFLER



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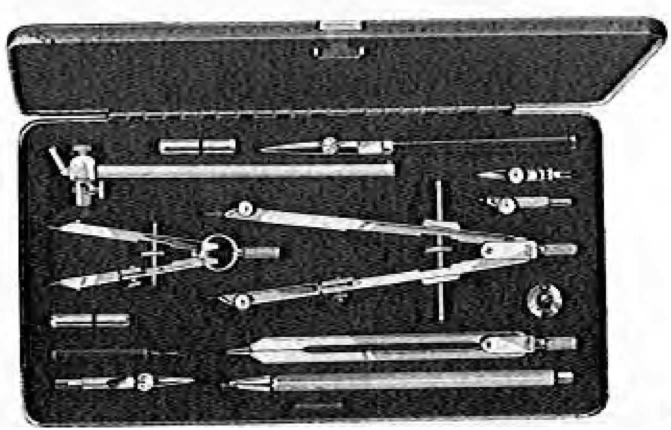
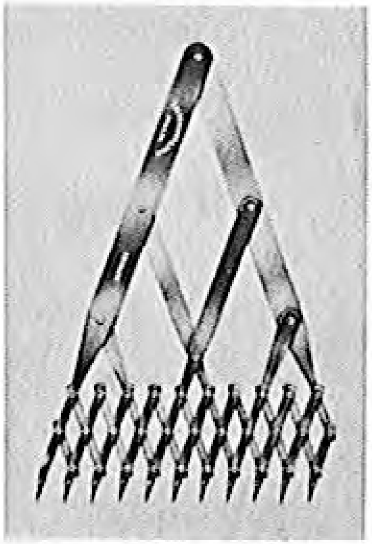


G 8 AP METAL CASE

# THE SPACING DIVIDER



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