MODERN OPTICS AND SYSTEMS ENGINEERING

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In the early days of training devices and simulator technology, optics played only a minor role or no role at all. Edward Link's first pilot trainer contained not more than plain eyeball optics. We must admit that there are training devices which do not warrant a larger role of optics even today. But there are others where optics has to provide for a very important interface between man and machine, so important that optical devices are indispensable for achieving a training purpose. These optical devices may be complex and sophisticated and require exceptional engineering effort.

Results have been obtained already which apply uniquely to simulation technology, such as large virtual image displays, the utilization of the Scheimpflug condition for the large depth of field requirements of optical probes, the VAMP system, which makes it possible to change, within certain limits, the perspective (or the viewpoint) of a film presentation, to mention a few.

However, the purpose of my presentation is not to expound such details; it is a tutorial explanation of modern concepts and methods of optical engineering and their proper integration into overall systems engineering.

After a preliminary overall systems approach (Figure 9) has been formulated, a detailed discussion with experts from the various engineering disciplines involved leads to the modified system's concept, which becomes the basis for design, manufacture, and test. Optical engineering contributions seem often the least important as far as expenses and manpower are concerned, and are then neglected at this level. However, it is only in the best interest of overall systems engineering that optics does not become innocently the weakest link at which the chain will break. Inviting optical engineers to participate in the first high level discussions will prevent that almost impossible tasks are left to them as it happens too often otherwise, but it will help to find feasible solutions with a chance of optimum integration into the overall system even in areas where an optical solution was not originally anticipated.

If we consider now optical systems contributions (Figure 10), the procedure is similar to the previous one. The preliminary concept will have to be worked through with considerations of physical optics and sensors (which may be the human eye), lens design, mechanical design, and manufacturability. All of these will have to lead to the formulation of the design instructions.

Of the design areas involved, we will discuss lens design in some detail, because of important advances made since World War II. The computer has not only taken time consuming drudgery out of ray-tracing, but made it possible to automate lens design itself, namely, in such a way that the computer changes design parameters so that a lens system with improved performance criteria is obtained. It is, however, not so that a computer and a good lens design program will entirely dispense with the services of an expert lens designer. It is necessary (see Figure 11) to start with a reasonable preliminary design approach. In addition, boundary conditions, a representative number of rays, a table of image errors defined by the help of these rays, and correction requirements will have to be formulated, which all require expert knowledge.

This is the procedure followed with the ACCOS-GOALS program which we use at NTDC and which was designed by Dr. Gordon Spencer. Some lens designers claim that other programs are "better," because they relieve the designer of some of these steps and may have some other advantages. But such statements can never be absolute; they can only be accepted relative to a special purpose or application. A larger freedom of choice as provided by ACCOS-GOALS may be burdensome at one time, but grant a higher degree of versatility at another time. This versatility seemed to us of paramount importance in the large variety of tasks found in simulation technology - only time will teach us whether we were right.

After a lens design has reasonably well progressed, the designer will ask the computer to compute and plot a spot diagram; that means, 100 or 200 rays will be traced and the points determined where they penetrate the image plane. Figure 12 shows the spot diagram for three spectrally weighted wavelengths; it gives the first impression of the light distribution in an image "point."

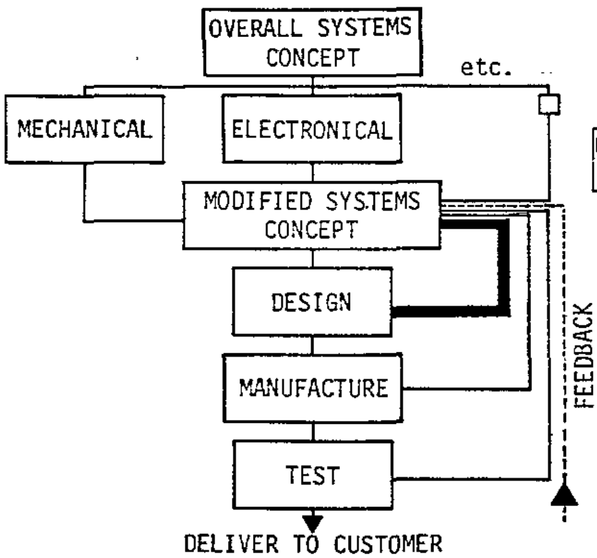


Figure 9. Overall Systems Approach

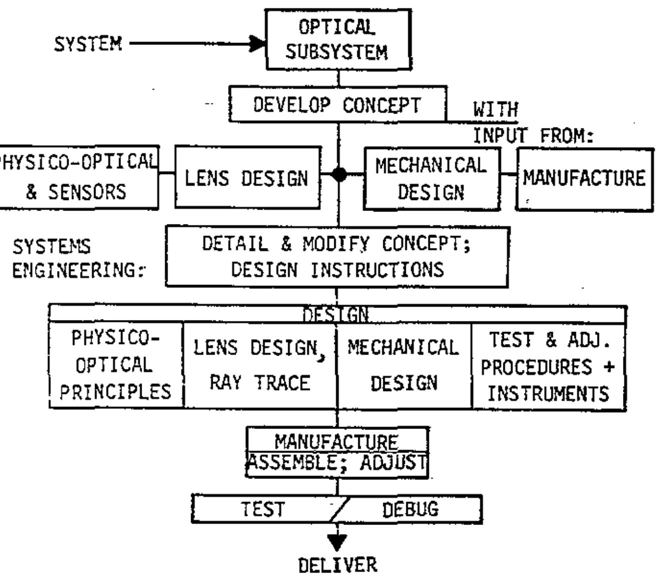


Figure 10. Optical Systems Approach

The spot diagram can be evaluated with respect to other performance functions, about which we will hear in the next paper.

How do we measure performance in practice (Figure 13)? We could measure these performance functions directly and do measure them if we want complete information about the performance of an optical system. But this complete information is often too much information for the purpose of systems engineering. The systems engineer would prefer to have as few characteristic performance numbers as possible for ease of handling.

This may explain why resolution enjoyed so much popularity for so long a time. Regrettably, image sharpness, which is an important quality of an optical image, cannot be related to resolution of fine detail, as conclusively shown by Higgins and his co-workers at the Kodak Research Laboratories.* Acutance, the normalized mean square average of the slope of an edge trace, is a much better expression of image sharpness.

*We thank Dr. Higgins for having made the originals of Figures 14 and 15 available to us; they were published in Phot. Sc. and Eng., vol. 2, p. 66-76, 1958.

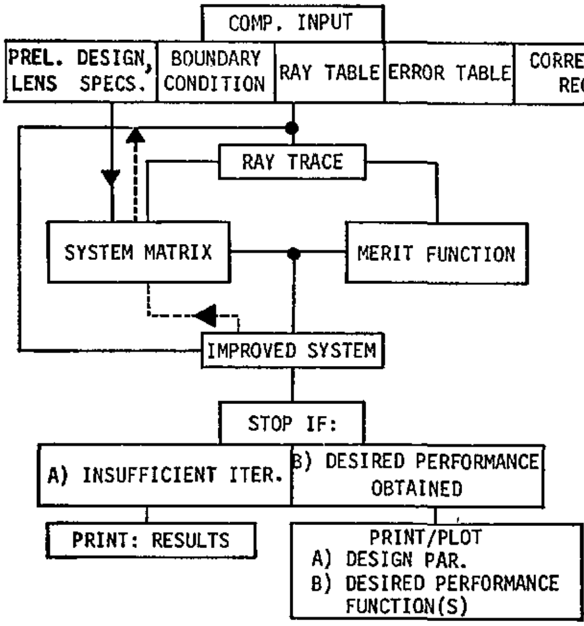


Figure 11. Lens Design by Computer

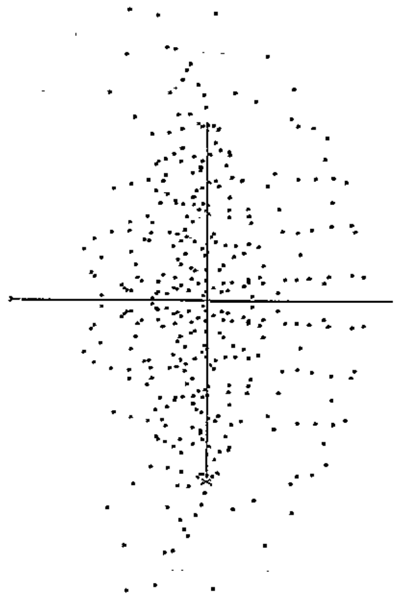


Figure 12 - Spot Diagram for Three Wavelengths (Taken from ACCOS-GOALS User's Manual; Scientific Calculations, Inc., 100 Allen's Creek Rd., Rochester, N. Y.)

PRACTICAL PERFORMANCE EVALUATION

1) RESOLUTION
   WITH RESOLUTION TARGETS
   (SQUARE WAVE CHARTS)

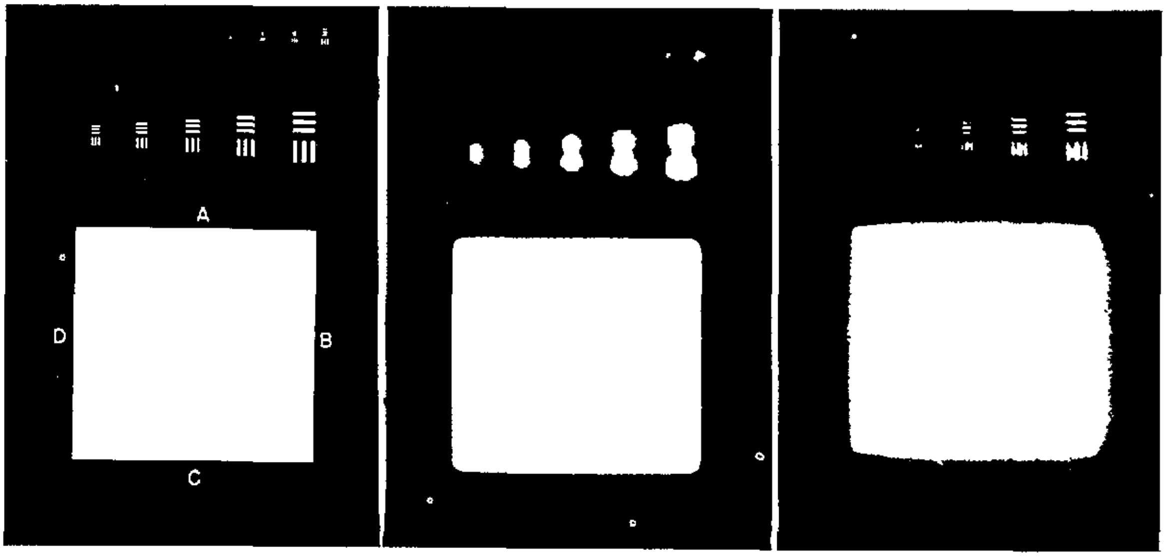
2) IMAGE SHARPNESS
   BY DETERMINING ACUTANCE
   FROM EDGE TRACE (HIGGINS ET. AL.)

$$AC = \sum_{i=1}^{k} (\Delta D_i / \Delta x_i)^2 / (k \cdot \Delta D_{max})$$

3) MEASUREMENT OF
   A) MODULATION AND PHASE
      TRANSFER FUNCTION
   B) POINT OR LINE SPREAD
      FUNCTION, OR EDGE TRACE

Figure 13.

This requires exemplification. Figure 14 shows two images of a test target (first frame), one with low resolution but good contour sharpness (second frame), the other one with high resolution and low contour sharpness (third frame). Figure 15 shows the pictorial effect of this



a. Original Test Target b. Good Contour Sharpness, Bad Resolution c. Good Resolution, Bad Contour Sharpness

Figure 14. Test for Contour Sharpness versus Resolution by Special Test Target

a. High Resolution, Low Sharpness b. Good Sharpness, "Low" Resolution

Figure 15. Pictorial Test for Image Sharpness versus Resolution

difference. "A" has high resolution and low contour sharpness, or low acutance; "B" has low resolution and high acutance. Though tiles and leaves are better resolved in A than in B all will agree that the general appearance of B is better than A, because B is a sharper image.

These findings are, of course, extremely important for applications in simulation technology where we have often to be contented with less than perfect imagery. Then, it is important to find an optimun solution within the scope of feasible effort and available funds. Obviously, resolution alone does not suffice to arrive at the optimum solution; it has to be supplemented by another quality number for image sharpness. Acutance seems to serve this purpose well.

Much work will be required to introduce this new concept into general engineering. Methods have to be developed to measure acutance simply and reliably. Acceptance tolerances will have to be established which will correspond to the one and four minute rule for acceptable resolution. Finally, engineers will have to be convinced of the usefulness and practicality of this concept and educated in its proper use. The Physical Science Laboratory of NTDC does hope to make contributions in this respect.

But we should definitely start as soon as possible in relating psycho-physiological effects of image quality, such as recognizability of targets, legibility of alphanumeric displays, etc., not only to resolution but also to acutance, or at least to measurements of physical performance which would permit us to retrieve acutance. Only then will we learn what constitutes good imagery in a way which is usable for improved systems engineering. This appeal to experimental psychologists, popularly known as human factors engineers, shall conclude my presentation.