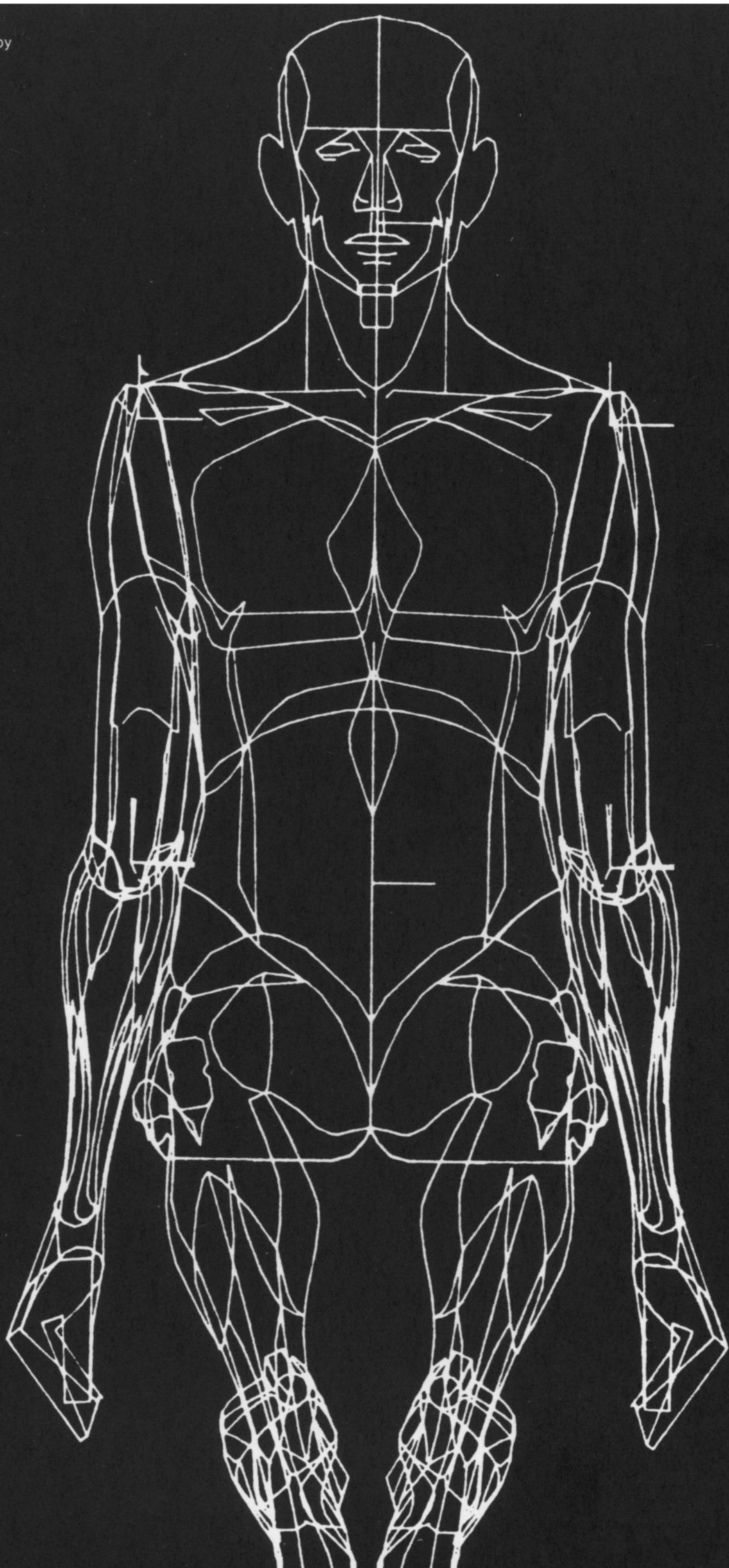


Animated human figure drawn by the computer.

William Fetter is supervisor of Computer Graphics at the Boeing Company in Seattle, Washington, where Computer Graphics was developed and made available as a tool for the visualization of the many problems related to airplane production. Fetter's department, made up of graphic designers, illustrators and writers, prepares and produces publications, documents, slides and motion picture animation for the development and promotion of new products.

Computer Graphics is the technique which uses the computer to produce still or moving images, whether on paper, tapes or film. In 1960 Fetter outlined a new concept of perspective which abandoned the accepted academic drawing methods. Fetter and Walter Bernhardt converted this concept into mathematics. A programmer then translated the concept into computer language. Data from an aircraft drawing was supplied to the computer connected to a plotter (automatic drawing equipment) which delineated a perspective drawing.

This first perspective drawing produced by a computer already indicated the possibility of using computers in many areas. In fact, during the past few years a whole new area of graphics has been created with the application of Computer Graphics to many visualization problems. The examples shown in the following article by William Fetter demonstrate how Computer Graphics can be applied to the visualization of acoustical graphs, the evaluation of preliminary cockpit designs, the location of radar stations, the design of a cockpit display system and the simulation of an aircraft carrier landing.

Recent developments of more sophisticated equipment for computer-generated images increase the area of Computer Graphics while eliminating most of the tedious work that is usually required. It is now up to the designer to use Computer Graphics and thereby extend his ability to solve complex visual problems.

COMPUTER GRAPHICS

by William A. Fetter

Computer Graphics represents a new stage in the art of visual communication. Several thousand years ago the Babylonians recorded their accomplishments with stylii on tablets in characters not unlike those punched in IBM cards. Early printing was a technique for reducing the laborious and expensive process of writing on paper. Present-day typesetting equipment, related photomechanical processes, and the modern printing presses have further simplified the translation of thought into visual form.

Through Computer Graphics visual communication has developed into a technology with computers converting virtually unlimited engineering or scientific data into visual images. Just as in the past, however, this latest development has brought new standards, changes in the accompanying human crafts, and even greater demands upon human judgment and management in operating the machines, facilities and tools involved.

Perhaps the best way to define Computer Graphics is to find out what it is not. It is not a machine. It is not a computer, nor a group of computer programs. It is not the know-how of a graphic designer, a programmer, a writer, a motion picture specialist, or a reproduction specialist.

Computer Graphics is all these — a consciously managed and documented technology directed toward communicating information accurately and descriptively.

The term "Computer Graphics" was coined at the Boeing Company in 1960. It was obvious that comprehension through the human eye was the primary goal in employing computer technology to visualize complicated relationships and images. Special graphic skills were required to meet these goals and only the utilization of the maze of electronic circuitry in contemporary computers, along with the necessary computing skills, could help to produce graphic images economically and rapidly.

In Computer Graphics, three aspects have to be understood: first, the communicator who has an idea or message to communicate; second, the communication specialist who decides whether the problem should be solved graphically, verbally or as a combination of both; third, the computer specialist who selects the computer equipment and interprets the problem so that the computer can act upon it. The present make-up of the Computer Graphics organization at Boeing recognizes these aspects and thus provides a combination of creative communication and engineering accuracy for managers, engineers, and others in any Boeing division.

COMPUTER GRAPHICS IN RESEARCH

One important research area is found in the relation of Computer Graphics to Numerical Control of machine tools. Numerical Control is a system that regulates the action of one or more machines by the automatic interpretation of instructions which are made up in numerical form.

For instance, a particular surface is defined by selecting 25 points. The computer then provides a complete definition of the surface which then can be produced by employing Computer Graphics capabilities. To check its correctness or examine its acceptability, it can be presented as a true perspective or any other projection. Working from the same data, with some modifications for machine tool characteristics, a punched tape can be prepared which controls a machine that cuts this surface from metal. It is obvious that here is a great potential for producing many items necessary to aircraft manufacture. Other research activities in Computer Graphics result in films showing visually structural dynamics, that is, changes due to maximum stress, etc. With a plotter (automatic drawing equipment controlled by a computer) it is possible to produce pictures of an airplane for a film in which the wings assume different positions because of particular flutter modes. Instead of examining long listings of computed numbers, through the film the structural engineer can study visually and in motion the forecasted performance of a new design.

The results of this and other research are documented in procedures that match the work flow of applications — from authorization, communication design, data transcription, computer programming, automatic drawings and final rendering to reproduction. Long lists of skills, programs, equipment and systems are involved. Computer Graphics technology depends on identifying these elements, developing the means to manage them and, perhaps as important, knowing which pathway to choose through this maze.

The following is an outline of the procedure and indicates how Computer Graphics was applied at Boeing:

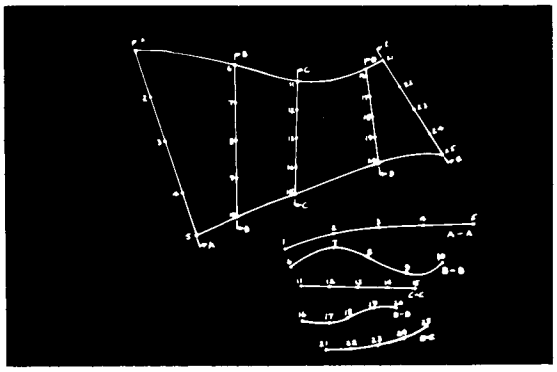
Authorization includes examining the application to determine if Computer Graphics is, in fact, the best method for solving the problem presented. If so, authorization papers are prepared to assure an agreement of the aims of the application.

Communication design is the key to the remainder of the Computer Graphics process. For instance, in the case of a motion picture, a storyboard is prepared by the designer. All subsequent activity, including computing, will be based on the communication sequence which the designer prepares with full knowledge of the capabilities, costs, and time available to him.

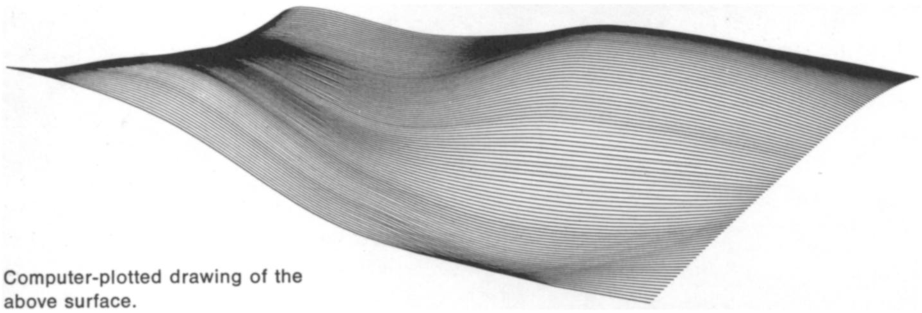
Data transcription, the process of transferring measurements into data acceptable to the computer, is accomplished by marking a transparent overlay on an orthographic view of an airplane, and selecting the numbers and the type of coordinate points indicated by the designer. This transparent sheet is given to a Telereader operator to complete the data transcription step. The operator places the sheet on a backlighted screen, aligns cross hairs on the screen by two control knobs, and then produces a punch card by pressing a foot button for each point.

Computing and programming follows when the airplane is defined by a complete deck of cards. The cards are combined with Computer Graphics programming cards in the computer which then produces a magnetic tape.

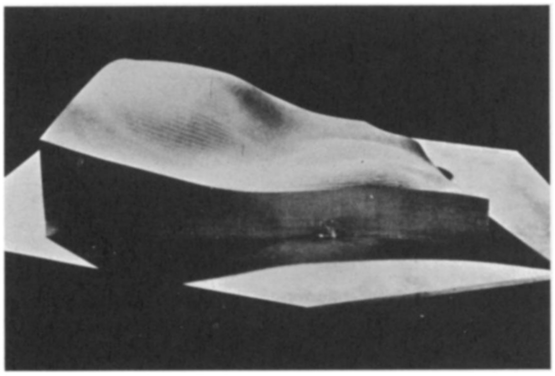
Automatic drawing is the next step. The magnetic tape operates automatic drawing equipment such as the Orthomat, a plotter which produces drawings automatically. A computer/ recorder, which is usually used for motion



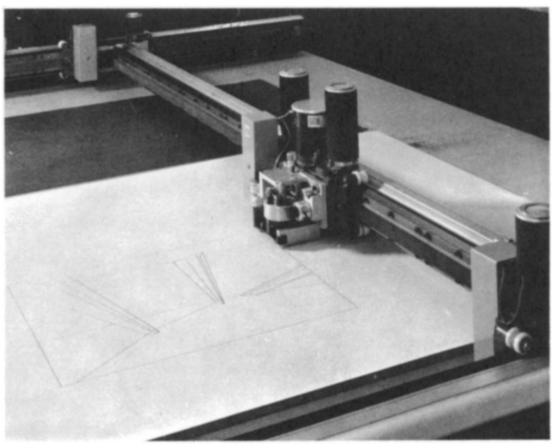
Surface defined by 25 points across different sections.



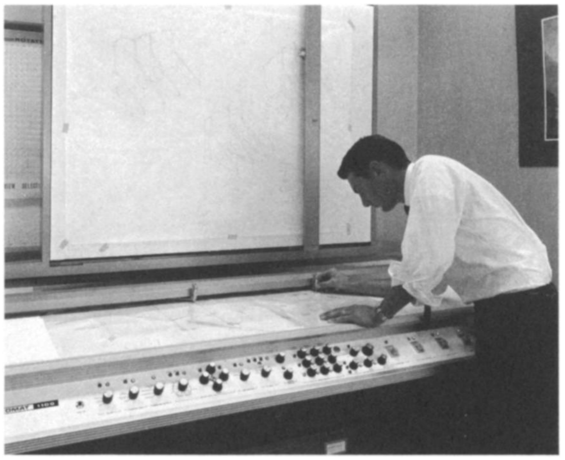
Computer-plotted drawing of the above surface.



Same surface cut into metal by numerically-controlled machine tools.



Automatic drawing produced by a plotter, which is either operated by a magnetic tape or directly controlled by the computer.



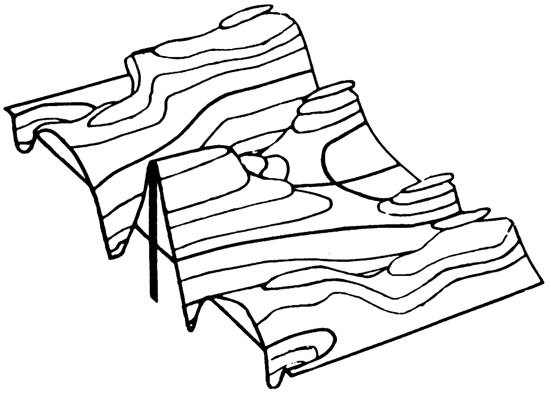
The Illustromat 1100, a computer-directed drawing instrument capable of automatically drawing perspective views.

pictures and documents, produces, instead of drawings on paper, a 4 x 4 inch image on a cathode ray tube, a television-like screen, which is automatically photographed on 16mm or 35mm film within the equipment. Many options are possible within these systems. For instance, the Illustromat 1100, a computer directed drawing instrument, combines the steps of data transcription (on a horizontal surface), computing programming (at a front console) and automatic drawing (on a vertical drawing board), and simultaneously draws any type of projection as the operator moves the stylii along coordinated lines on the horizontal surface.

Final rendering is the next step which may include illustrating the automatic drawings and the addition of lettering and animation in the case of motion pictures. Final rendering produces some type of master (either plates, negatives, or a motion picture master) from which the final step, reproduction in quantity, can be accomplished.

APPLICATIONS OF COMPUTER GRAPHICS

ACOUSTICAL ENGINEERING



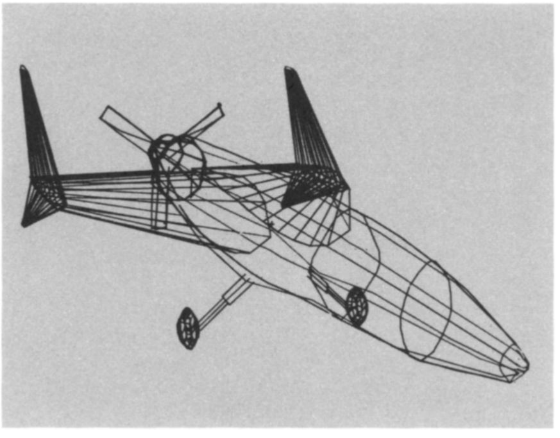
Three-dimensional acoustical engineering graph shown in perspective for better understanding.

The results of an advanced aerodynamic-acoustics study can be presented as a three-dimensional acoustical engineering graph. The graph can be shown in isometric projection and also in rotated perspective views to allow the engineer a better understanding of its topology.

ENGINEERING DRAWINGS

In selecting a type of drawing projection, one of the major considerations is the *ease of measuring.* In assessing the value of the type of projection — orthographic, oblique, isometric, dimetric and trimetric views as well as true perspectives — we realize that measuring becomes more difficult when moving toward a true perspective view.

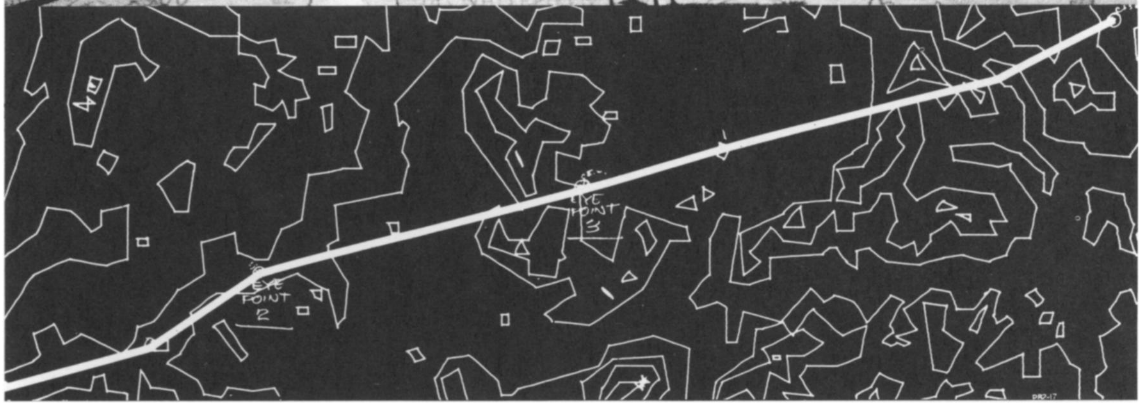
Another consideration in selecting a type of drawing projection is the *ease of understanding.* Since perspective projections represent objects just as the eye sees them, *measuring* becomes difficult while *understanding* increases. With the addition of shading, color, and especially motion to the perspective projection, the graphic effect can be most effective and thus facilitate communication.



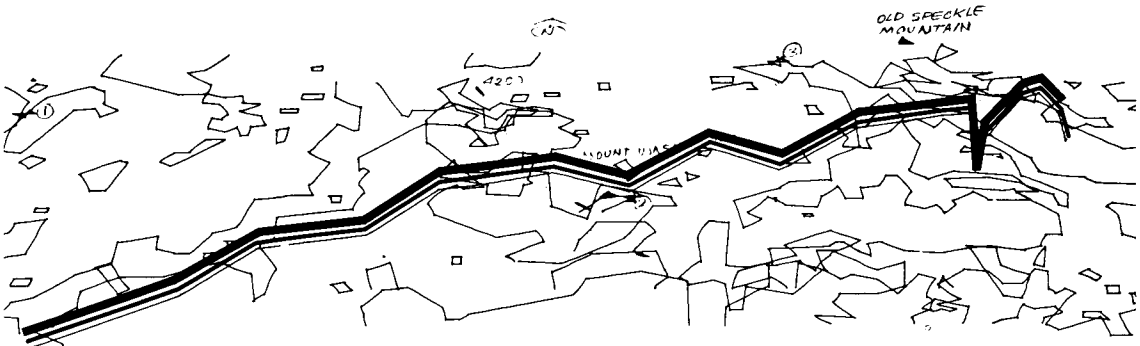
Perspective drawing of an airplane, constructed by a computer and delineated by a plotter. Any projection type can be generated after the information about the plane has been punched on IBM cards.

Once the engineering data is stored in the computer, Computer Graphics can present any type of projection from orthographic to oblique, isometric, dimetric and trimetric, to a true or central perspective. Any required combination of measurability and understanding plus details and parts of the projection can be selected and presented.

Original map with three hypothetical radar station locations.



Transcription of the above map, with simplified contour lines of the same terrain.



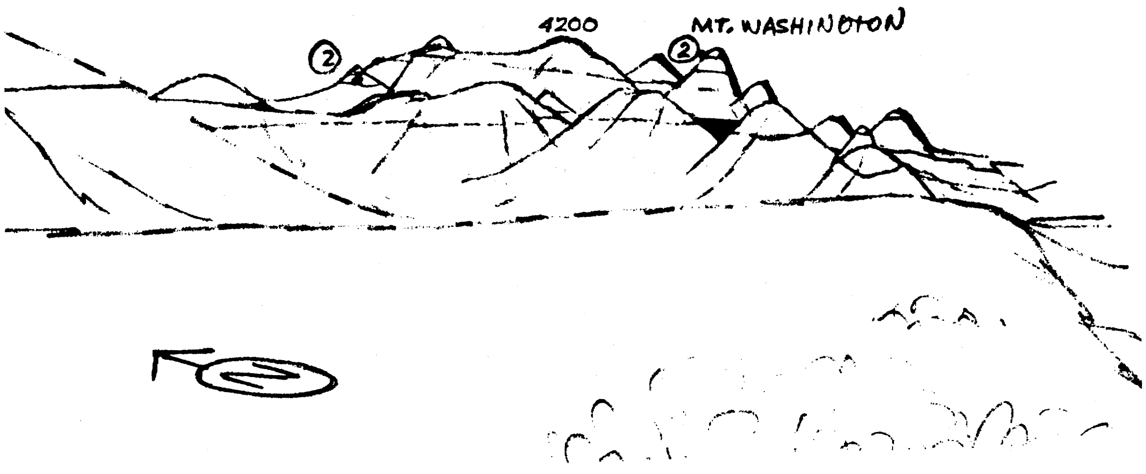
Computer drawn plot showing the area in perspective as seen from an altitude of 20,000 ft.

Rendered version of computer plot with hidden lines removed and mountain slopes drawn in.

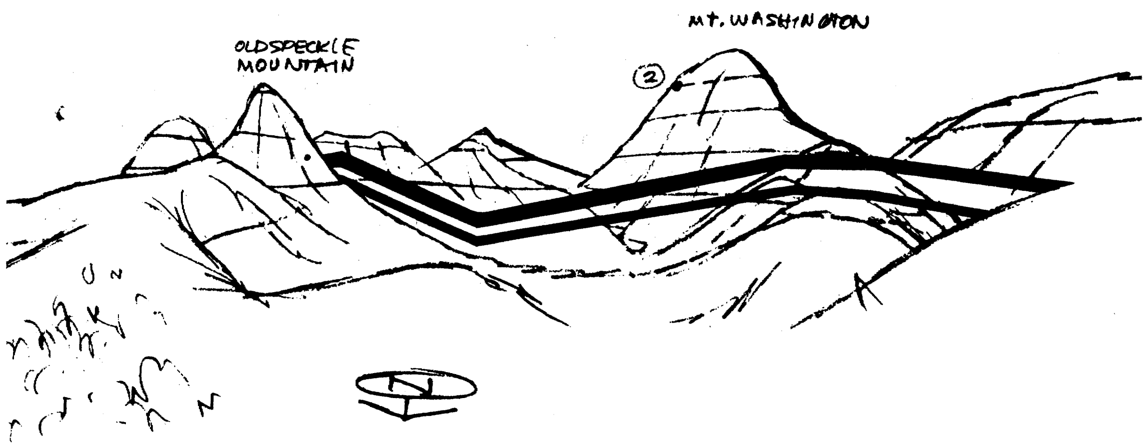
OPERATIONS ANALYSIS

Computer Graphics was also applied to Operations Analysis in a study concerning an area of mountainous terrain in New England. The object was to determine the location of three radar stations by tracking an aircraft flying along a selected flight path at two different altitudes, to plot the terrain interference and to measure the exposure of the flight path to each radar station at 500 and 200 foot ground clearances. A minimum number of points on a contour map was selected for economy in proving the method, and an orthographic *computer plot* was obtained in the exact size of the original map. To assure accuracy this plot was checked by overlaying it on the map.

The computer was then provided with a program that established a viewing point at an altitude of 20,000 feet and six miles from the center of the area. A plotter drawing of an



View from one radar station in which only a small amount of the flight path is visible (solid black area).



View of the same terrain from a different radar station showing a large segment of both flight paths.

over-all perspective was then obtained, showing the area as seen from the selected viewpoint, with the flight paths curving along the mountains and valleys. Working from this plot, the designer produced a more understandable picture by purposely exaggerating the vertical dimensions, drawing in the slopes and leaving in the visible contour lines. The hidden contour lines, also drawn by the computer, had to be removed manually. This conversion to a solid appearance was made with an accuracy of plus or minus 50 feet for each mile from the viewing point. Using a similar combination of computer and artist's drawings, views from each radar station were produced in order to determine where and for how long the airplane would be visible.

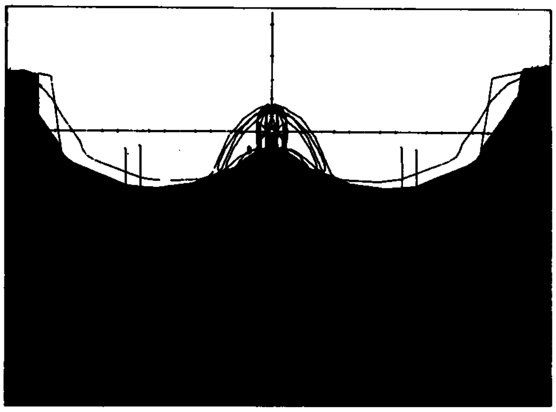
It was found that, in some views, tracking periods were very short — in other views, long segments of both the upper and lower flight paths could be observed at a particular radar station. These pictures, rather than mathematics alone, allowed trained radar personnel to see those parts of the flight path that would not appear on a radar screen because of its relationship to the terrain and the radar's characteristics. From these drawings it was then possible to make a map summary of the radar visibility of the airplane, at both altitudes, from any of the radar stations and thus evaluate the location of the radar stations.

HUMAN FACTORS APPLICATIONS

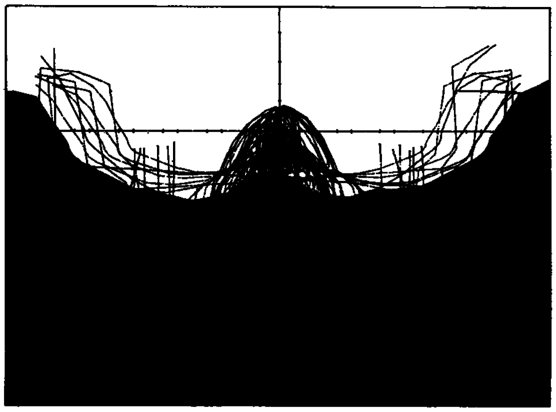
The need to know more about the visibility characteristics of a preliminary cockpit design prompted a study in the human factors area. The object of this particular study was to determine the cockpit design of a combat aircraft emphasizing visibility which is of vital importance for the aircraft.

A single plot of cockpit visibility is very tedious and costly if manually produced. During cockpit development constant refinements are necessary in order to achieve the best design. Computer Graphics using the previously described techniques, make it possible to have the results available in a form that is understood by the engineer and the non-technical observer as well. In the illustrated 360 degree view from a cockpit, the vision straight ahead is located at the center of the drawing, and the degrees of vision to the left and right are flattened out so that the left and right edges of the sheet actually represent the straight backward view. The horizontal line represents the full 360 degrees of the horizon, while the areas shown in black indicate blocked visibility.

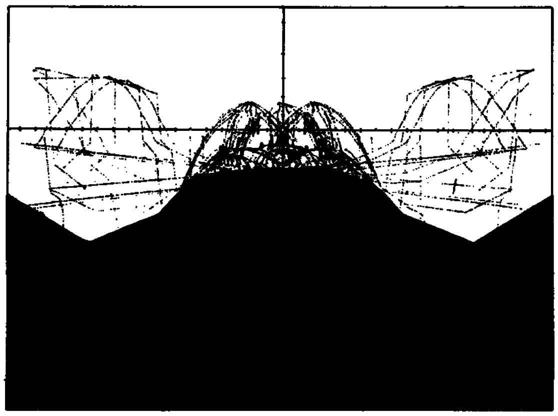
The visibility improvements which are obtained by turning and tilting the pilot's head were demonstrated by selecting a number of extreme viewpoints. All of these views were then automatically drawn on one sheet. The further improvement of the field of vision was shown for movements of the pilot's upper body.



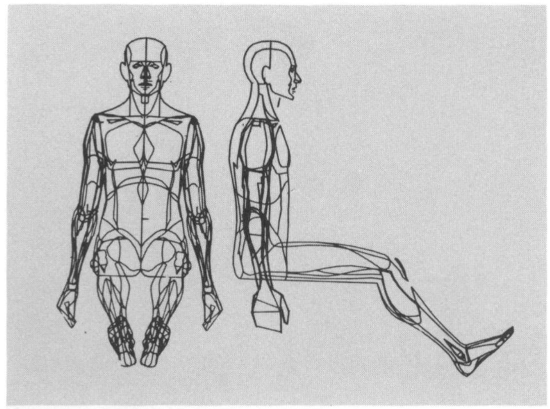
Computer plots of cockpit visibility studies for a combat aircraft. The black area indicates where visibility is blocked.

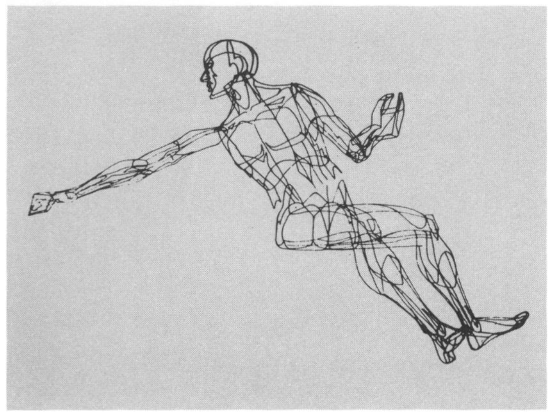


Visibility is increased by turning and tilting of the pilot's head.



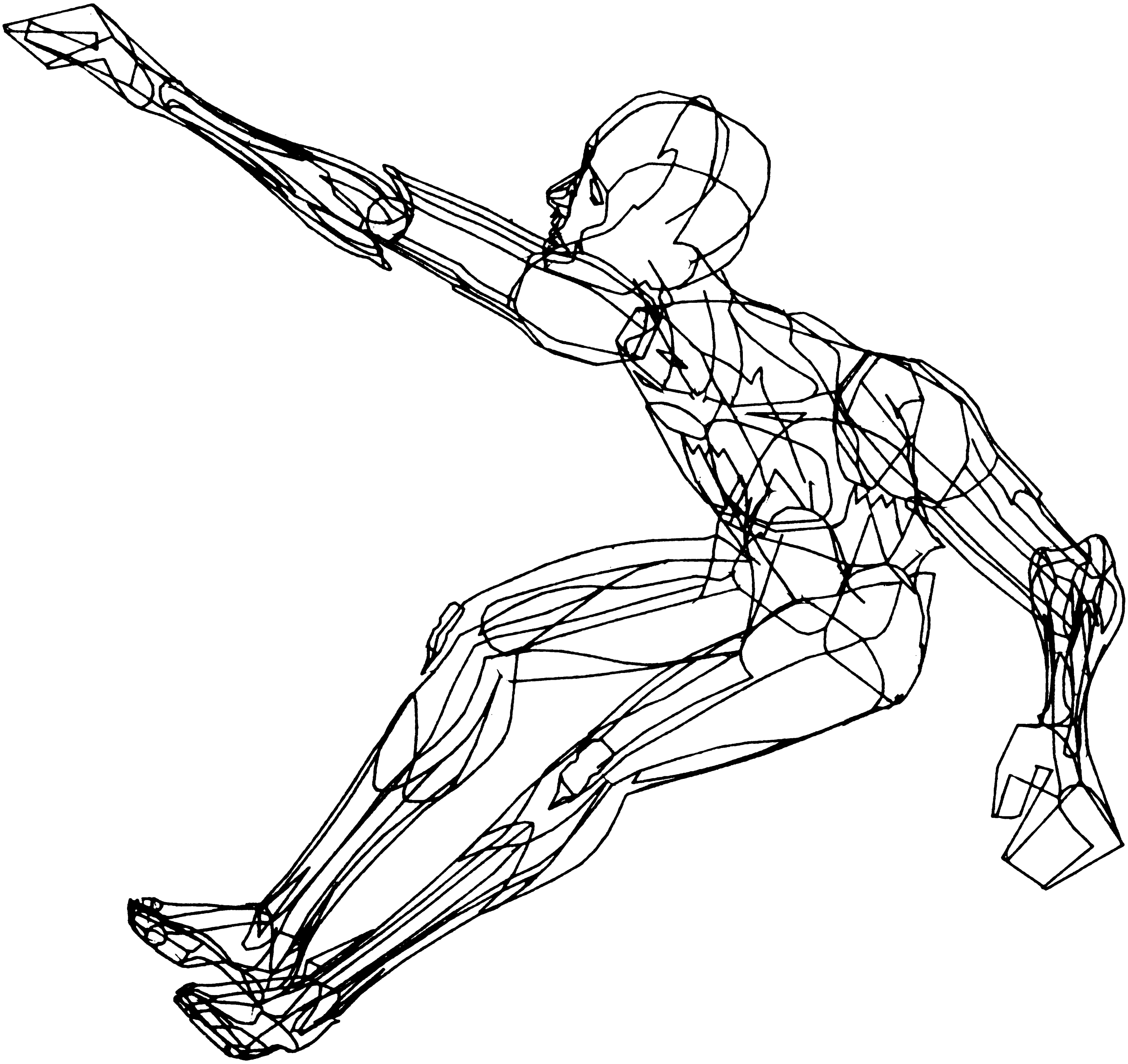
Visibility is further improved by including movement of the pilot's upper body.





One of the most exciting possibilities for Computer Graphics techniques is represented in an animated human figure, which has been designed, stored, and drawn by computer for personnel subsystems studies. The figure is accurately measured to meet Air Force anthropometric data for what is called a 50 percentile figure (the figure size of about 50 percent of Air Force pilots). The figure is composed of seven articulated systems and used for human factors studies. It can be easily animated for extreme reach situations as well as for plain sitting. Future figures used in Computer Graphics will have variable percentile ratings and will contain a larger number of systems for greater accuracy and realism of body motion.

Top right and center: **Animated human figure designed, stored and drawn by the computer. This figure can be used to visually determine all types of reach situations, and is extremely useful in designs involving human factors.**



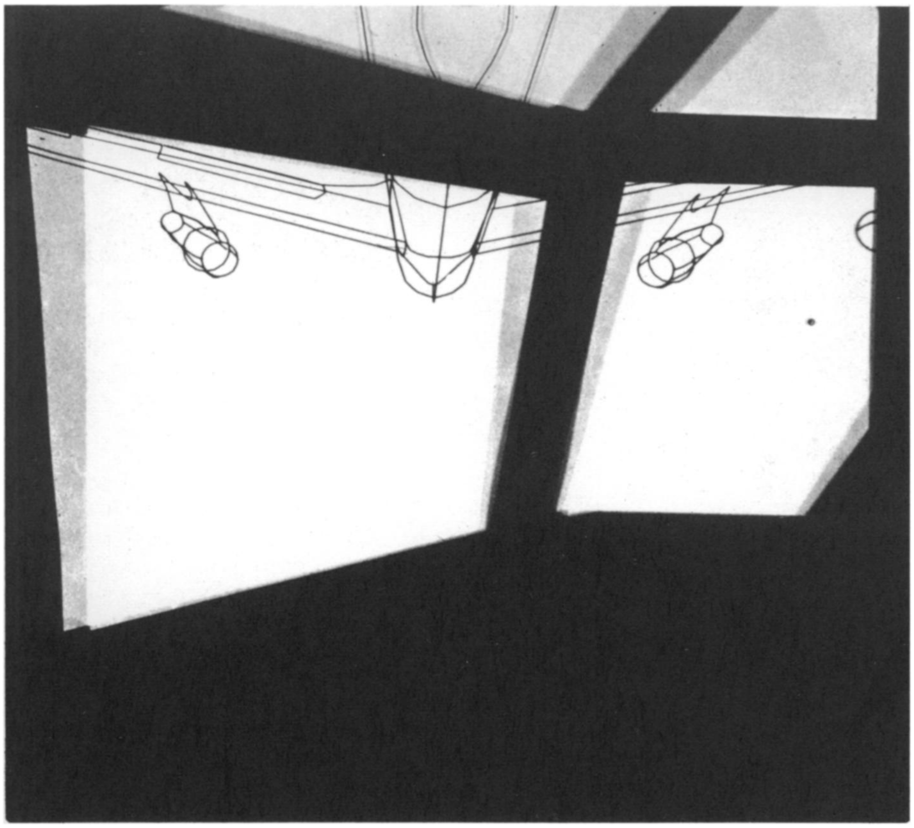
Animated human figure drawn by the computer and here shown in extreme reach situation.

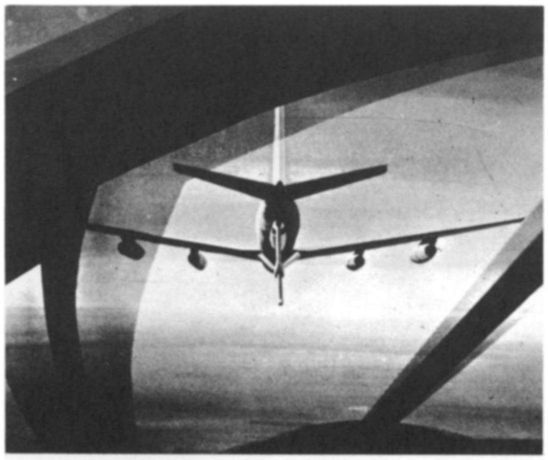
Some Computer Graphics drawings may be used by the design engineer right at his desk to evaluate the suitability of a cockpit design quite early in the design effort. By overlaying a carrier drawing with a transparent sheet indicating the cockpit, the designer is able to examine effects on visibility during carrier landings from different airplane approach altitudes. The same technique can be used to simulate what would be seen of an existing airplane during refueling operations. The precisely computed images of the complex movements of the airplane maneuvering into position to be refueled in the air can be illustrated to show realistically an approach to the tanker up to the view at refueling contact. This simulation can be used as a basis for comparing cockpit designs for an airplane still on the drawing board.

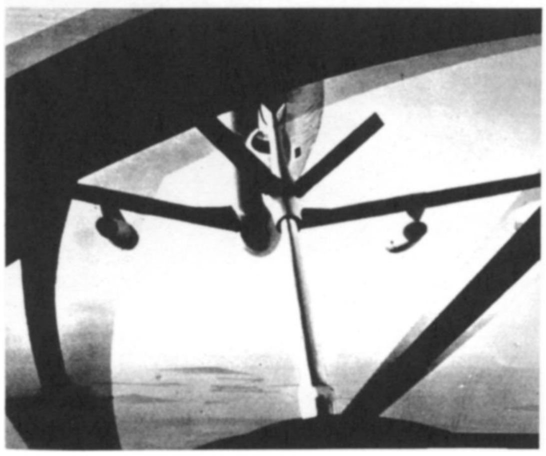
Computer Graphics is being applied to Supersonic Transport design especially in comparisons of preliminary nose configurations with those of existing aircraft. Renderings in color, based on plotter drawings and shown in quick succession, can be used to demonstrate cockpit designs which show the projected effect during a landing. Other Computer Graphics contributions to the Supersonic Transport program at Boeing involved production of a diorama for the evaluation of three different Supersonic Transport cabin and nose mockup configurations. A specific curvature of the diorama was calculated in order to be visually correct and the view from the mockup placed in the center was accurate for a precise location and altitude simulation in the final approach.

COCKPIT DISPLAY SYSTEMS

The complexity of instruments and devices necessary in today's aircraft cockpits is continually increasing. Design efforts in this area have to be directed toward presenting the information to the pilot in as understandable a form as possible. Because demonstration cockpit display designs are very costly and limited in effectiveness, Computer Graphics produced a film presentation in which a cockpit design was simulated in operation before the system itself was constructed. The system was designed to show the pilot desired views of part of the ground ahead of the airplane by means of a television screen in the cockpit. The television image was not a true perspective view but a carefully transformed image which made it possible to identify specific areas easily and inspect objects on the ground ahead at slow motion.

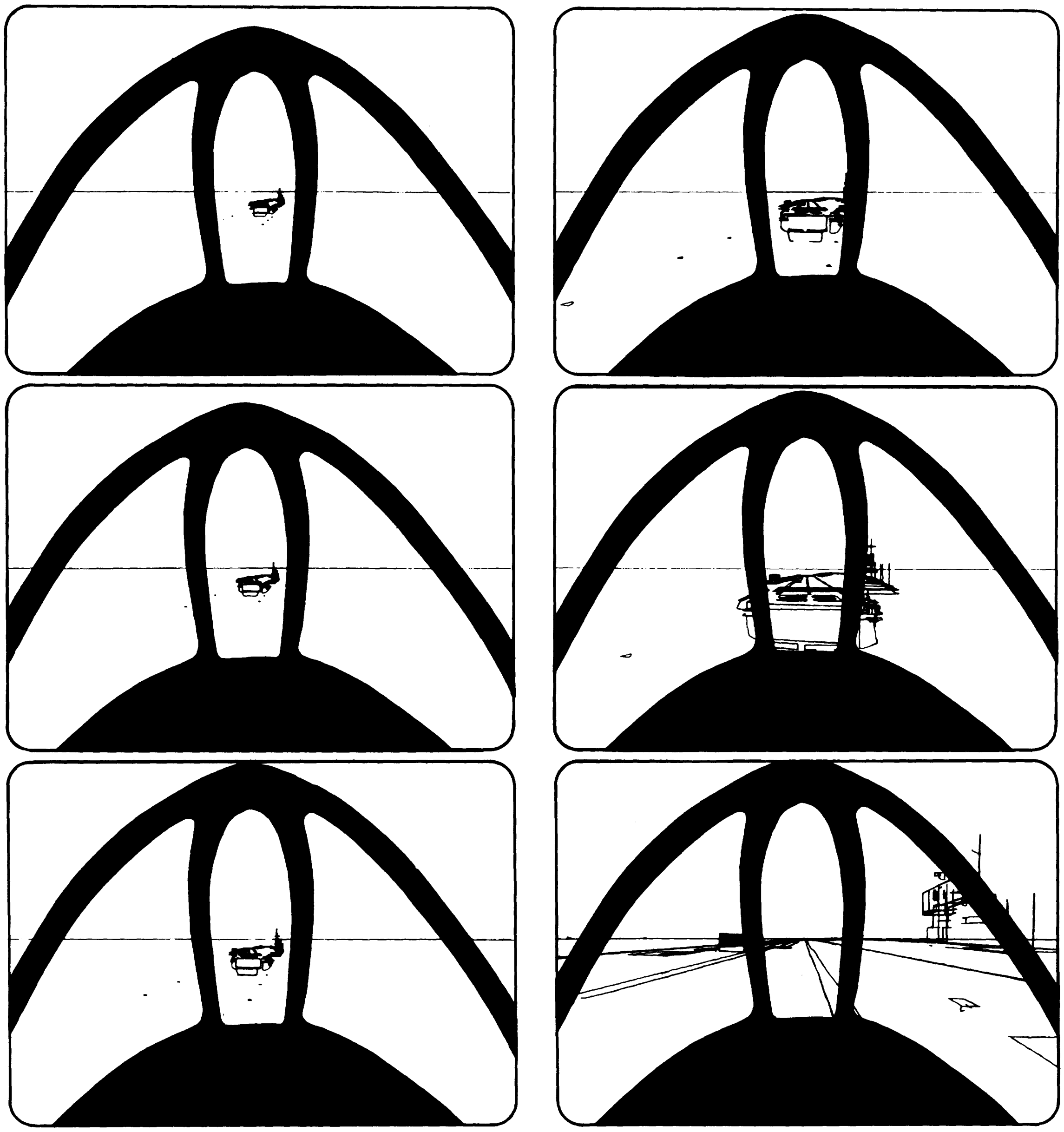






Top: Computer plot used as the basis for a rendering to demonstrate visibility in critical situation of mid-air refueling.

Top right and right: **Renderings based on computer plots used for a Computer Graphics film showing cockpit visibility of an airplane yet to be built.**



Frames of a Computer Graphics film on visibility studies during an aircraft carrier landing (black area is cockpit mask).

AIRCRAFT CARRIER LANDINGS

The difficult problem of testing the visibility of preliminary cockpit designs during a landing on a carrier can be best solved by producing a motion picture of the whole event. With Computer Graphics this film can be made before costly and time-consuming mockups are produced or actual landings are undertaken.

The landings can be demonstrated by computer plotting directly on standard animation cells and thus produce a motion picture that exactly simulates the pilot's view. The specific characteristics of the carrier had to be determined as well as airplane yaw, pitch and roll, speed and angle of descent. The basic animation, drawings at one second intervals, took everything into account, even the effects on the pilot's eye position after the compression of the shock absorbers when the airplane sets down.

Two hundred and forty computer drawn plots were needed to simulate the last ten seconds of a carrier landing. The animation drawings produced by Computer Graphics could then be turned over to the artist to add color and shading for an even more realistic motion picture.

Computer Graphics represents a new addition to the communication spectrum available to the designer. The almost unlimited capability of modern electronic data processing equipment, combined with the skill of a trained graphic designer, are the tools of this new communication medium. Effective, clear and pleasing visual solutions to engineering problems that have already been defined mathematically can be obtained through joint planning by engineers, graphic designers and computer programmers. Through thoughtful use of Computer Graphics, designers and engineers should have a more complete understanding of the problem at hand and should be able to produce designs more efficiently, economically and objectively.