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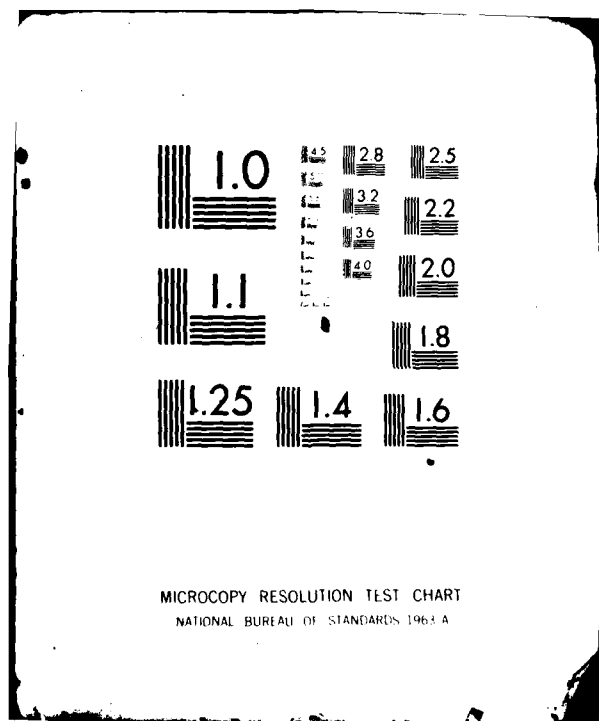
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Technical Report: NAVTRAEQUIPCEN IH-332
COMPUTER PROGRAM FOR ANALYSIS OF SPHERICAL SCREEN DISTORTIONS

Richard C. Hebb
ADVANCED SIMULATION CONCEPTS LABORATORY

March 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) In visual simulation, the distortion of imagery in wide-angle display systems is a major concern. Effective flight training requires that the imagery presented to a trainee provide a proper perspective view of his simulated environment without distortion. Use of spherical screens (domes) introduces perspective and geometrical distortion into these wide-angle displays. Use of video projection systems with Computer Image Generation (CIG) offers the options of raster shaping or computer remapping for distortion correction.		

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The method is to correct the imagery before projection in order to provide a "non-distorted" scene to a trainee. This report is documentation of a computer program for analysis of the required raster correction for specific projector/viewpoint positioning within a spherical screen. The programs and report were initiated to provide input to the F-18 simulator (Device 2E7) being developed by Hughes Aircraft.

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I. INTRODUCTION

Visual Flight Simulators

Visual Flight Simulators are used to enhance the training of pilots by adding visual cues to the simulated mechanical and physical aspects of a particular aircraft. The ultimate visual goal is to provide a realistic view of an environment about the simulated aircraft to increase training effectiveness.¹ Imagery is often provided by Computer Image Generation (CIG) and displayed via video projection systems. Typically the CIG system takes account of viewpoint and heading direction within a mathematically modeled landscape (database) to generate a view of this database during a simulated flight.² The imagery generated is in a video format, usually a 1023 line raster, and can be projected by light valves on the screen surface.³ Image content depends on the database model and may include a horizon line. A trainee's view of this imagery, in conjunction with the aircraft dynamics and structure, can induce many physical/psychological effects of actual flight depending on the attention paid to modeling the actual aircraft and database.⁴

Wide-Angle Visual Displays

The goal of realism in visual displays has led to the use of very wide angle displays filling a horizontal field of view (FOV) of 90° or more at the pilot's viewpoint.⁵ This has led to the use of spherical screens (domes) with a number of projectors filling parts of the FOV to form a wide-angle scene.⁶ Ideally, the exit pupils of the projectors, along with the viewpoint, should be located at the center of the spherical screen to eliminate distortions. However, due to the physical structure of the simulated aircraft and the size of the projection systems, the exit pupils cannot all be placed at the screen center. Also, the viewpoint and projector exit pupils cannot coincide. Necessarily, this forces the oblique projection of the imagery onto the dome resulting in distortion of the imagery.

Distortion

Distortion refers to the geometry of an image as compared to the geometry of the objects involved. Perhaps the best way to describe the concept of distortion as related to optical systems is to consider first the concept of a distortionless lens mapping. Figure 1 shows the mapping process for a well corrected F Tan θ lens as a rectangular object is mapped through the lens. The resulting image formed on the image plane is again a rectangular figure. The radial distance, R, to an image point on this image plane is determined by the tangent of the angle that an object point subtends from the optical axis of the lens system. Hence, the lens mapping equation, $R = F \tan \theta$, where F is the focal length of the lens. If the direction of the mapping process is reversed, we now have the case of the lens being used as a projection lens instead of use as a taking lens. For this case, any imagery placed on the image plane will be transferred to the object plane without distortion. This is the concept of a distortionless lens mapping.

Next, we should consider the concept of distortionless viewing of a projected image. If it were physically possible to place the eye of a viewer at the exit pupil of a F Tan θ lens as in Figure 2, then the viewer would perceive no distortion of the projected imagery. However, if the viewer's eye is removed from the exit pupil location, the shape of a rectangular figure would no longer appear rectangular. This removal of the eyepoint from the lens exit pupil results in a form of distortion known as Perspective Distortion, which usually results in rectangular objects exhibiting a keystone shape. The key to reducing Perspective Distortion is to place the exit pupil of the projector as close as possible to the viewer's eyepoint.

In a dome display system there exists another form of distortion. This form is labeled as Geometric Distortion, which involves the projection of imagery onto curved screen surfaces at oblique angles. The result is that the projection of straight lines onto the screen surface are viewed as being curved lines by the viewer. The amount of distortion produced depends on the size and shape of the screen, and projector/viewpoint positioning. As the viewpoint and/or the projector are displaced from each other, or removed from

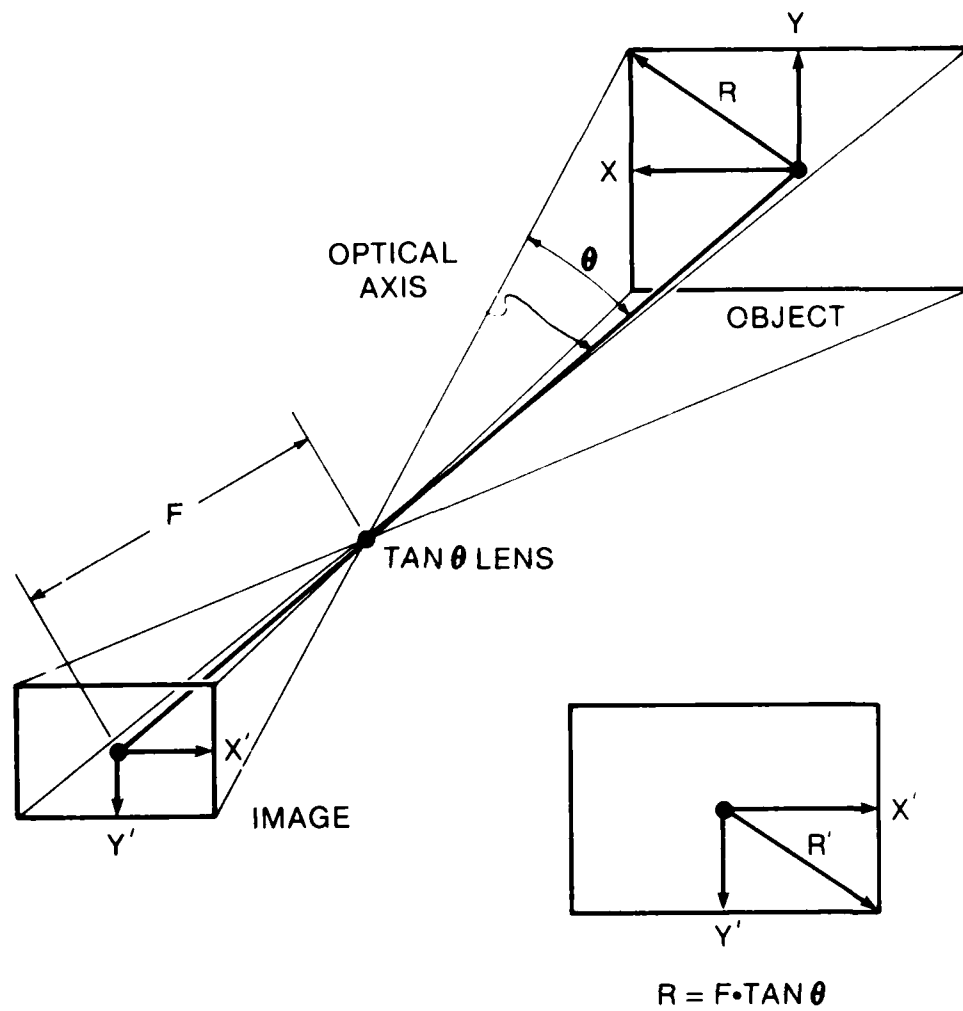


Figure 1. Mapping via Tangent Lens, Non-Distorted

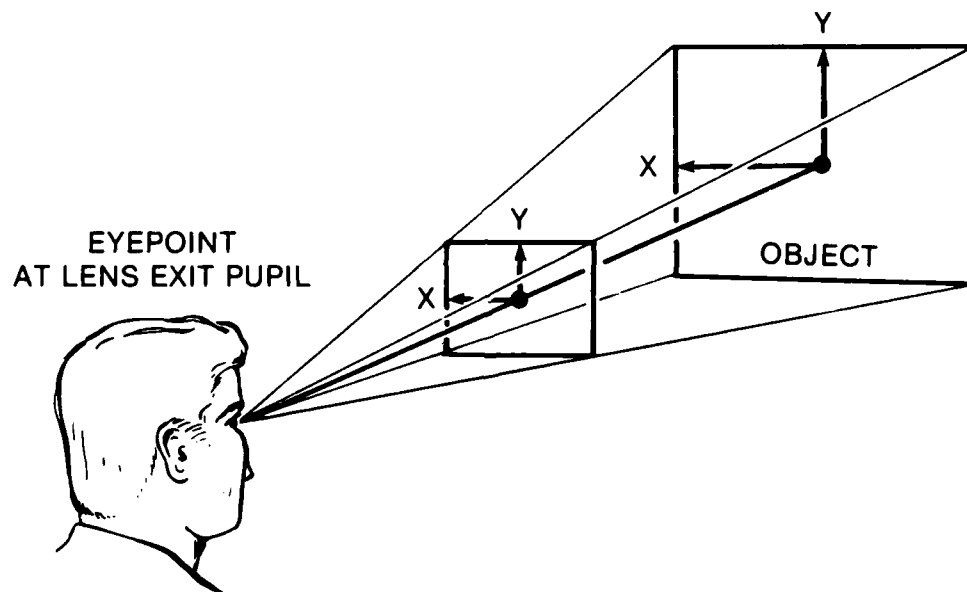


Figure 2. Distortionless viewing

the center of the screen, the apparent size and shape, as well as the angular subtense and position of objects will vary accordingly. It should be noted that if the viewpoint and lens exit pupil are coincident, then the shape of the screen cannot contribute to distortion⁷. It is the purpose of the computer program to be described to consider these two forms of distortion, Perspective and Geometric Distortion, in spherical screen displays.

Distortion definitions vary according to the type of projection system involved. The method of calculating distortion in this report is based on the Institute of Radio Engineers (IRE) Standards for Television.⁸ This method defines the Geometric Position Error (GPE) for any point on a flat display screen as the magnitude of the distance from the point to its ideal location. This implies a radial distance measurement from the ideal location of a point to its actual position. The percentage of distortion is then found by dividing the GPE by the full field height of the image.

The use of video projection systems offers the option of correcting distortions by altering the scanning geometry of the video imaging system (i.e., raster shaping). In this way, the image can be pre-distorted (as compared to a rectangular raster) before projection, according to specific projector/viewpoint relationships, in order to produce a non-distorted view.⁹ Alternately, the object points can be remapped in the CIG computation plane to provide the required object pre-distortion before being placed on the rectangular raster for projection. Raster shaping and remapping may be combined, if desired, to reduce the complexity of the individual corrections. These corrections must take into account the type of projection lens to be used and its inherent distortion, for the lens is an integral part of the system.

Lens Mappings

In the computer program that will be described there are four types of lens mappings considered for the projection lens. They are:

1. $F \tan \theta$ (distortionless lens),
2. $F \tan \theta$ with primary distortion,

3. $F \theta$,
4. $F \sin \theta$.

All these lens mappings imply a radially symmetric mapping, with the center of the mapping plane on the optical axis of the lens system. The $F \tan \theta$ lens provides a one-to-one mapping from object space to image space with a magnification constant included. The $F \tan \theta$ lens places an image point on the image plane according to the tangent of the angle between the optical axis and the object point. The $F \tan \theta$ with Primary Distortion is defined as a departure from $F \tan \theta$ due to an approximation of $\tan \theta$ by only two terms of a power series, the resulting equation is:

$$R_p = R_t (1 + (DFACTOR * R_t^2)),$$

where R_p is the radial distance for the primary distortion mapping, R_t is the radial distance for $\tan \theta$ mapping and DFACTOR is the primary distortion factor. An $F \theta$ lens maps object space to image space according to the angle in radians to an object point from the optical axis, while the $F \sin \theta$ implies a mapping according to the sine of the angle from the optical axis. Appendix B contains the derivation for the $F \tan \theta$ mappings and the conversion to the three other mappings mentioned above.

For the points on these mappings, the angle from the optical axis of the projection lens can be found by calculating the radial distance to the point in question and then converting the radial distance to an angle depending on the type of mapping.

Figure 3 shows the mapping process for a $F \tan \theta$ lens from the View Window on the dome, through the View Plane, and onto the Target Plane of the lens. The figure also depicts the viewpoint mapping of the View Window onto the Comparison Plane. This mapping produces a two-dimensional representation of the View Window as seen from the viewpoint.

The projection mappings produced by the program are mappings at the View Plane, which provide a perspective view of the object points on the dome from the projection point. A perspective view of the Target Plane from the

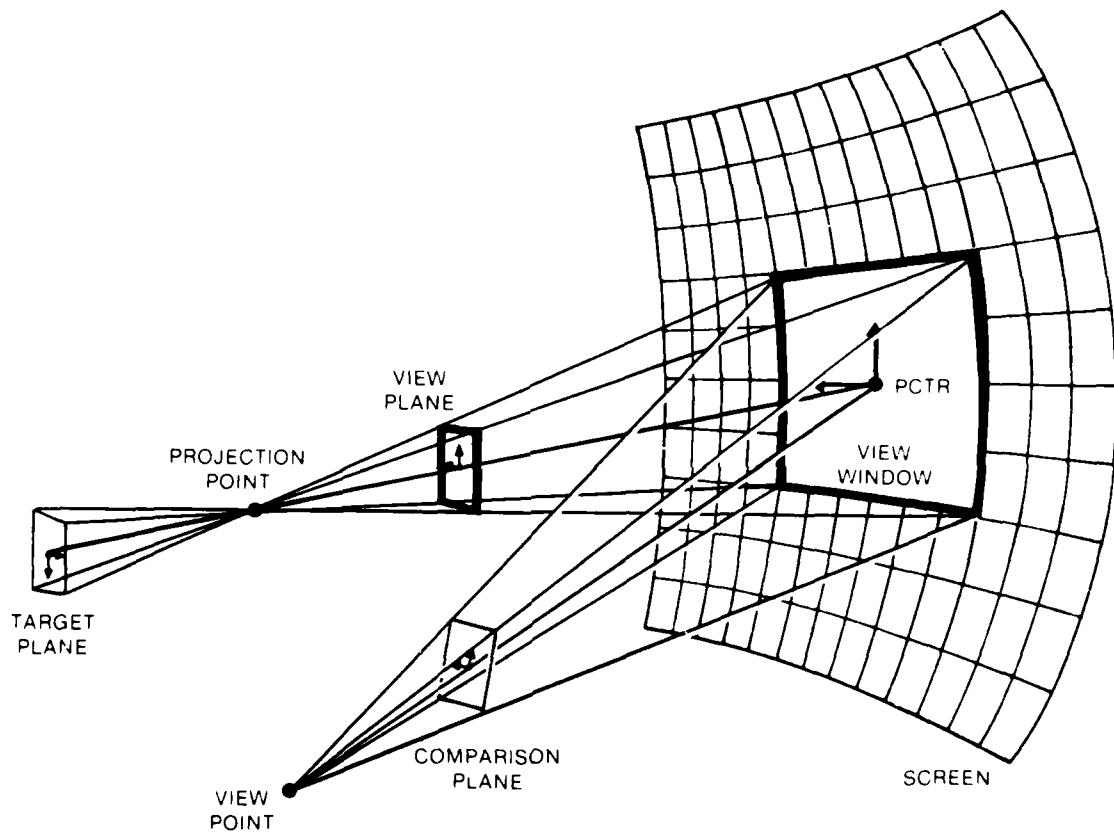


Figure 3. Projection/Viewing Diagram

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projection point (a view of the required raster pattern) is obtained by a rotation of the mapping about its center by 180° and observing the pattern through the reverse side of the mapping. In all mappings, the value of F is considered to be unity, allowing mappings for a lens of focal length f^1 to be represented by multiplying the mapping point coordinates by f^1 .

The Comparison Plane is a perspective view of the View Window from the viewpoint and contains the image of the non-distorted reference raster which has been placed on the View Window. Use of the Comparison Plane coordinates requires the scaling of the coordinates to reduce the Comparison Plane's height to the height of the View Plane. The scaling factor is defined as the ratio of the View Plane height to the Comparison Plane height. For purposes of distortion calculations in the program to follow, the GPE is found by effectively overlaying the View Plane on the Comparison Plane via coordinate tables for the planes. The distance from a point on the Comparison Plane (X_C , Y_C) to a point on the View Plane (X , Y) is found via the equation:

$$D = [(X - X_C)^2 + (Y - Y_C)^2]^{1/2}.$$

II. THE PROGRAM - MAPTAG

Introduction

MAPTAG is an acronym for Mapping Table and Graph, a program written in FORTRAN for distortion analysis. The facilities for operation of the program are part of the NAVTRAEQUIPCEN Computer Systems Laboratory. The computer system is a VAX-11/780 with graphics provided on a Tektronix graphic terminal, Model 4014-11. The program is designed to find the required distorted raster shape for projection onto a dome from a particular projection point. This projected raster is to be viewed at a viewpoint as a non-distorted raster. The location of the viewpoint and projector can be located inside or outside the dome of radius R . The raster to be viewed is created as an Input Plane with variable height and width, as required, to fill a desired vertical and horizontal angular field relative to the viewpoint. This Input Plane is subsequently mapped on the surface of the dome to provide the View Window.

In order to describe the projection/viewing system, the location of the projector, viewpoint, and image points are referenced to a 3-D coordinate system located at the center of the dome (Figure 4). In this system, the Z-axis is positive upwards, the X-axis is positive forward, and the Y-axis is positive to the left. Additionally, the angles for projection and viewing are spherical angles referenced to the positive X-axis. Vertical angles are positive above the dome horizon and negative below the horizon with a maximum magnitude of 90° . Horizontal angles are positive for a counter-clockwise rotation (positive X-axis into the positive Y-axis) when viewed from a point on the positive Z-axis. The horizontal angles have a maximum magnitude of 180° . There are three other coordinate systems involved in the program. These are two 3-D coordinate systems, located at the viewpoint and projection point, and a 2-D coordinate system used to describe the raster plane defined as the Input Plane. This plane is used to provide a non-distorted raster pattern for comparison purposes.

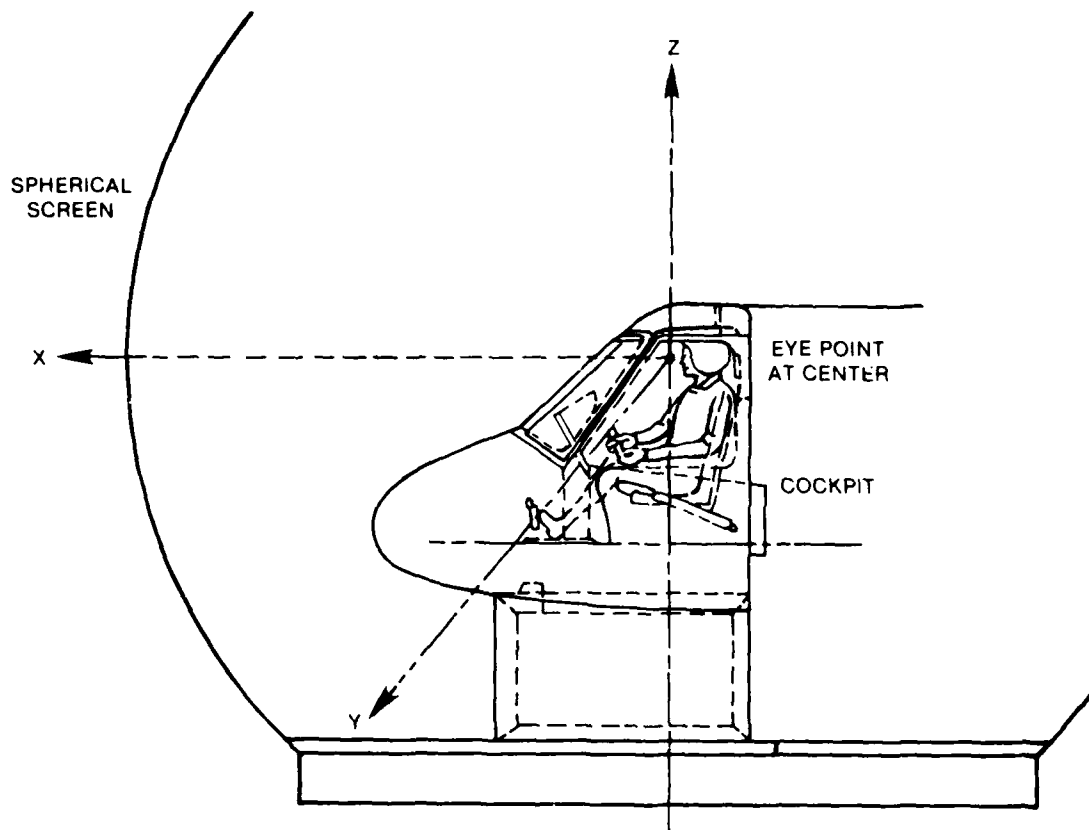


Figure 4. 3-D Coordinate System For Spherical Screen

View Window

The View Window is defined as that part of the available FOV that is being filled by one projector. Ideally, the viewer will see objects projected onto this window as non-distorted. If a crosshatch pattern is the projected object, then the viewer will want to see the crosshatch pattern with equal spacing between the horizontal and vertical lines on the view window. This is the Input Plane and is constructed by considering the desired angular height and width as well as the position of the center of the view window (PCTR) relative to the viewpoint. These values are used to find the height and width of the crosshatch pattern in dimensional units that are fixed with respect to dimensional units used for all 3-D locations.

The Input Plane has a 2-D coordinate system with its origin set at the center of the plane (Figure 5). In this coordinate system the Y-axis is positive upward and the X-axis is positive to the left. Once the height and width of the Input Plane are known, then the first point on the plane is found by dividing the height and width in half. This first point is defined as the top left point on the plane. Subsequent points on the plane are found by considering the number of horizontal lines (NHORIZ) and the number of vertical lines (NVERT) on the plane. The width of the plane is divided by (NHORIZ-1) to find the linear increments along the lines (HINCREMENT), while the height is divided by (NVERT-1) to find the linear increments between lines (VINCREMENT). To find the next point along a line on the plane, the HINCREMENT is subtracted from the previous points' X-coordinate with the Y-coordinate remaining the same. At the end of a line, the VINCREMENT is subtracted from the previous points' Y-coordinate, and the X-coordinate is reset to the X-coordinate of the first point. In this way, lines are drawn from left to right and top to bottom on the Input Plane.

After a point on the Input Plane is found, the Input Plane is aligned to be normal to the viewers' Line of Sight (LOS) and translated to the desired View Window center (Figure 6). This operation is performed by the subroutine TROPLN (see Appendices). At this point, the View Window is projected onto the surface of the spherical screen but still appears to be a flat non-distorted raster from the viewpoint.

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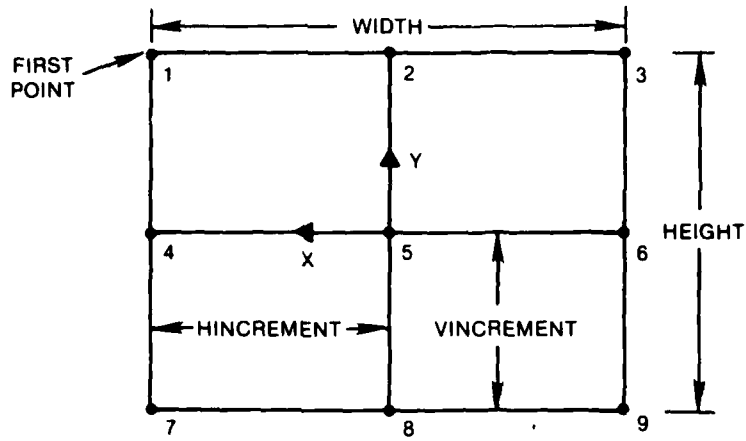


Figure 5. 3x3 Input Plane

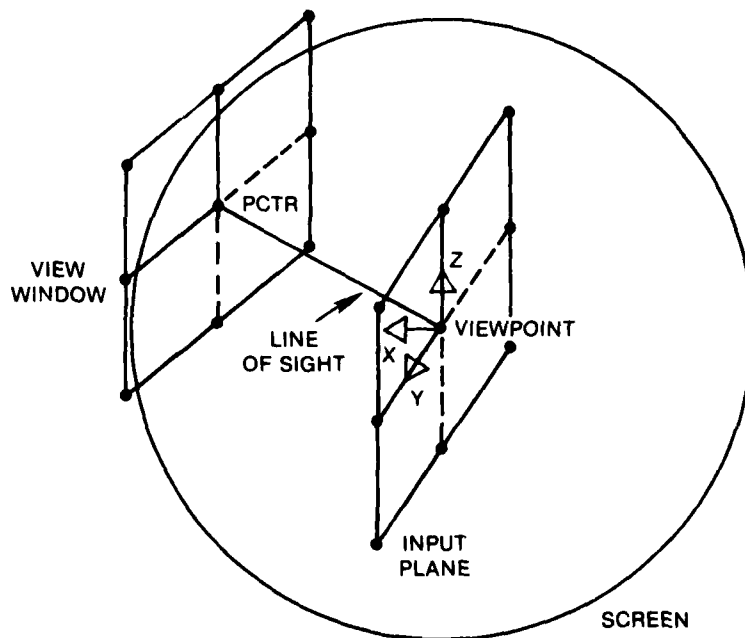


Figure 6. View Window Generation

Spherical Screen Projection

To find the intersection of a ray projected from the viewpoint towards the spherical screen, the subroutine SPTFAN "Sphere Point from Angles" is used. This subroutine uses spherical angles of projection to define the direction of individual rays at the viewpoint. This distance from the viewpoint to the screen is calculated and used to find the terminus of the ray in 3-D coordinates.

The angles to points on the View Window plane from the viewpoint are found by subroutine SANGFPT "Spherical Angles from Points" and then are input to SPTFANG. The View Window is then mapped onto the screen surface and we are now ready to find a perspective view of the View Window from the projection point.

Perspective View

Another subroutine, PSPECTIVE, is used to find the perspective view of the View Window from the projection point. Initially, the subroutine translates the origin of the 3-D coordinates for the View Window to the projection point. Then, the View Window is rotated about the projector to align the center of the View Window (PCTR) with the projector's X-axis. Having accomplished these operations, the tangents to points on the View Window can be found relative to PCTR.

PSPECTIVE allows this tangent mapping to be altered by a remapping through one of the three other lens mappings listed previously. Only the tangent mappings will give a correct perspective from the projection point, with the three additional mapping choices distorting the view according to their mapping functions. These mapping coordinates are sent to plotting programs which draw the View Plane on a graphic terminal with hard-copy available.

Reference circles, indicating total Fields-of-View (FOV) of 90° and 110°, are included on the output mappings. These FOV are generated by subroutine FOV and are dependent on the type of lens mapping specified. These reference

circles can be used to determine the location of object points relative to the optical axis of the lens. Points that lie on a circle are defined as being located at the half-angle of the total FOV. For example, if a point is on the 90° FOV circle, then the angle between the optical axis and the ray to that point is 45°. Points outside the FOV reference circle are at greater angles, while points inside the FOV reference angles are at an angle less than the FOV half-angle. The FOV reference circles give an excellent way to approximate the total FOV required for a particular projection arrangement.

Mapping Tables

The coordinates for the View Plane output mapping can also be placed in table form. Each table contains specific information on the projection/viewing system and the type of mapping used. The coordinates are printed in the table according to their relative position on the view plane. Also placed in the table output are the coordinates of the Comparison Plane, allowing distortion calculations to be made from the table. If table output is desired, only 12 horizontal points should be requested on the crosshatch pattern. This limit is due to the fixed width of the printer paper and the width of numerals for each coordinate value in the table.

Subroutine TBLDIST uses the coordinates sent to the mapping tables to calculate distortion percentages for nine points in the field. These nine points, assuming an odd number of points on the plane, are the four corner points, the central point, and the four points at the midpoint of each edge of the plane. The percentages found are included on the mapping table output.

III PROGRAM OPERATION

Running the Program

In order to operate the program, variables describing the projection/viewing system must be entered. Upon instructing the computer to execute the program (RUN MAPTAG), the user is prompted to enter the necessary values. Definition of the view window starts with the location of the center of the view window (PCTR). This location is in 3-D coordinates relative to the screen center and must be on the screen surface. Next, the height and width in degrees and the number of points across and down the window are entered. The maximum height or width of the window is less than 180° due to the method of creating the input plane. Additionally, the number of points should be odd for use in the distortion calculation subroutine.

Describing the rest of the system requires entering the radius of the screen (R), the projector location EX(FX, FY, FZ), and the viewpoint, EN(XE, YE, ZE). The units for these coordinates are arbitrary, but must be the same for all 3-D coordinates. As an option, the projector axis can be offset from PCTR during operation of the program by entering degree offsets other than zero for VCFFP and HOFFP.

The rest of the values to be entered are concerned with the type of output mapping and table. The type of lens mapping is chosen by entering a value from 1 to 4 corresponding to the four lens mappings available. If a Tan θ mapping with a primary distortion is desired, then the user is prompted to enter a distortion factor (DFACTOR). Additionally, for initialization of the graphics terminal screen, the user is instructed to enter a graphic scaling factor (FSCALE), screen magnification factor (SMAG), and offsetting values for the origin of the screen (XBIAS, YBIAS) in inches. Finally, the user can decide if table output is wanted during the present run of the program.

After the program has completed the graphics, the user is instructed to enter "C" to continue execution. The user is then offered the option of changing the projection axis offset, graphic scaling, graphic screen magnification, and table output option. If a change is desired, the program again prompts

the user to enter values and the graphic screen is cleared in order to draw a new perspective view according to the new values. If no changes are desired, the program will clear the graphic screen and execution is stopped.

Sample Projection Systems

As examples, the results of two sample projection/viewer systems are included in the Appendices. The first sample is a simple projector/viewer arrangement where the viewer is placed at the center of a 20-foot radius dome and the projector is located at the 3-D location (0.0, 0.0, 12.0) inches. This results in a 12-inch displacement of the projector directly above the viewer. In this case, the projected View Window subtends angles of 70° vertical by 90° horizontal from the viewpoint. On this View Window, there is an 11 by 11 raster pattern which forms one hundred rectangular blocks as depicted on Figure A-1. The window is centered on the surface of the dome at the 3-D location (240.0, 0.0, 0.0) inches, or at the intersection of the X-axis with the dome surface. Table A-1 shows the program prompts and user inputs to describe the above system. Figures A-2, A-3, and A-4 show the required raster shapes to be projected from the defined projector location for the use of projection lenses with mapping functions of $\tan \theta$, $\sin \theta$, and θ , respectively.

The second projection/viewer arrangement is a projector arrangement with the View Window and projector located on opposing sides of the dome surface. In this system, the viewpoint is again coincident with the center of a 20-foot radius dome. However, the projector is located behind the viewer on the surface of the dome at the 3-D location (-218.0, 0.0, 101.0) inches, and the View Window is placed at the 3-D location (218.0, 0.0, -101.0) inches. This arrangement directs the optical axis of the projector to pass through the center of the dome on its way to the center of the View Window, and provides for a symmetrical projection onto the window at a distance of twice the dome radius, or 40 feet. The View Window contains an 11 by 11 raster pattern and subtends angles of 160° by 160° from the viewpoint as shown in Figure A-5. Figures A-6, A-7, and A-8, with Tables A-6, A-7, and A-8, describe the required raster shapes for Example 2. Table A-5 shows the necessary inputs to describe this second system.

Analysis of the Sample Systems

Analysis of the required raster shapes for a projection system involves looking at the graphic mapping outputs and their corresponding table outputs. From these a visualization of the raster shapes is obtained, along with the distortion percentages related to each mapping.

Examining the coordinate tables A-2, A-3, and A-4, which are for the first example, specific information for each type of lens in this projection arrangement is revealed. The tables are labeled as to the type of lens mapping function considered along with identification of the projector, viewer, and View Window locations. The tables contain the coordinates of the intersection points for the distorted raster shape and the coordinates of the non-distorted Comparison Plane. Notice that the coordinates are preceded by the labels (X, Y) and (XC, YC) which denote the coordinates of the view plane and Comparison Plane, in turn. These coordinates are included in the tables in the same manner that the raster lines are drawn on the View Window; that is, left to right and top to bottom. The tables provide only the coordinates of the points used in the distortion calculation routine, and not all the points of the 11 by 11 pattern. The coordinates of all the points are available, but are not included here due to the size of the tables.

The first output mapping for Example 1, Figure A-1, is a tangent mapping of the View Window, or equivalently, the Comparison Plane. This is the raster shape that the viewer should see for the condition of no distortion. The tangent mapping for this projection system, Figure A-2, shows a maximum distortion of 2.6 percent, with symmetrical distortion about the center vertical line of the raster pattern. All the distortion percentages for this mapping are low and reflect the close proximity to the viewpoint of a projector with a $F \tan \theta$ mapping function. Looking at the $F \theta$ and $F \sin \theta$ outputs, the maximum distortion percentages jump to 15.7 percent and 20.3 percent. These percentages are large and reflect the departure of the individual lens mapping functions from a distortionless, or $F \tan \theta$, lens. In this system, a lens with a $F \tan \theta$ mapping would be preferred due to the closeness of the projector and viewer, and the less than 90° projection angles required.

The second example is offered as an extreme case compared to the preceding case. The separation of the projector and viewer is increased to 20 feet and the View Window is required to fill a field of view of 160° by 160° at the viewpoint. Examining the mappings and tables for this second system, it can be seen that the distorted raster shapes for all the mapping functions fall within the 90° reference circle. In fact, the maximum projection angle for any of the lenses is approximately 80° . This angle is appropriate considering the View Window to fill a 160° by 160° field of view at the viewpoint with projection from a distance of twice the dome radius. A projection lens with a total field of view of 90° would provide more than enough of the projection field required to fill the View Window.

The distortion percentages for all three lens types are quite large and are approximately equal. Examining Tables A-6, A-7, and A-8, the maximum distortion required for the F ϕ mapping is slightly greater than the tangent mapping (18.09 percent vs. 18.90 percent), while the F Sin ϕ mapping requires the most raster shaping at 19.22 percent. These raster shapes may be hard to implement by raster shaping alone as can be seen in Figures A-6, A-7, and A-8.

Other information to be gained from the program output concerns the re-distribution of the raster points on the projection lens target plane. In the second system, the points are crowded together near the edges of the target plane with only a few points in the center of the target plane. The effect of this distribution depends on the projection lens in use, but would tend to reduce the resolution capacity of the imaging system. This is due to the crowding of resolution elements (RESELS) on the target plane where most lenses lose resolution capability, and lack of RESELS where most lenses have their greatest resolution.

IV SUMMARY

The program MAPTAG is a very useful tool for determining the required raster shape to be projected which provides for distortionless viewing. The graphic output provides visualization of distortions encountered in spherical screen projections. The table output allows distortion calculations to be performed and can also provide for equations that describe the raster distortion, line by line. The subroutines used by MAPTAG have been written in general form to allow their use in building other specific distortion routines.

Extension of the program to provide more information about projection systems is possible and is being investigated. These programs provide an excellent basis for distortion analysis of video projection systems and efforts are being taken to include projection of generalized imagery. Additionally, the type of screen surface used in the program is being expanded to include cylindrical screens.

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- 1 WOOD, M., "The Fidelity Issue in Visual Simulation", Proceedings of 1977 Image Conference, Williams AFB, pp. 291-295, May 1977

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NAVTRAEQUIPCEN IH-332

APPENDICES

NAVTRAEQUIPCEN IH-332

EXAMPLE 1

RUN MAPTAG

DESCRIBE PLANAR INPUT SCREEN

ENTER DESIRED COORDINATES FOR PLACEMENT OF CENTER OF PLANE IN SPHERE
COORDINATE SYSTEM, THE X-AXIS IS POSITIVE FORWARD WITH THE Y-AXIS POSITIVE
TO THE LEFT, AND THE Z-AXIS IS POSITIVE UPWARDS

240,0,0

ENTER VERTICAL AND HORIZONTAL FOV'S IN DEGREES

70,90

ENTER NUMBER OF POINTS ALONG VERTICAL AND HORIZONTAL AXES

11,11

DESCRIBE SPHERICAL SCREEN DISPLAY SYSTEM

ENTER SPHERICAL SCREEN RADIUS

240

ENTER PROJECTOR POSITION (FX,FY,FZ)

0,0,12

ENTER VIEWPOINT POSITION (XE,YE,ZE)

0,0,0

ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)

0,0

ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS

NORMALLY SCREEN MAG = 1. ,XBIAS = 0.,YBIAS = 0,

THE SCALE FACTOR DETERMINES THE TFOV (FSCALE * 90)

1,5,1.1,0.0

PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" ,
FOR AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH
PRIMARY DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"

1

IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE

T

TYPE C TO CONTINUE EXECUTION

1

\$ C

TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
ENTER "F"

F

TO CHANGE SCREEN MAGNIFICATION,ENTER T ,TO STOP ENTER F

F

FORTTRAN STOP

\$

TABLE A-1

COMPARISON PLANE
70° V × 90° H

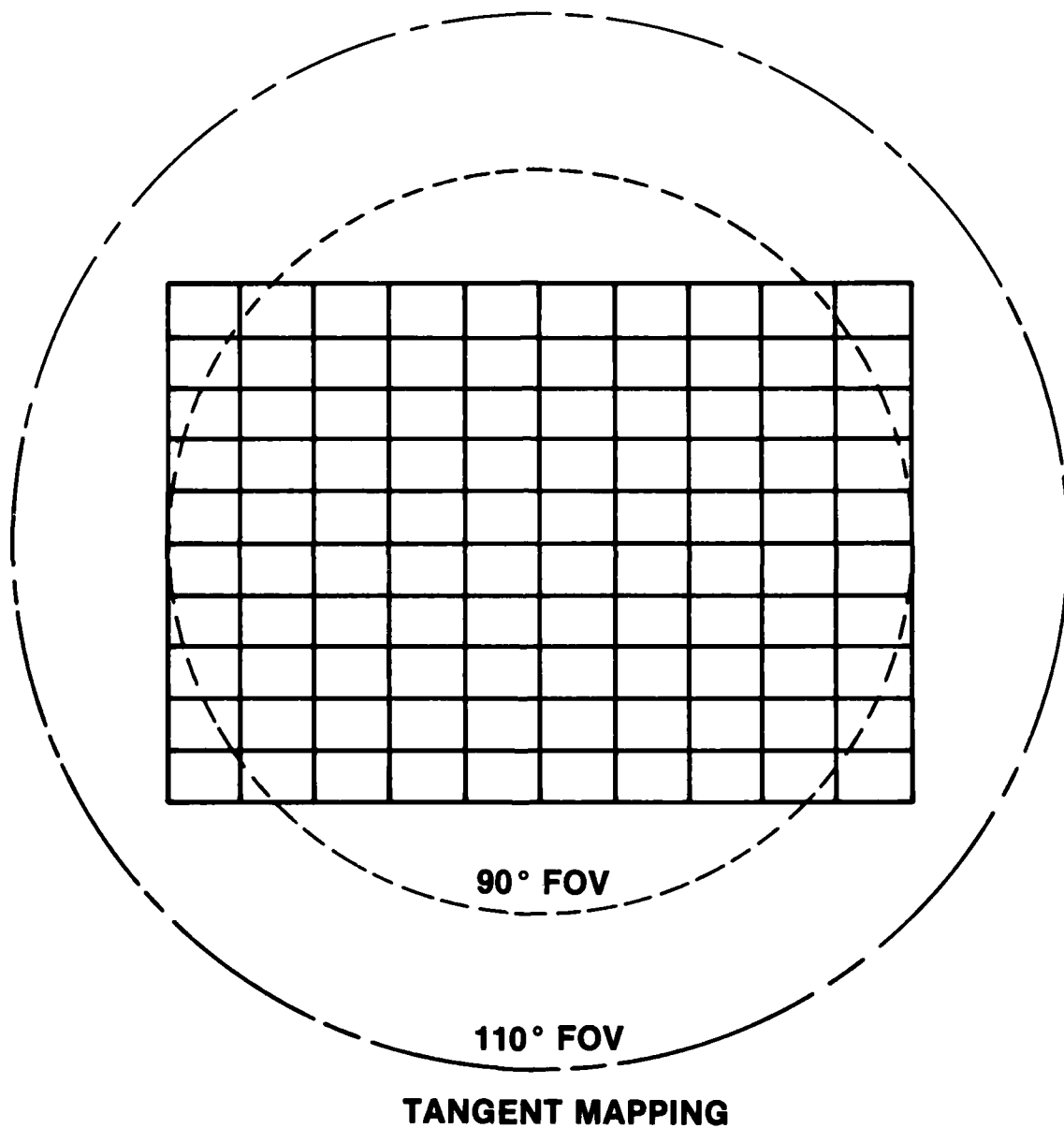


Figure A1. Tangent mapping.

NAVTRAEQUIPCEN IH-332

TAN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :
 X = 0.000 Y = 0.000 Z = 0.000
 OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF
 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A
 POINT X= 240.000 Y = 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT:
 X = 0.0000 Y = 0.000 Z = 12.000
 THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000 FROM THE
 DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	1.033	0.000	-1.033
Y	0.693	0.712	0.693

XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700

X	0.998	0.000	-0.998
Y	-0.021	0.000	-0.021

XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000

X	0.964	0.000	0.964
Y	-0.702	-0.685	-0.702

XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.397

1	2	3
2.59%	0.96%	2.59%
4	5	6
1.48%	0.00%	1.48%
7	8	9
2.44%	0.96%	2.44%

TABLE A-2

VIEW WINDOW
70° V × 90° H

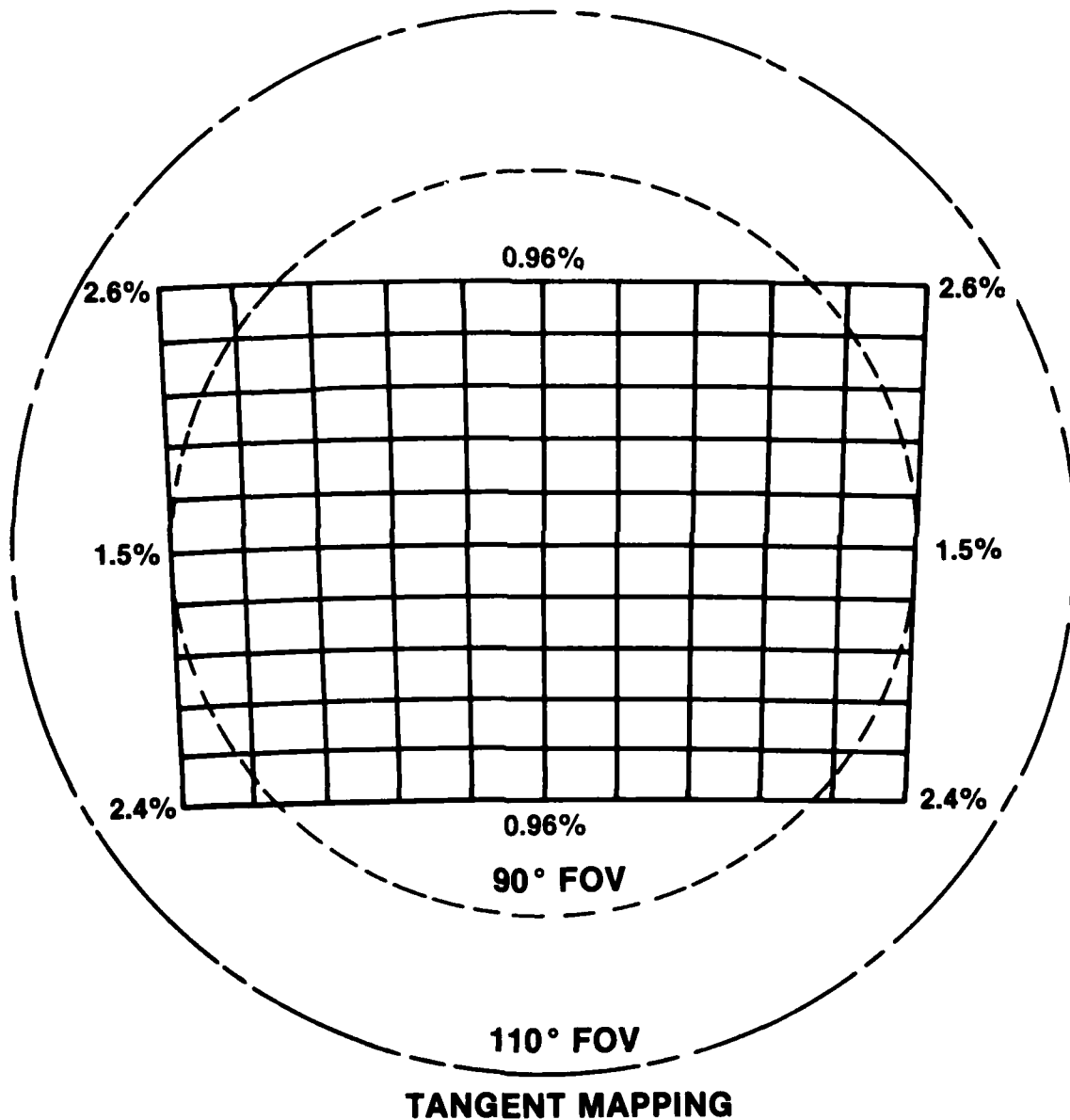


Figure A2. Tangent mapping.

NAVTRAEQUIPCEN IH-332

R-THETA MAPPING COORDINATES

THE VIEWPOINT IS AS :

X = 0.0000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF
70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A
POINT X= 240.000 Y= 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :

X = 0.0000 Y = 0.000 Z = 12.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 R = 0.000 FROM
THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.742	0.000	-0.742
Y	0.498	0.619	0.498

XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700

X	0.784	0.000	-0.784
Y	-0.016	0.000	-0.016

XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000

X	0.706	0.000	-0.706
Y	-0.514	-0.601	-0.514

XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.219

1	2	3
13.97%	0.74%	13.97%
4	5	6
7.22%	0.00%	7.22%
7	8	9
15.66%	0.74%	15.66%

TABLE A-3

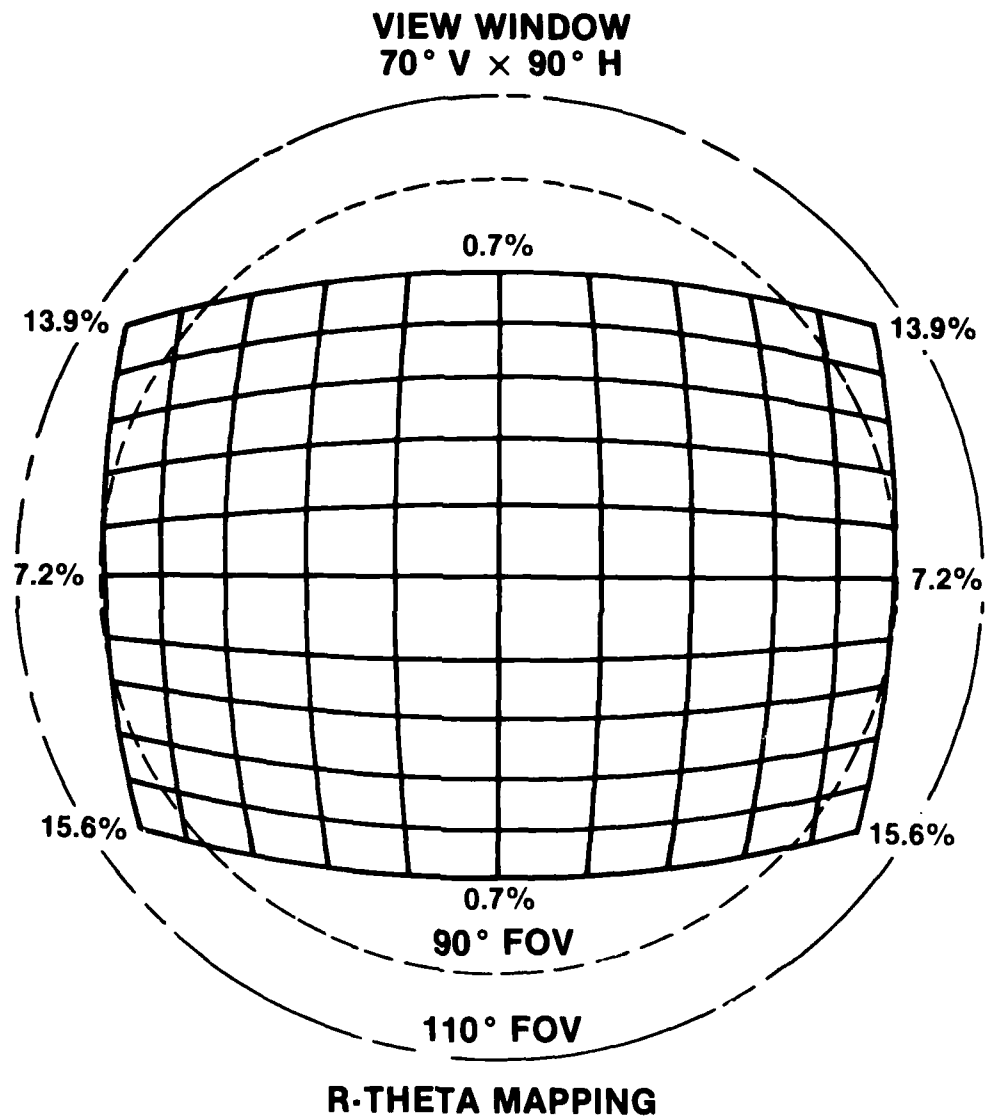


Figure A-3. R-Theta Mapping.

NAVTRAEQUIPCEN IH-332

SIN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :

X = 0.0000 Y = 0.000 Z = 0.000

OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN FILLING A FIELD OF 70.000 DEGREES VERTICALLY, AND 90.000 DEGREES HORIZONTALLY ABOUT A POINT X= 240.000 Y= 0.000 Z= 0.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :

X = 0.0000 Y = 0.000 Z = 12.000

THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000 FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.647	0.000	-0.647
Y	0.434	0.580	0.434

XC	1.000	0.000	-1.000
YC	0.700	0.700	0.700

X	0.706	0.000	-0.706
Y	-0.015	0.000	-0.015

XC	1.000	0.000	-1.000
YC	0.000	0.000	0.000

X	0.619	0.000	-0.619
Y	-0.451	-0.565	-0.451

XC	1.000	0.000	-1.000
YC	-0.700	-0.700	-0.700

DISTORTION PERCENTAGES

THE TARGET PLANE HEIGHT IS 1.145

1	2	3
19.17%	0.64%	19.17%

4	5	6
9.82%	0.00%	9.82%

7	8	9
20.32%	0.64%	20.32%

TABLE A-4

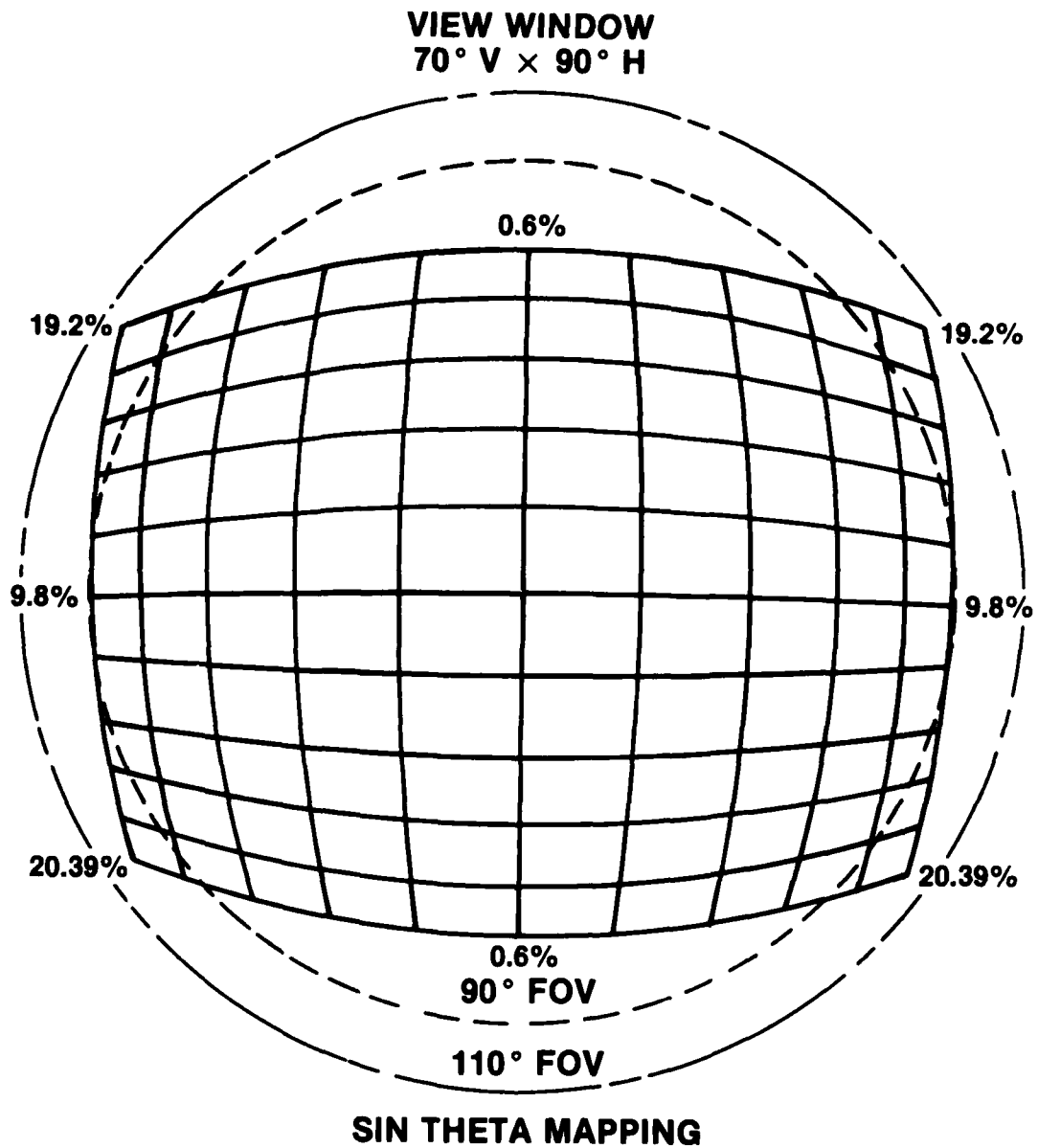


Figure A-4. Sin Theta Mapping.

EXAMPLE 2

SAMPLE RUN OF MAPTAG

```

RUN MAPTAG
DESCRIBE PLANAR INPUT SCREEN

ENTER DESIRED COORDINATES FOR PLACEMENT OF CENTER OF PLANE IN SPHERE
COORDINATE SYSTEM .THE X-AXIS IS POSITIVE FORWARD WITH THE Y-AXIS POSITIVE
TO THE LEFT, AND THE Z-AXIS IS POSITIVE UPWARDS

276,0,-101

ENTER VERICAL AND HORIZONTAL FOV'S IN DEGREES

160,160

ENTER NUMBER OF POINTS ALONG VERTICAL AND HORIZONTAL AXES

11,11

DESCRIBE SPHERICAL SCREEN DISPLAY SYSTEM

ENTER SPHERICAL SCREEN RADIUS

240
ENTER PROJECTOR POSITION (FX,FY,FZ)

-276,0,101
ENTER VIEWPOINT POSITION (XE,YE,ZE)

0,0,0
ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)

0,0
ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS  NORMALLY SCPEEN MAG = 1.
,XBIAS = 0. ,YBIAS = 0.  THE SCALE FACTOR DETERMINES THE TFOV (FSCALE
* 90)
1.5,1,0,0
PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" , FOR
AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH PRIMARY
DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"

1
IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE

T
TYPE C TO CONTINUE EXECUTION

1
$
C
TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
ENTER "F"

T
ENTER VERTICAL AND HORIZONTAL OFFSET FOR PROJECTION DIRECTION (DEGREES)

0,0
ENTER SCALE FACTOR , SCREEN MAG , YBIAS, XBIAS
NORMALLY SCREEN MAG = 1. ,XBIAS = 0.,YBIAS = 0.  THE SCALE FACTOR
DETERMINES THE TFOV (FSCALE * 90)
1.5,1,0,0
PICK WHICH TYPE OF MAPPING DESIRED, FOR A TANGENT MAPPING ENTER "1" ,
FOR AN IDEAL R-THETA MAPPING ENTER "2" , FOR TANTHETA MAPPING WITH
PRIMARY DISTORTION , ENTER "3" ,FOR SIN THETA MAPPING, ENTER "4"

2
IF TABLE OUTPUT IS DESIRED TYPE TRUE ; IF NOT FALSE

F
NO OUTPUT FOR TABLE
TYPE C TO CONTINUE EXECUTION

1
$
C
TO CHANGE VOFF,HOFF,MAG,FSCALE,LTABLE,TYPE OF MAPPING ENTER "T" , IF NOT
ENTER "F"

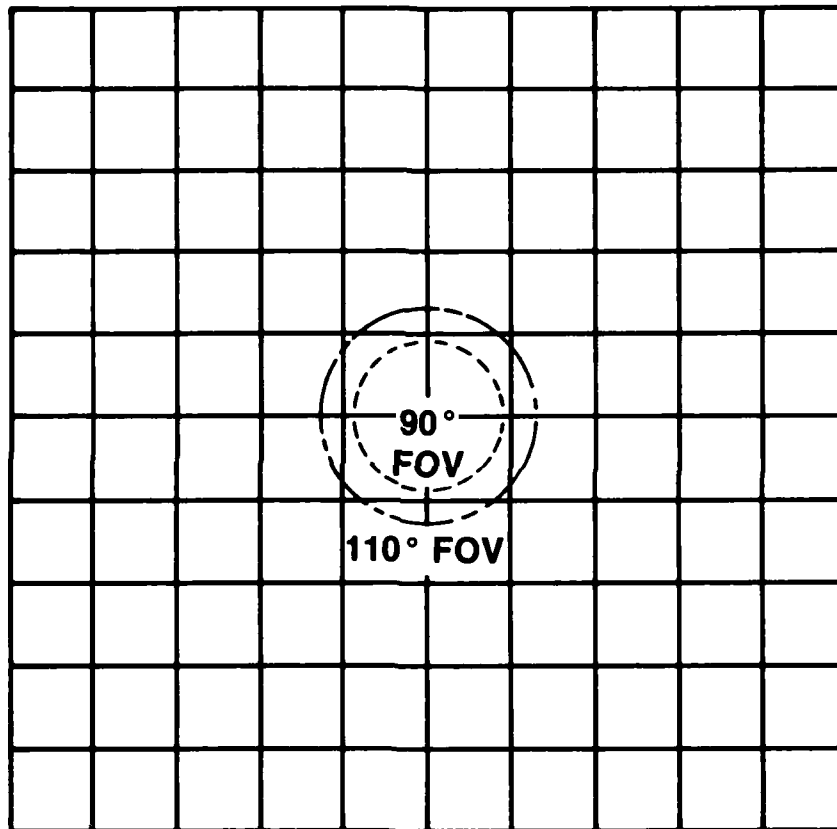
F
TO CHANGE SCREEN MAGNIFICATION,ENTER T ,TO STOP ENTER F

F
FORTRAN STOP
$

```

TABLE A-5

**COMPARISON PLANE
VIEW WINDOW
160° × 160°**



TANGENT MAPPING

Figure A-5. Tangent mapping (Example 2).

TAN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :

X = 0.000 Y = 0.000 Z = 0.000

OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160.000 DEGREES HORIZONTALLY

ABOUT A POINT X= 218.000 Y= 0.000

Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :

X = -218.0000 Y = 0.000 Z = 101.000

THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.624	0.000	-0.624
Y	0.624	0.838	0.624

XC	5.671	0.000	-5.671
YC	5.671	5.671	5.671

X	0.838	0.000	-0.838
Y	0.000	0.000	0.000

XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000

X	0.624	0.000	-0.624
Y	-0.624	-0.838	-0.624

XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
18.09%	0.00%	18.09%
4	5	6
0.00%	0.00%	0.00%
7	8	9
18.09%	0.00%	18.09%

TABLE A-6

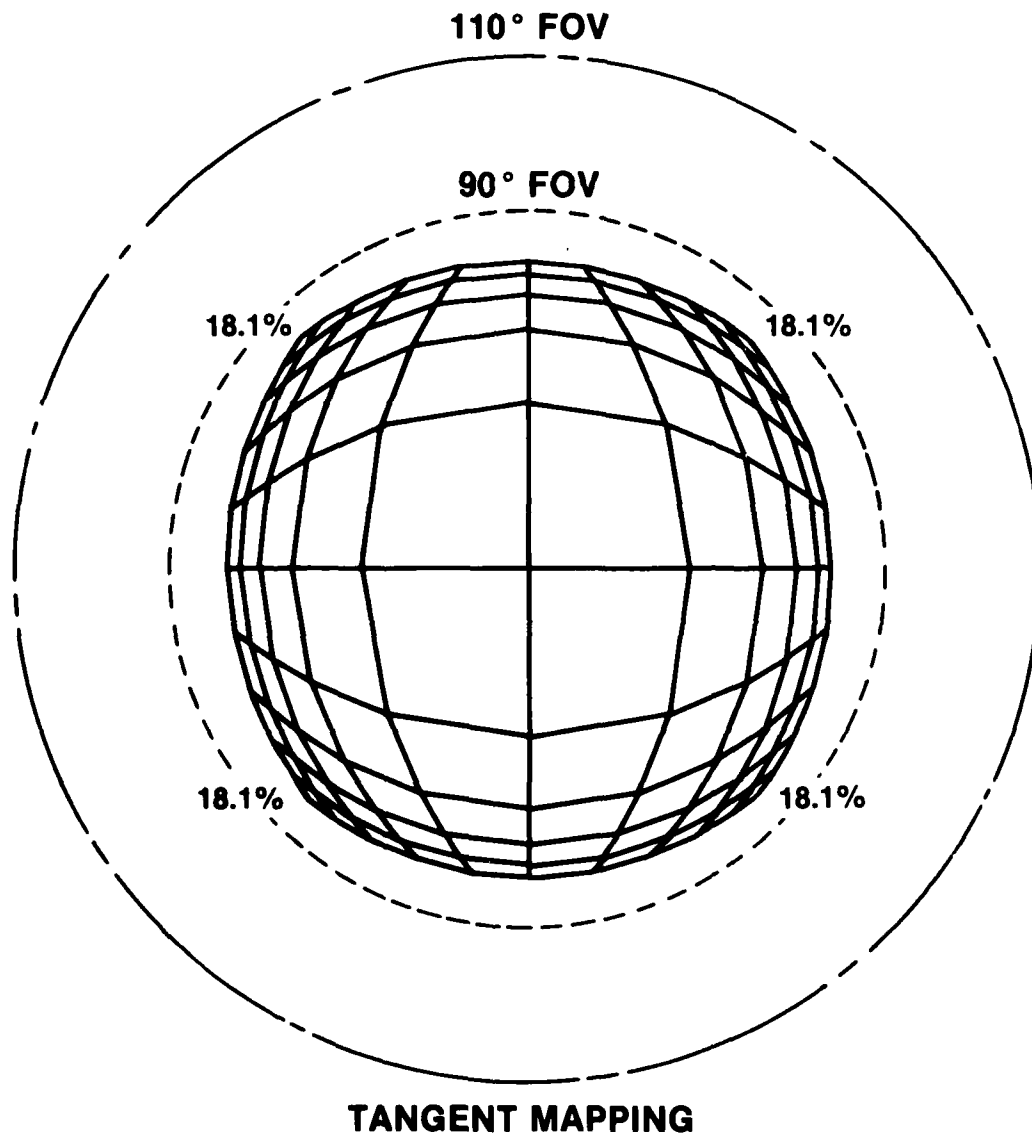


Figure A-6. Tangent mapping (Example 2).

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R-THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :

X = 0.000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160.000 DEGREES HORIZONTALLY
ABOUT A POINT X= 218.000 Y= 0.000
Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :

X = -218.000 Y= 0.000 Z = 101.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.511	0.000	-0.511
Y	0.511	0.698	0.511
XC	5.671	0.000	-5.671
YC	5.671	5.671	5.671
X	0.698	0.000	-0.698
Y	0.000	0.000	0.000
XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000
X	0.511	0.000	-0.511
Y	-0.511	-0.698	-0.511
XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
18.90%	0.00%	18.90%
4	5	6
0.00%	0.00%	0.00%
7	8	9
18.90%	0.00%	18.90%

TABLE A-7

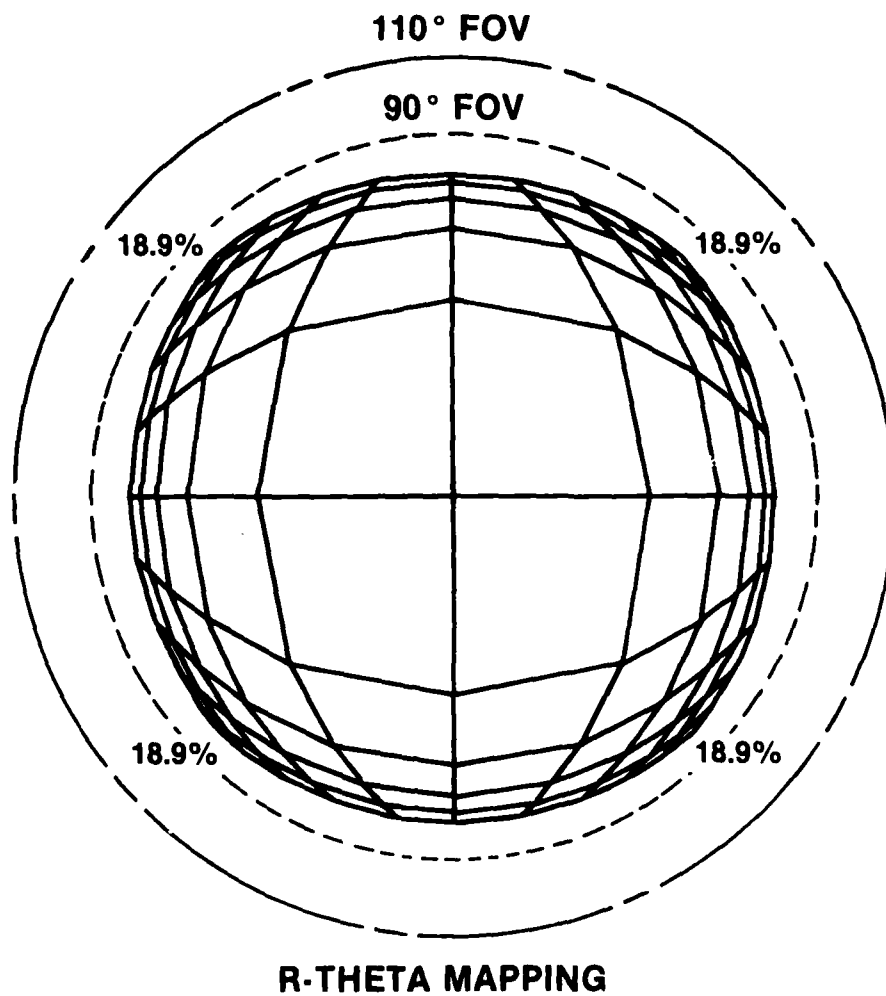


Figure A-7. R-Theta mapping (Example 2).

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SIN THETA MAPPING COORDINATES

THE VIEWPOINT IS AT :

X = 0.000 Y = 0.000 Z = 0.000
OBSERVING A LINEAR RASTER PATTERN ON THE SCREEN
FILLING A FIELD OF 160.000 DEGREES VERTICALLY,
AND 160.000 DEGREES HORIZONTALLY
ABOUT A POINT X= 218.000 Y= 0.000
Z= -101.000 DEFINED AS CENTER OF "FOV".

THE PROJECTOR IS AT :

X = -218.000 Y= 0.000 Z = 101.000
THE PROJECTION DIRECTION IS OFFSET BY V= 0.000 H = 0.000
FROM THE DEFINED FOV CENTER.

THE RADIUS OF THE SPHERICAL SCREEN IS 240.000

X	0.468	0.000	-0.468
Y	0.468	0.642	0.468
XC	5.671	0.000	-5.671
YC	5.671	5.671	5.671
X	0.642	0.000	-0.642
Y	0.000	0.000	0.000
XC	5.671	0.000	-5.671
YC	0.000	0.000	0.000
X	0.468	0.000	-0.468
Y	-0.468	-0.642	-0.468
XC	5.671	0.000	-5.671
YC	-5.671	-5.671	-5.671

DISTORTION PERCENTAGES

1	2	3
19.22%	0.00%	19.22%
4	5	6
0.00%	0.00%	0.00%
7	8	9
19.22%	0.00%	19.22%

TABLE A-8

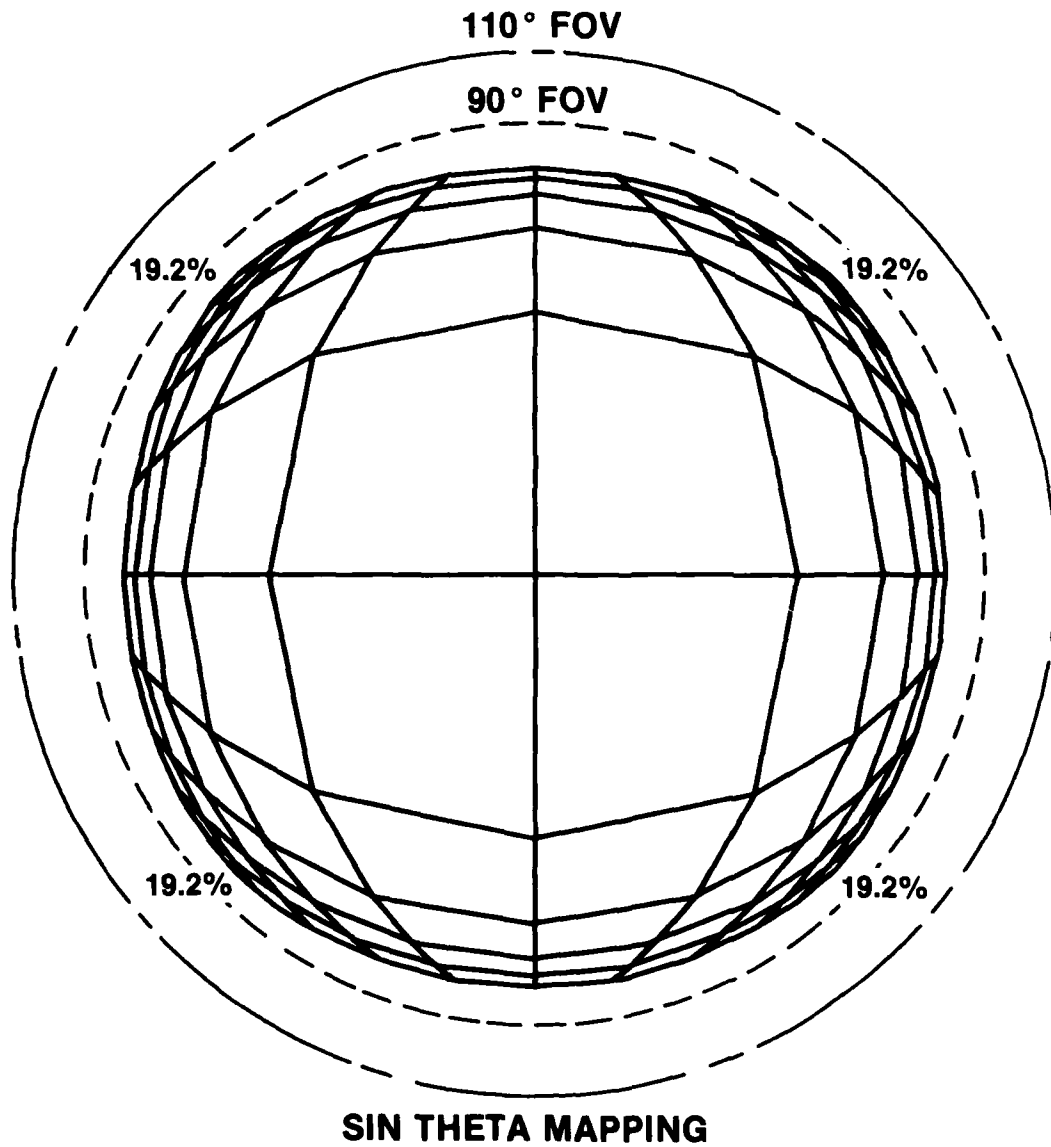


Figure A-8. Sin Theta mapping.

NAVTRAEQUIPCEN IH-332
CONVERSION FROM F TAN ϕ MAPPINGS TO F_{θ} , $F \sin \phi$,
AND F TAN ϕ WITH PRIMARY DISTORTION MAPPINGS

F Tan ϕ mapping

Using spherical angles ϕ and θ to define angles along the X and Y axes of the mapping plane relative to the origin (center of plane) for a point on the plane, the coordinates of the point are found by the equations:

$$\begin{aligned} X_t &= F * \tan \phi \\ Y_t &= F * \tan \theta \end{aligned}$$

F θ mapping

A point on the F Tan ϕ mapping plane (for $F = 1$) is located at a radial distance from the origin given by:

$$R_t = [(\tan \phi)^2 + (\tan \theta)^2]^{1/2}.$$

Considering the difference between the radial distance for a Tan ϕ mapping and a θ mapping for the same point in the field, the θ mapping radial distance is given by:

$$R_{\theta} = R_t * \frac{\alpha}{\tan \alpha},$$

or equivalently,

$$R_{\theta} = R_t * CR.$$

Where CR is the conversion ratio constant for a particular point on the plane (Tan ϕ), α is the angle from the optical axis.

To find the X and Y coordinates on the θ mapping plane, expand the conversion equation to:

$$[(X_{\theta})^2 + (Y_{\theta})^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} * CR,$$

and using the property of a scalar multiplication of a vector the resulting coordinates for a $F \theta$ mapping are given by:

$$X_{\theta} = X_t * CR ,$$

$$Y_{\theta} = Y_t * CR .$$

F sin θ Mapping

Again considering the radial distance for a point on a Tan θ mapping, if the radial distance (R_s) for a Sin θ mapping is desired, then

$$R_s = R_t * \frac{\sin \alpha}{\tan \alpha} ,$$

or,

$$[(X_s)^2 + (Y_s)^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} \times \frac{\sin \alpha}{\tan \alpha} .$$

using the scalar multiplication process again,

$$X_s = X_t * \frac{\sin \alpha}{\tan \alpha} ,$$

$$Y_s = Y_t * \frac{\sin \alpha}{\tan \alpha} .$$

Tan θ mapping with Primary Distortion

Primary distortion of a Tan θ lens is a distortion of the radial position of a point on the mapping plane relative to the square of the radial distance to that point multiplied by a constant factor (DF), i.e.:

$$R_p = R_t + (DF * R_t^2) ,$$

or,

$$R_p = R_t * (1 + (DF * R_t)).$$

Using the general formula for radial distance the above equation expands to:

$$[(X_p)^2 + (Y_p)^2]^{1/2} = [(X_t)^2 + (Y_t)^2]^{1/2} * (1 + DF * R_t),$$

again scalar multiplication process leads to:

$$X_p = X_t * (1 + (DF * R_t)),$$

$$Y_p = Y_t * (1 + (DF * R_t)),$$

where X_p and Y_p are the coordinates of the distorted mapping. Obviously, letting $DF = 0$ will give a Tan θ mapping, with a negative DF value giving barrel distortion and a positive DF value giving pincushion distortion.

The figures below illustrate the difference between the mappings through a lens of a rectangular object for the four general mappings described above. Notice that for the proper choice of DF , an $F \theta$ mapping or $F \sin \theta$ mapping can be approximated if the field angles are not too large.

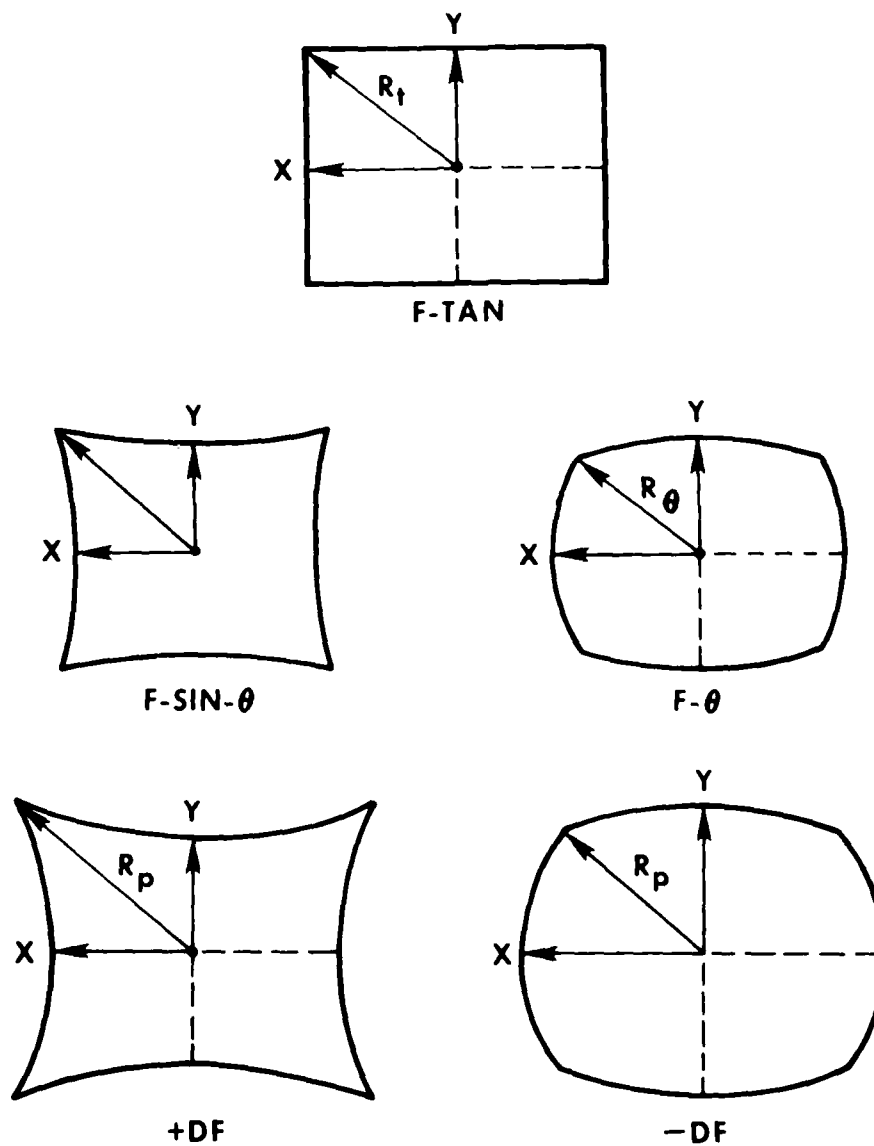


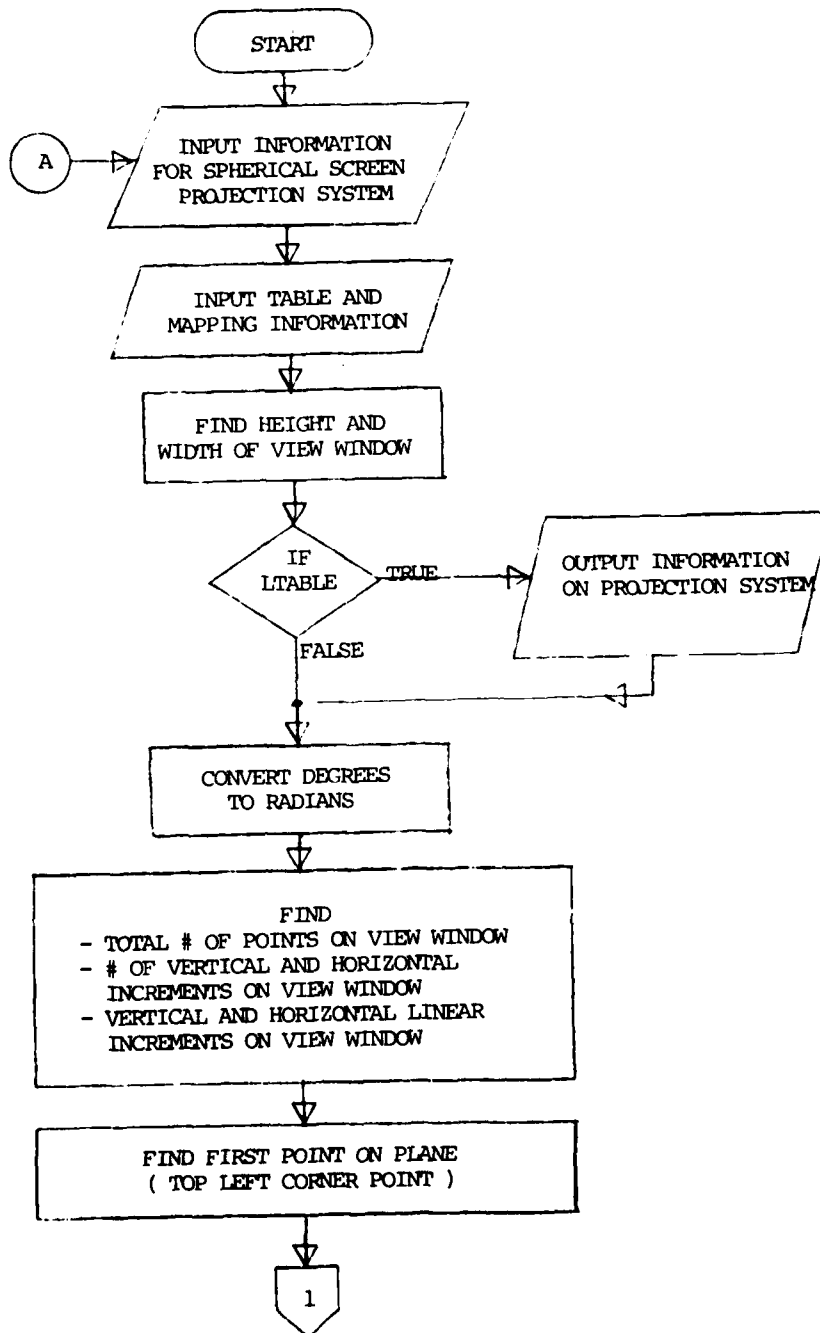
Figure B-1. Relative Distortions of a Rectangular Object by Various Lens Mapping Functions.

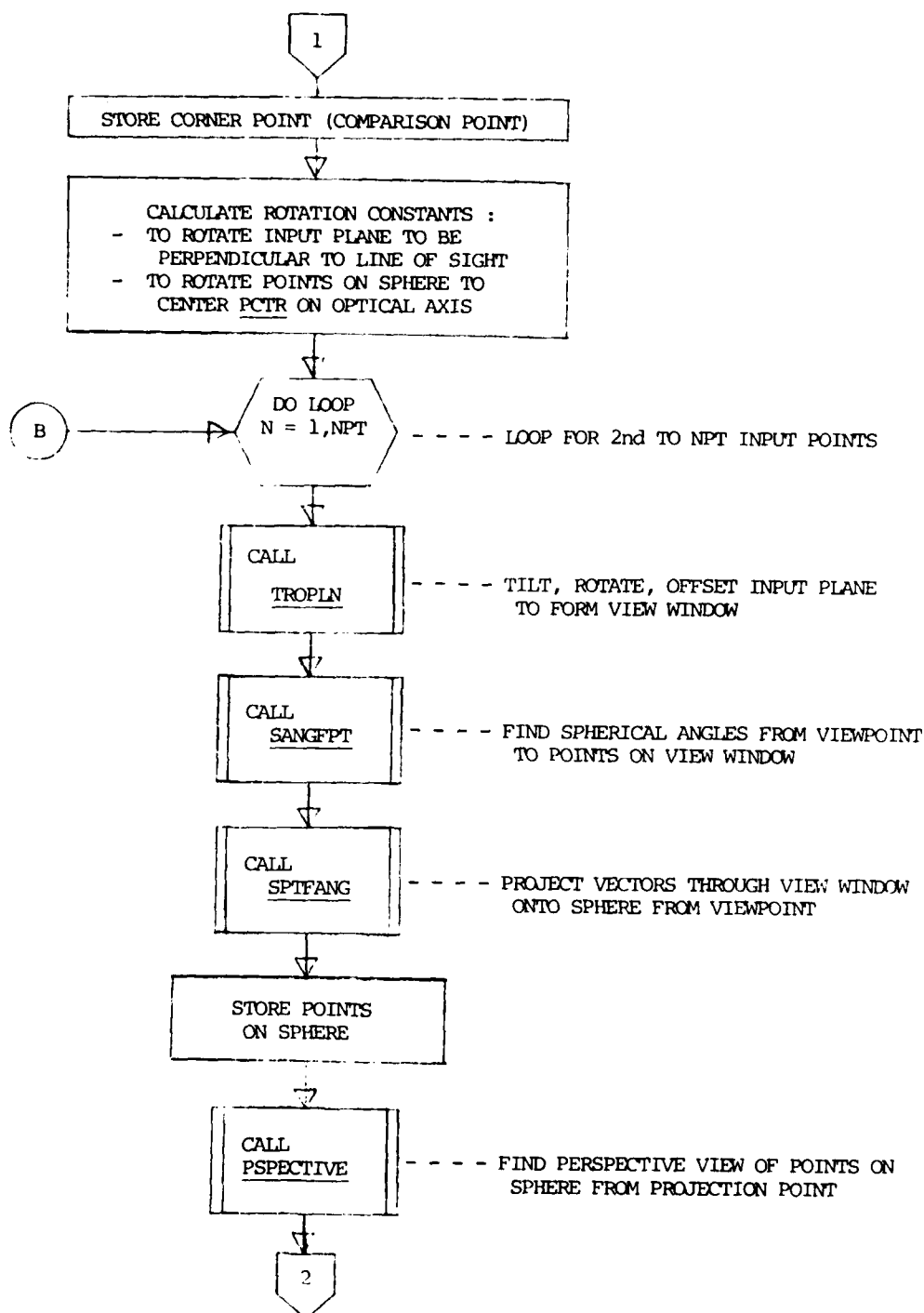
NAVTRAEQUIPCEN IH-332

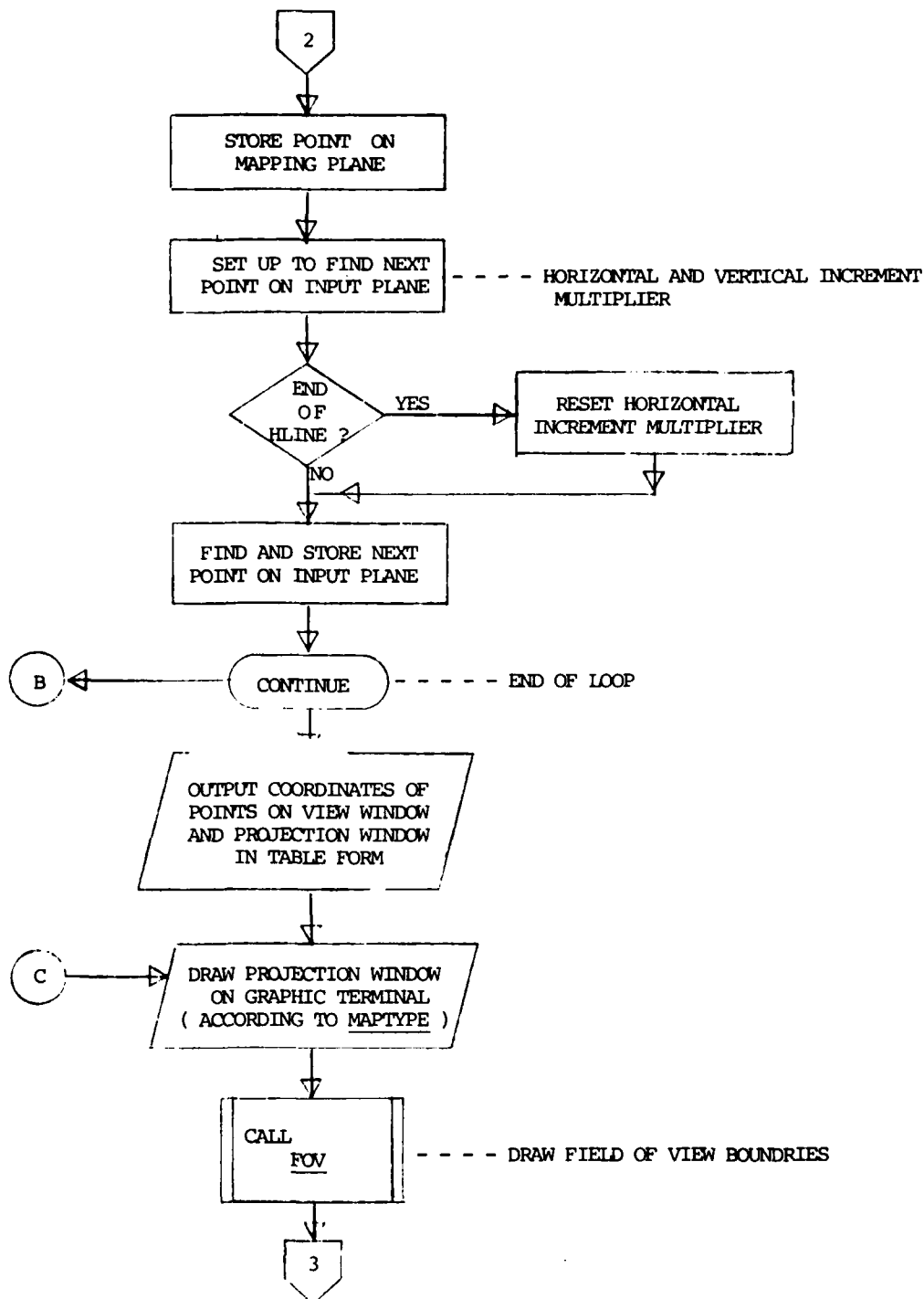
PROGRAM FLOWCHARTS AND CODING

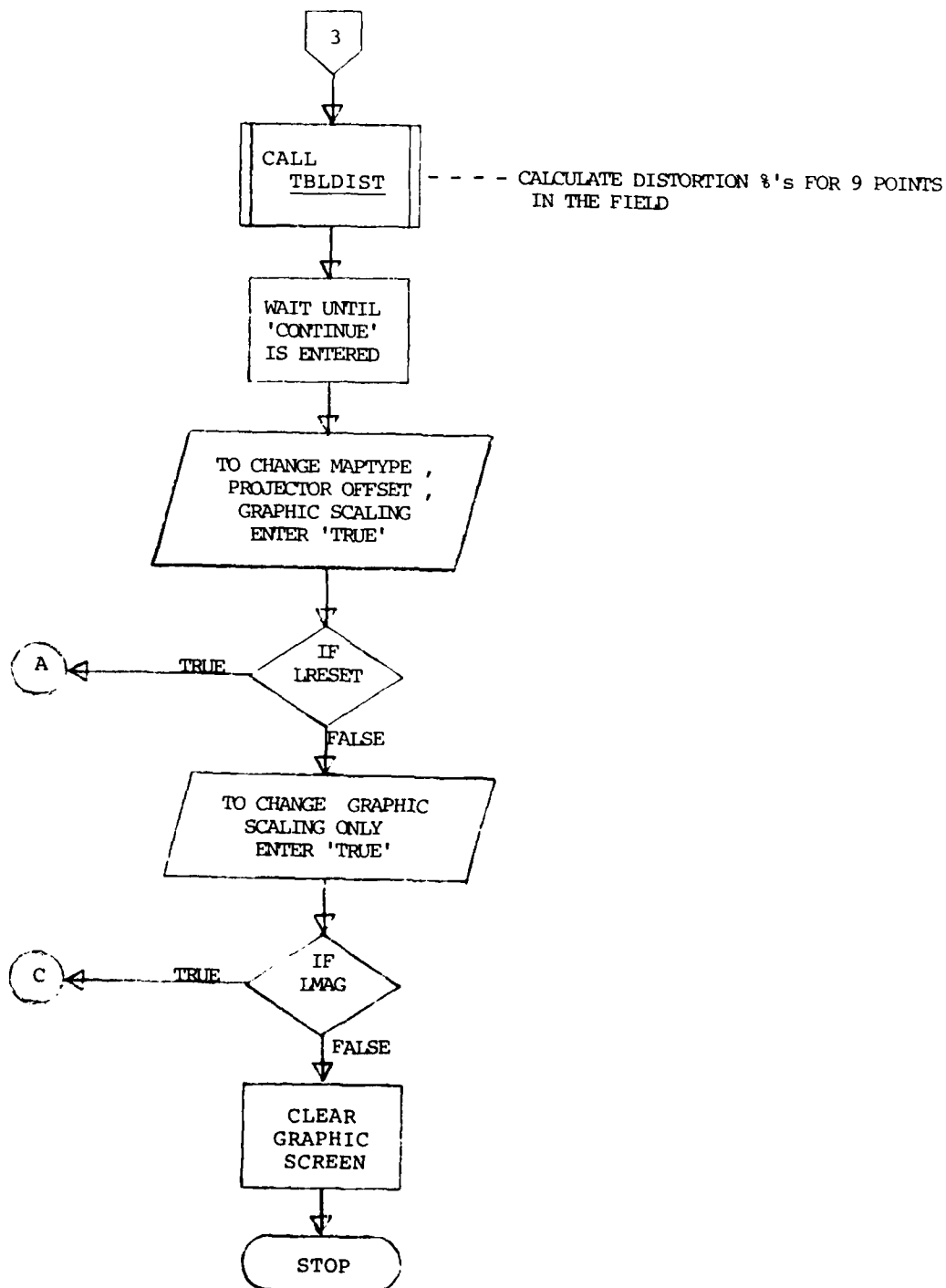
NAVTRAEQUIPCEN IH-332

MAPTAG



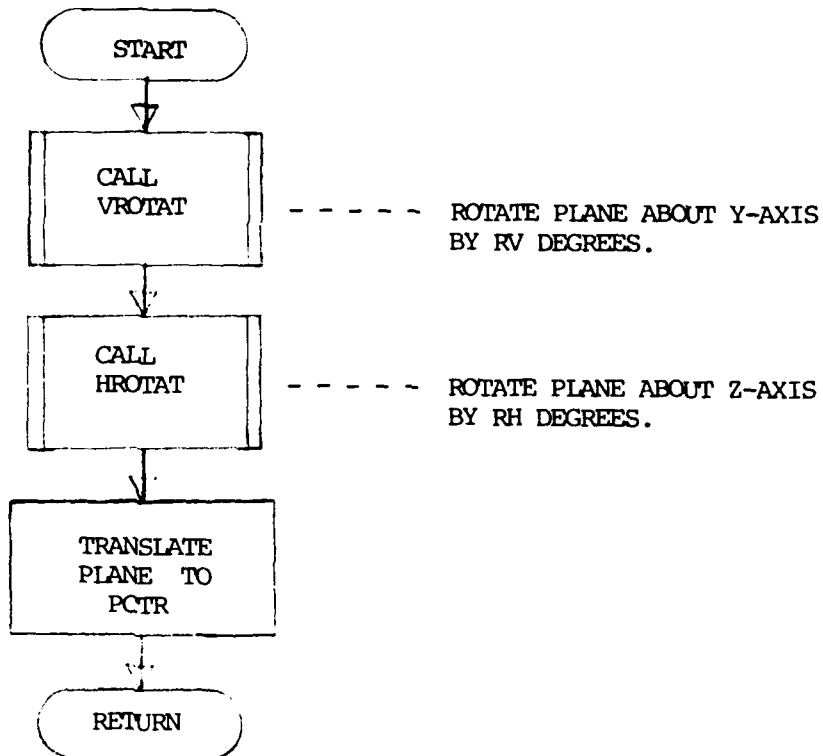






NAVTRAEQUIPCEN IH-332

SUBROUTINE TROPLN



INPUT: POINT ON PLANE, $P(PX, PY, PZ)$, VERTICAL ROTATION ANGLE (RV) , HORIZONTAL ROTATION ANGLE (RH) , PLANE CENTER $PCTR(PXC, PYC, PZC)$, ORIGIN OF PLANE (XO, YO, ZO) .

OUTPUT: POINT ON PLANE $P(PX, PY, PZ)$ - (TILTED, ROTATED AND OFFSET)

22-JAN-1981 15:45:10 VAX 11 FORTRAN IV-PLUS V1.2-13
SUBDIST.FOR.1

Page 1

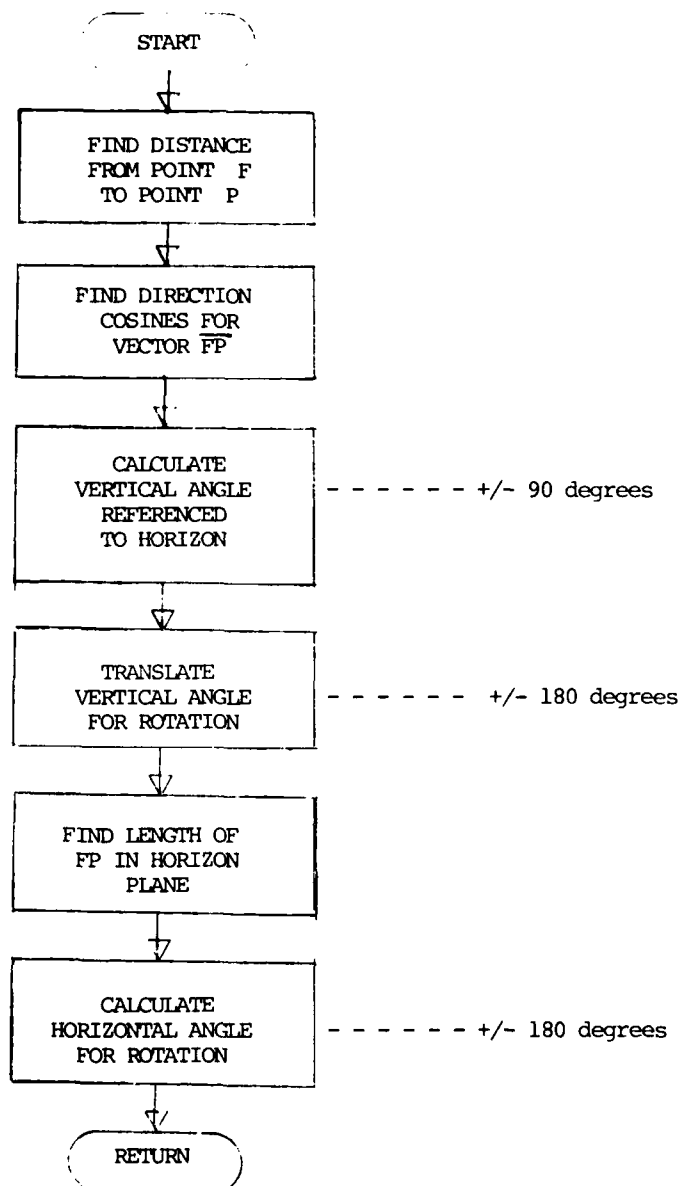
```

C
C
C
C      *****
C      *          *
C      *  TRCPLN  *
C      *          *
C      *****
C
C  THIS SUBROUTINE COVERTS POINTS ON A Y-Z PLANE CENTERED AT
C  AN ORIGIN TO POINTS ON A PLANE THAT IS TILTED ABOUT THE Y-AXIS
C  BY RV DEGREES AND THEN ROTATED RH DEGREES ABOUT THE Z-AXIS.
C  THE PLANE IS THEN TRANSLATED FROM THE ORIGIN TO (PXC,PYC,PZC).
C  THE PLANE PRODUCED WILL BE TANGENT TO THE PROJECTION
C  DIRECTION IF CTHE ROTATION ANGLES ARE THE NEGATIVE OF THE
C  ANGLES FROM PROJECTOR TO (PXC,PYC,PZC) OF THE SPHERE CENTERED
C  COORDINATE SYSTEM.
C
C
0001      SUBROUTINE TRCPLN (RV,RH,PXC,PYC,PZC,XO,YO,ZO,PX,PY,PZ)
0002      IMPLICIT DOUBLE PRECISION (D,F,P,P,X,Y,Z)
C
C
C      TRANSLATE PLANE TO ORIGIN AT (XO,YO,ZO)
C
0003      PX = PX - XO
0004      PY = PY - YO
0005      PZ = PZ - ZO
C
C
C
C      ROTATE PLANE ABOUT Y-AXIS BY RV DEGREES
C
0006      CALL VROTAT(RV,PX,PY,PZ)
C
C      ROTATE ABOUT Z-AXIS BY RH DEGREES
C
0007      CALL HROTAT(RH,PX,PY,PZ)
C
C
C      TRANSLATE PLANE FROM PROJECTION POINT TO POSITION CENTERED AT
C      PXC,PYC,PZC.
C
0008      PX = PX + PXC - XO
0009      PY = PY + PYC - YO
0010      PZ = PZ + PZC - ZO
C
C
0011      RETURN
0012      END

```


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SUBROUTINE SANGFPT



INPUT : DEGREES TO RADIAN FACTOR (PI), POINT F(FX,FY,FZ), POINT P(PX,PY,PZ).

OUTPUT: 'VANG' (VERTICAL +/- 90 DEGREES FROM HORIZON), 'TILT' (-'VANG'), 'VANGR' (VERTICAL +/- 180 DEGREES), 'HANGR' (HORIZONTAL +/- 180 DEGREES), 'DIST' (DISTANCE FP)

```

C
C
C
C      *****
C      *          *
C      *  SANGFPT  *
C      *          *
C      *****
C
C
C      THIS SUBROUTINE FINDS SPHERICAL ANGLES TO POINT PX,PY,PZ
C      FROM POINT FX,FY,FZ. ANGLES ARE EXPRESSED IN RADIAN. ALSO
C      THE DISTANCE FROM F TO P IS RETURNED IN THE SAME UNITS AS
C      POINT LOCATIONS ARE GIVEN.
C      THREE ANGULAR SIGN CONVENTIONS ARE USED IN THIS PROGRAM
C      1. POSITIVE ABOVE HORIZON , NEGATIVE BELOW HORIZON
C         CONVENTION . VERTICAL ANGLES ONLY (+/- 90 DEG.)
C         VALUES RETURNED AS "VANG".
C      2. POSITIVE FOR COUNTER-CLOCKWISE ROTATION , NEGATIVE
C         FOR CLOCKWISE ROTATION AS VIEWED FROM POSITION ON
C         A POSITIVE AXIS LOOKING TOWARDS PLANE DEFINED BY
C         REMAINING AXES. VERTICAL AND HORIZONTAL ANGLES;
C         VALUES RETURNED AS 'VANGR' AND 'HANGR'
C      3. VALUE FOR TILTING OF INPUT PLANE BY TROPLN SUBROUTINE
C         THIS ANGLE IS NEGATIVE OF VANG.
C
001      SUBROUTINE SANGFPT(PI,PX,PY,PZ,FX,FY,FZ,VANG,HANGR,DIST,VANGR,
C      TILT 1)
C
002      IMPLICIT DOUBLE PRECISION (A,B,C,D,F,H,P,T,V)
C
C      FIND DISTANCE FROM POINT F TO POINT P
003      A = PX - FX
004      B = PY - FY
005      C = PZ - FZ
006      DIST = DSQRT(A * A + B * B + C * C )
C
C      FIND DIRECTION COSINES TO P FROM F
007      DYC = B / DIST
008      DZC = C / DIST
C
C      FIND SPHERICAL ANGLES TO P FROM F
C
009      VANG = DASIN(DZC)
C      STORE ABSOLUTE VERTICAL ANGLE (+/- 180 DEG.)
010      IF (A .LE. 0. .AND. C .GT. 0.) THEN
011          VANGR = - 180.*PI + VANG
012      ELSE
013          IF ( .LT. 0. .AND. C .LT. 0.) THEN
014              VANGR = 180.*PI + VANG
015          ELSE
016              VANGR = - VANG
017          ENDIF
018      ENDIF
C
C

```

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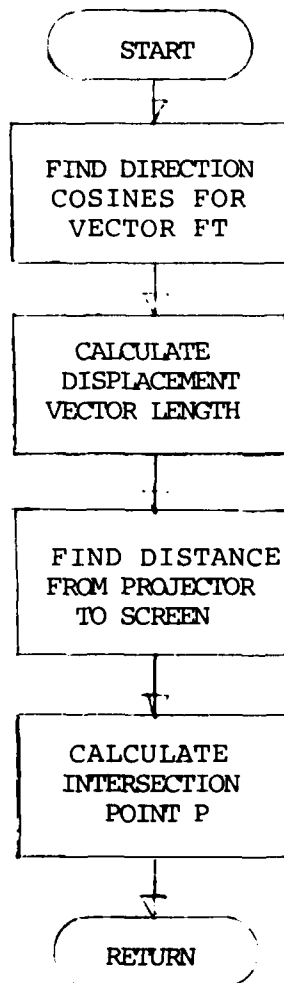
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```
C   STORE TITLE VALUE (+/- 90 DEG.)
C
0019  TILT = - VANG
C
C   FIND PROJECTION OF VECTOR ONTO X-Y PLANE
C
0020  CS = DSQRT(1.0 - DZC*DZC)
C
0021  IF (CS .EQ. 0.0) THEN
0022    HANGR = 0.0
0023  ELSE
0024    ARGH = DYC / CS
0025    IF ( ARGH .GT. 1.0) ARGH = 1.0
0026    IF ( ARGH .LT.-1.0) ARGH =-1.0
D    WRITE(2,*),'ARGH =' CS =',CS
0027  HANGR = DASIN(ARGH)
    ENDIF
C
C   CONVERT HORIZONTAL ANGLES TO +/- 180 DEGREE CONVENTION
C
0029  IF ( B .LE. 0. .AND. A .LT. 0. ) HANGR = -180. * PI - HANGR
0030  IF ( B .GT. 0. .AND. A .LT. 0. ) HANGR = 180. * PI - HANGR
C
0031  RETURN
0032  END
```

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SUBROUTINE SPTFANG



INPUT: RADIUS (R), VERTICAL ANGLE (VANG), HORIZONTAL ANGLE (HANG),
PROJECTION POINT F (FX,FY,FZ).

OUTPUT: INTERSECTION POINT ON SCREEN T (TX,TY,TZ).

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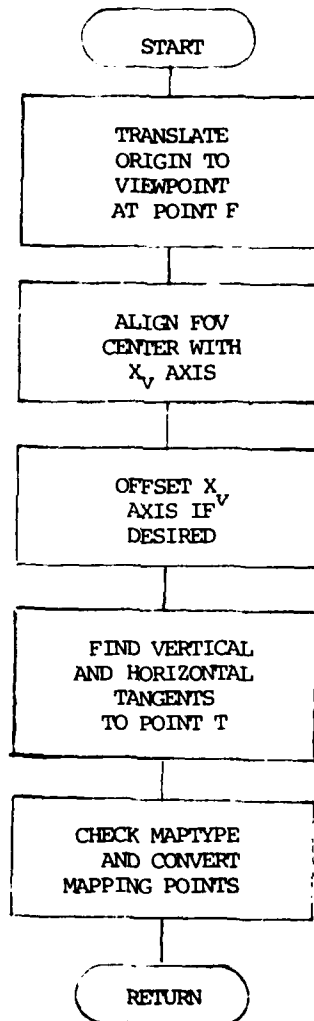
```

C
C
C *****
C *          *
C * SPTFANG *
C *          *
C *****
C
C
C THIS SUBROUTINE FINDS THE POINT OF INTERSECTION OF A VECTOR
C PROJECTED FROM A POINT ( FX,FY,FZ ) AT SPHERICAL ANGLES OF 'VANG'
C AND 'HANG' ONTO THE SURFACE OF A SPHERE WITH THE CENTER DEFINED
C AS THE ORIGIN OF THE 3-D SYSTEM. THE COORDINATE SYSTEM OF THE
C PROJECTION POINT IS PARALLEL TO THE SCREEN COORDINATE SYSTEM.
C THE POINT RETURNED IS GIVEN BY ( PX,PY,PZ ) AND IS ON THE
C SURFACE OF THE DESCRIBED SPHERE OF RADIUS (R)
C
0001          SUBROUTINE SPTFANG (R,VANG,HANG,FX,FY,FZ,FX,FX,TX,TZ)
0002          IMPLICIT DOUBLE PRECISION (D,F,H,R,T,V)
C
C FIND DIRECTION COSINES FROM F TO T
C
0003          DCV = DCOS(VANG)
0004          DZP = DSIN(VANG)
0005          DYP = DCV * DSIN(HANG)
0006          DXP = DCV * DCOS(HANG)
C
C FIND LENGTH OF DISPLACEMENT VECTOR DUE TO PROJECTOR OFF CENTER
C OF SPHERE
C
0007          DVMS = FX * DXP + FY * DYP + FZ * DZP
C
C FIND DISTANCE FROM PROJECTION POINT TO POINT ON SCREEN
C
0008          DVAL = DABS (DVMS*DVMS + R*R - FX*FX -FY*FY - FZ*FZ)
0009          DIST = - DVMS + DSQRT( DVAL )
C
C FIND COORDINATES OF POINT
C
0010          TX = FX + DIST * DXP
0011          TY = FY + DIST * DYP
0012          TZ = FZ + DIST * DZP
C
0013          RETURN
0014          END

```

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SUBROUTINE PSPECTIVE



INPUT : VIEWPOINT F(FX,FY,FZ) , POINT TO BE VIEWED T(TX,TY,TZ) , ANGLES TO ALIGN X_v AXIS TO FOV CENTER (VOFF,HOFF) , ANGLES TO OFFSET X_v AXIS (VOFFP,HOFFP) , MAPTYPE, PRIMARY DISTORTION FACTOR (DFACTOR).

OFFSET : COORDINATES OF POINT ON VIEWPLANE (XOUT,YOUT).

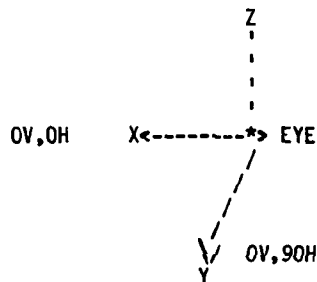
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 10-FEB-1981 10:27:38 DB

```

*****
*                                     *
*      PERSPECTIVE                   *
*                                     *
*****

```

THIS SUBROUTINE IS USED TO FIND THE PERSPECTIVE MAPPING OF POINTS IN 3-D SPACE WHERE THE COORDINATE SYSTEM IS DESCRIBED AS: X IS POSITIVE FORWARD, Y IS POSITIVE TO THE RIGHT, AND Z IS POSITIVE UPWARDS (RIGHT-HAND SYSTEM). THE PERSPECTIVE IS FOUND FROM A POINT (FX,FY,FZ) WITH THE VIEWING VECTOR OFFSET FROM OH,OV DEGREES BY -VOFF DEGREES AND -HOFF DEGREES IN AN ANGULAR SYSTEM THAT DEFINES THE DIRECTION OF POSTIVE ROTATION AS COUNTER-CLOCKWISE ROTATION OF TWO AXES WHEN VIEWED FROM THE REMAINING AXIS.



THE POINT TO BE MAPPED IS (TX,TY,TZ) ACCORDING TO MAPTYPE (1-TAN-THETA,2-THETA,3-TAN-THETA W/ DFACTOR,4-SIN-THETA)

VOFFP AND HOFFP ALLOW FURTHER OFFSETTING OF THE VIEWING AXIS. XOUT AND YOUT ARE THE COORDINATES FOR PLANAR PERSPECTIVE VIEW.

```

0001 SUBROUTINE PSPECTIVE(FX,FY,FZ,TX,TY,TZ,VOFF,HOFF,VOFFP,HOFFP,
      1MAPTYPE,DFACTOR,XOUT,YOUT)
0002 IMPLICIT DOUBLE PRECISION (A-H,O-Z)
0003 TRANSLATE ORIGIN TO VIEWPOINT POSITION (FX,FY,FZ)
      TX = TX - FX
      TY = TY - FY
      TZ = TZ - FZ
0004
0005 POINT Xv AXIS TOWARD FOV CENTER AND FIND NEW COORDINATES
0006 CALL HROTAT (HOFF,TX,TY,TZ)
0007 CALL VROTAT (VOFF,TX,TY,TZ)
0008
0009 OFFSET VIEWING AXIS IF HOFFP AND VOFFP ARE NOT ZERO
      IF(VOFFP .NE. 0.0) CALL VROTAT (VOFFP,TX,TY,TZ)
      IF(HOFFP .NE. 0.0) CALL HROTAT (HOFFP,TX,TY,TZ)

```

4

C FIND TANGENTS OF ANGLES TO POINTS

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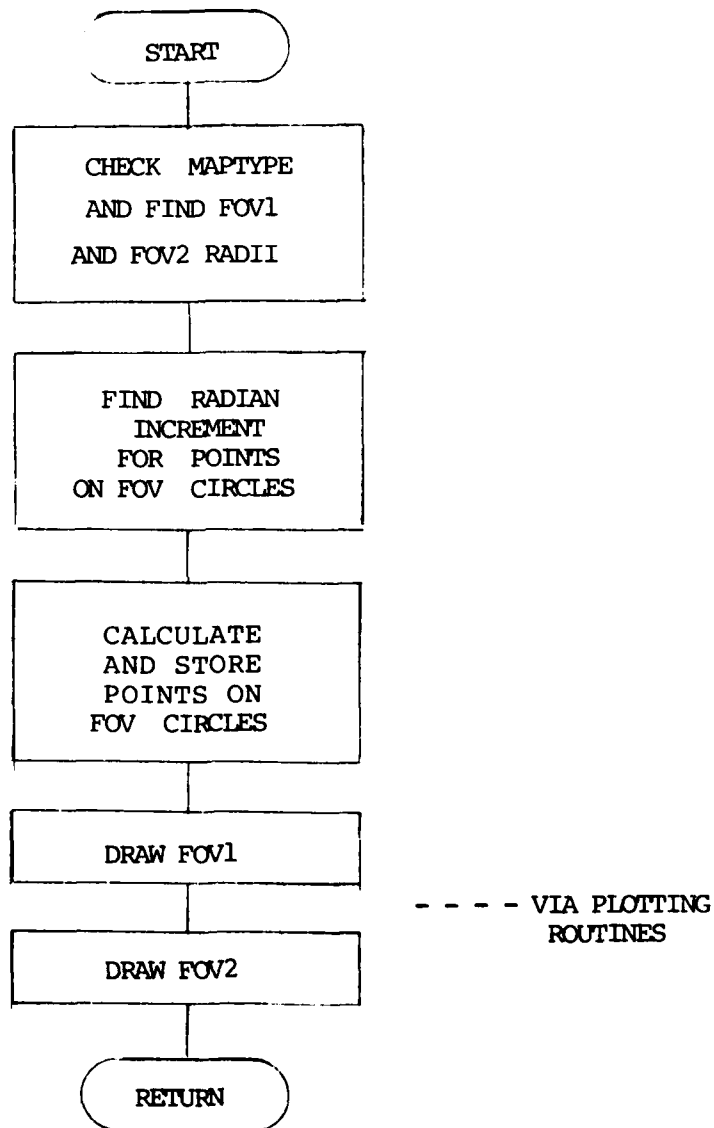
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[illegible]

NAVTRAEQUIPCEN IH-332

SUBROUTINE FOV



INPUT : FIELD OF VIEW #1 (FOV1), FIELD OF VIEW #2 (FOV2), NUMBER OF POINTS ON FOV's (NPT), LINE TYPE FOR FOV1 (L1), LINE TYPE FOR FOV2 (L2), DEGREES TO RADIANS FACTOR (CONVR), MAPTYPE (MAP), PRIMARY DISTORTION FACTOR (DFACTOR).

OUTPUT : TO GRAPHIC TERMINAL ONLY - CIRCLES INDICATING FOV1 AND FOV2.

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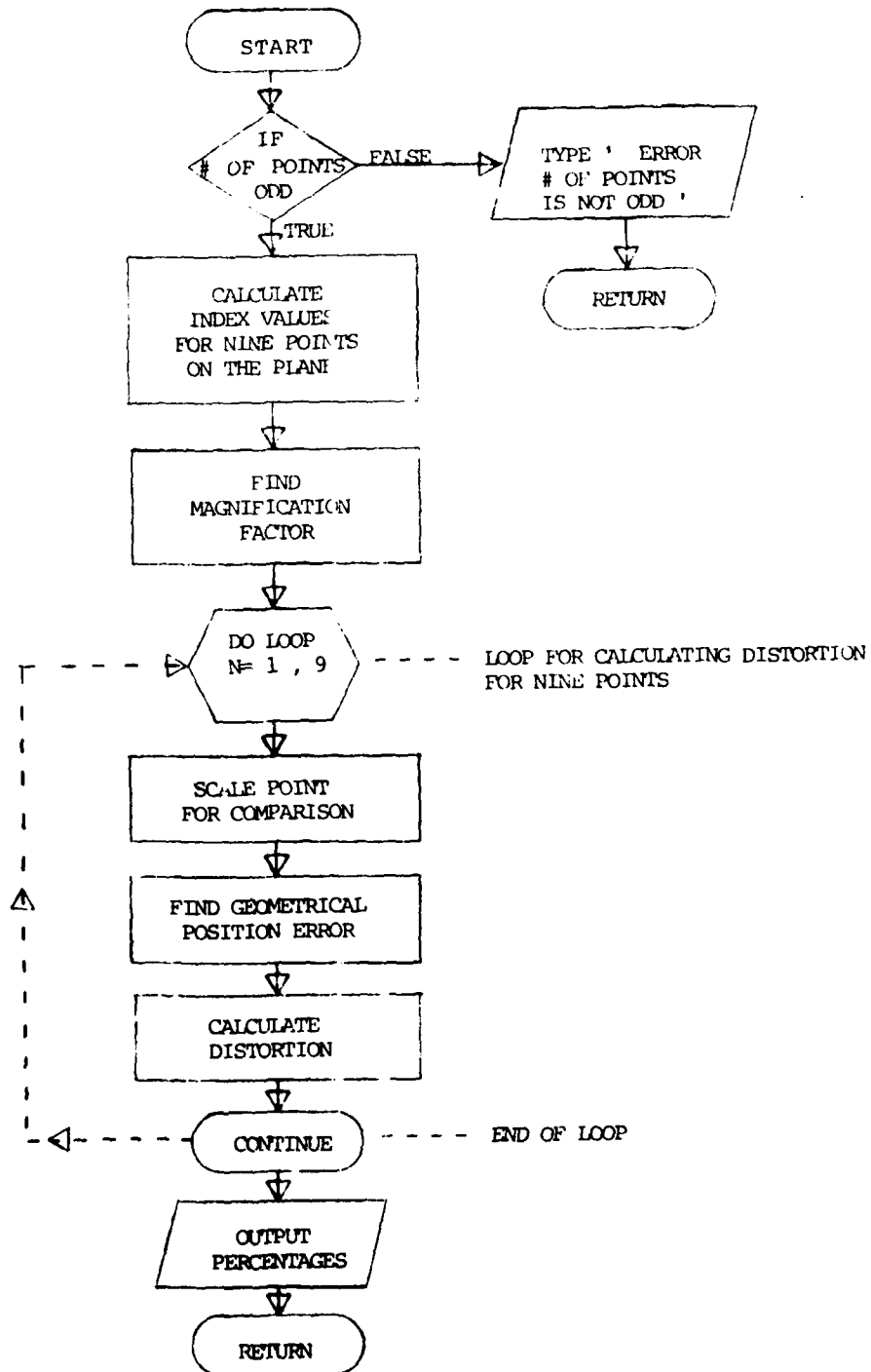
```

0019      R2 = SIN( FOV2 * .5 * CONVR)
0020      ENDIF
      C
      C      FIND RADIAN INCREMENT FOR POINTS ON CIRCLE
      C
0021      RADINCR = 2. * 3.14159265349 / ( NPT - 1 )
      C
0022      DO 100 N = 1,NPT
      C
0023          ARGH = (N - 1) * RADINCR
0024          CSA = COS(ARGH)
0025          SNA = SIN(ARGH)
      C
      C      STORE POINTS ON CIRCLE
      C
0026          X1(N) = R1 * CSA
0027          Y1(N) = R1 * SNA
0028          X2(N) = R2 * CSA
0029          Y2(N) = R2 * SNA
      C
0030      100 CONTINUE
      C
      C      DRAW FOV1 WITH LINETYPE 'L1'
      C
0031          CALL SETLINE(L1)
0032          CALL LINE (X1,Y1,NPT,1,-1,0.,1,0,0)
      C
      C      DRAW FOV2 WITH LINETYPE 'L2'
      C
0033          CALL SETLINE(L2)
0034          CALL LINE(X2,Y2,NPT,1,-1,0.,1,0,0)
      C
0035      RETURN
0036      END

```

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SUBROUTINE TBLDIST



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DE

```

0014      ENDIF
      C
      C      CALCULATE INDEX VALUES FOR THE NINE POINTS ON THE PLANE
      C
0015      I(1) = 1
0016      I(2) = RNHD2 + 0.5
0017      I(3) = NHORIZ
0018      I(4) = NVD2 * NHORIZ + 1
0019      I(5) = I(4) + I(2) - 1
0020      I(6) = I(5) + I(2) - 1
0021      I(7) = (NVERT - 1) * NHORIZ + 1
0022      I(8) = I(7) + I(2) - 1
0023      I(9) = I(8) + I(2) - 1
      C
      C      FIND MAGNIFICATION RATIO 'ACONST'
      C
0024      PHT = Y(I(2)) - Y(I(8))
0025      CPHT = YC(I(2)) - YC(I(8))
0026      ACONST = PHT / CPHT
      C
      C
      C      LOOP FOR CALCULATING PERCENT DISTORTION FOR THE NINE POINTS
      C
0027      DO 100 N = 1,9
0028          IN = I(N)
0029          TX = X(IN)
0030          TY = Y(IN)
0031          TXC = XC(IN) * ACONST
0032          TYC = YC(IN) * ACONST
      C
      C
      C      FIND RADIAL DISTANCE FROM POINT ON VIEW PLANE TO POINT
      C      ON VIEW WINDOW 'GPE'.
      C
0033      GPE = SQRT((TXC-TX)*(TXC-TX)+(TYC-TY)*(TYC-TY))
      C
      C      CALCULATE DISTORTION
      C
0034      PCTDIST(N) = GPE / PHT * 100.
0035      100 CONTINUE
      C
      C
0036      WRITE(4,*),'DISTORTION PERCENTAGES'
0037      WRITE(4,2)
      C
0038      WRITE(4,3) ,(I(L),L=1,3)
0039      WRITE(4,1) ,(PCTDIST(J),J=1,3)
0040      WRITE(4,2)
0041      WRITE(4,3) ,(I(L),L=4,6)
0042      WRITE(4,1) ,(PCTDIST(J),J=4,6)

```

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```
0043      WRITE(4,2)
0044      WRITE(4,3) ,(1(L),L=7,9)
0045      WRITE(4,1) ,(PCTDIST(J),J=7,9)
          C
0046      RETURN
          C
0047      1  FORMAT(5X,F6.2,'% ',3X,F6.2,'% ',3X,F6.2,'% ')
0048      3  FORMAT(4X,I3,6X,I3,6X,I3)
0049      2  FORMAT(/)
          C
0050      END
```


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