Direction Judgement Errors in Perspective Displays

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ABSTRACT

In a study of spatial information transfer characteristics of perspective situation displays, eight subjects judged the directions of displayed targets relative to a fixed position in the center of computer generated perspective scenes. Their errors in judging azimuth angles varied sinusoidally with the azimuth of the targets. Errors alternated between clockwise and counterclockwise from one direction quadrant to the next. As the perspective geometry was varied between 'telephoto lens' and 'wide angle lens' views, the direction of error gradually reversed in all quadrants. The results can be explained by systematic differences between the three-dimensional stimulus angles and the perspective projections of those angles onto the display screen.

Introduction

Use of pictures as spatial information instruments has been of particular interest in aerospace [Getty, 1982], [Jauer and Quinn, 1982], [Jones et. al., 1950], [Roscoe et. al., 1981], [Warner, 1979]. Primary tasks involve maneuvering through a three dimensional space, amid other moving or fixed objects, both physical (aircraft, missiles, mountains, weather systems) and virtual (traffic control regions, threat zones). Assistance in monitoring the spatial relationships among objects of interest can best be provided by instruments matching the spatial dimensions of the tasks for which they are used. A typical approach has been to map two dimensions of information to the two dimensions of a display and to encode the collapsed dimension. Recent designs have used perspective projections to capitalize upon our natural spatial abilities. There is some evidence that perspective displays can have advantages over planview displays [Ellis et. al., 1984].

Although it is fairly simple to make a display that looks spatial, the quality of the spatial information transfer between the system and the user must be examined. When three dimensional information is projected onto a two-dimensional screen, the original information must be mentally reconstructed by the user. No matter how accurate the data base, the user may introduce distortions in the act of interpretation of the projection.

Complicating the design of perspective displays is the fact that the 2D projection varies dramatically in appearance depending upon the values of the perspective parameters (fig. 1). An example of a perspective parameter is the geometric field of view angle (fig 1). It is often referred to in this paper simply as the field of view. It is defined as the the visual angle of the display screen as seen from the station point, which is sometimes called the center of projection or geometric eyepoint. An example of the effect of field of view can be seen in figure 2. A narrow field of view, such as 30 degrees, produces an image that is similar to that obtained with a telephoto lens. A wide field of view, such as 120 degrees, produces an image that is similar to that obtained with a "wide angle" lens. Another perspective parameter is the distance between the station point and an object of interest located at the reference point. These two parameters are the major factors defining the geometry of the projection of the 3D information onto to 2D display screen. The purpose of the following experiment was to determine whether the differences in appearance that are due to these perspective parameters result in differences of interpretation.

Experiment

The perspective scene used in this experiment (fig. 3) was abstracted from a perspective display of air traffic for the cockpit [McGreevy, 1982] which compared to a plan-view display in a previous experiment [Ellis, et. al., 1984](fig. 4). In the scenes used in this experiment the aircraft symbols representing ownship and an intruder were replaced by cubes. The cube replacing ownship was always at the center of the display screen and served as a reference for judgement of the relative position of the target cube. For this reason, the ownship cube is also referred to as the reference cube and the intruder is called the target. A grid represented a "ground" plane below the reference cube. A line connected each cube with a point directly below it on the grid. A horizontal cross marked the point on the target cube's line where the reference cube's altitude plane intersected it.

In the experiment, subjects viewed a series of perspective scenes and judged the azimuth and elevation angles of the target relative to the reference (fig. 3). The azimuth angle of the target is the angle between the reference cube's heading and the horizontal direction to the target. The elevation angle is the angle from reference cube's altitude and the vertical direction to the target. In these scenes the viewing vector is rotated 22 degrees relative to a heading of 0 degrees azimuth and elevated 22 degrees above the altitude plane of the reference cube. Subjects responded by using a stylus and digitizer pad [1] to control two angle indicator dials that were drawn on the display screen, next to the perspective scene.

The experiment was a fully crossed, repeated measures design, with eight subjects. Five were airline pilots and 3 were non-pilots. Each subject was shown 640 perspective stimuli. The target cube appeared in 40 different orientation regions on a sphere centered on the reference cube.

[1] The center of the pad was the origin, where the (horizontal) azimuth axis crossed the (vertical) elevation axis. The range of azimuth was from minus 180 degrees to the far left, to plus 180 degrees to the far right. Elevation ranged from minus 90 degrees at the bottom of the pad, to plus 90 degrees at the top of the pad.

Four geometric fields of view, 30, 60, 90, 120 deg., were crossed with four distances between the reference cube and the station point [2], for a total of 16 perspectives. In this paper analysis will be limited to the subjects' judgments of the azimuth angles of the targets.

The subject's eye position was 61 cm. (24 in.) from a 19 cm. (7.5 in.) square image on a 25 cm. (10 in.) square screen of an Evans and Sutherland Picture System II monitor. The image subtended a visual angle of 8.9 degrees. Since the geometric fields of view were greater than this, the corresponding station points were closer to the screen: 14.0 in. (30 deg. fov), 6.5 in. (60 deg. fov), 3.8 in. (90 deg. fov), 2.2 in. (120 deg. fov).

Geometry of the Stimulus Angles

Since the task in this experiment required that the subjects interpret a three-dimensional stimulus angle from its two-dimensional projection, it seemed reasonable that the difference between the true 3D stimulus angle and its 2D projection would influence the subjects' judgements. Accordingly, this difference was plotted as a function of 3D azimuth to suggest the amount and direction of error that might be expected if the subject's 3D judgement is biased by the 2D projection of the stimulus angle. This function is the "2D difference effect" function (fig. 5). At narrow fields of view which produce perspectives similar to telephoto lenses, the magnitude of this function is large. As field of view increases, the magnitude decreases. This function is independent of the actual eye position of the viewer.

A second possible source of influence on subjects' judgements involves the position of the station point relative to the viewer's actual eye position. When

[2] The distances can be described in terms of the distance, d, of the reference cube above the grid. The four distances were 0.66d, 4.81d, 8.97d, 13.12d, approximately in a ratio of 1:5:9:13.

the eye is not at the geometrically correct station point the projectors are effectively bent at the point where they pierce the viewing screen (fig. 6). We call this the "virtual space effect." [1] If the subject assumes that all projectors are straight, just as they are when looking through a window, then the apparent 3D scene will differ from the true 3D scene. We call the subject's assumption the "window assumption."

The virtual azimuth and elevation angles that result from the window assumption can be computed. Our computation assumes shape alteration without translation. The difference between the actual 3D stimulus and the virtual 3D stimulus can be plotted as a function of the 3D stimulus angle to define the virtual space difference function (fig. 7). This describes the expected influence upon direction judgements if the concept of a window assumption is valid. The magnitude of this function varies directly with the distance between the station point and the actual eyepoint of the viewer.

Results

Direction judgement error was measured in terms of azimuth and elevation. The median of each subject's responses at each azimuth position was taken as his typical estimate.

Sixteen plots were made, one for each of the sixteen perspective conditions. While there were apparently only minor differences among the plots with respect to the distance parameter, there were obvious differences as field of view varied. The data were then grouped into four sets, one for each field of view. As a first approximation of these theoretically sinusoidal curves [1], a sixth order polynomial was fitted by least squares to each set of points to

[1] Farber and Rosinski (1978) studied a similar effect but assumed a translation along the viewing axis of the 3D stimulus to its virtual position. This would result in a significantly different virtual space.

obtain a summary curve for each field of view (eg. fig. 8). The standard error of estimate overall for each curve was approximately 7 degrees. When plotted together, the four data summary curves can be seen to vary systematically as field of view changes (fig. 9). These curves summarize the statistically significant interaction between field of view and the azimuth of the intruder cube shown by the analysis of variance of azimuth error. ($F = 10.3$; $df = 21, 147$; $p < .001$).

Since the two model components, the 2D and the virtual space difference functions, may be combined and fitted to the direction judgement data in a variety of ways, several different combinations were tried. The combination resulting in a fit most like the data summary polynomials is obtained when the component curves are separately weighted and added. The weights and an additive constant are determined by regression of each set of data points (four sets, one for each fov) against the expected errors based on the two model components. A visually good fit (see fig. 10) is achieved when the component curves are shifted 22 degrees counter-clockwise, prior to being fitted to the data. This could correspond to a process in which subjects make judgements relative to a line directly into the displayed space (22 deg. azimuth) and then rotate 22 degrees to account for the fact that the heading (zero deg. azimuth) is 22 degrees counter-clockwise of their actual reference direction.

A particularly interesting aspect of the best model curves is that they reproduce a trend seen in the original data which was not explicitly incorporated into the model itself. This trend shows a gradual general change in the direction of the azimuth error from counterclockwise to clockwise as the

[1] The fitted curve should be a projected sinusoid since the set of azimuth stimulus angles step around a circle of bearings in regular intervals. Projecting the positions of these stimulus angles onto a line in the plane of the circle, and translating this line in a direction perpendicular to the line, will trace out a sine-cosine function. Since the circle is viewed from an oblique angle, and in perspective, the sine-cosine function will be modified by the projection.

azimuth region changes from the left quadrants to the right quadrants. The trend corresponds to a significant main effect of azimuth ($F = 3.146$; $df = 7, 49$; $p < .008$).

CONCLUSIONS

The spatial interpretation of the data summary polynomials (fig. 9) is that for narrow fields of view, some azimuths are interpreted as being as much as 10 degrees farther to port or starboard than they are in fact. This bias gradually changes until it reverses at wide fields of view. For these, the azimuths are interpreted as being closer to the line of flight. The bias reverses by as much as 16 degrees in all four azimuth quadrants.

The set of four data summary polynomials and the four composite model curves are very similar (fig. 10). As field of view steps through 30, 60, 90, 120 degrees, the model follows the data through its reversal of the sign of the sinusoid, in regular steps. This suggests that the suspected influences represented by the 2D and virtual space difference functions could account for the systematic errors in direction judgements. Whether these influences actually cause the subject to err systematically remains to be confirmed by subsequent experiments.

It appears that the difference between the true 3D stimulus angle and its 2D projection has the greatest biasing effect when the magnitude of the difference is greatest, that is, at narrow fields of view (regardless of actual eye position of the observer). Similarly, it seems that the difference between the true 3D stimulus angle and the virtual 3D angle, the angle that would be required for the projectors to be straight, has the greatest biasing effect when the magnitude of this difference is greatest, that is, when the geometric station point and the actual eye position are at widely separate locations. Consistently, at intermediate fields of view, as one influence increases and the other decreases, the judgement bias is correspondingly intermediate.

The next experiment will involve keeping the virtual space difference function fixed as the 2D difference function varies and vice versa. This will help clarify the relative biasing effects of these two influences on direction judgements. It is possible that the use of 2D dials on the screen for elevation and azimuth responses was partly responsible for the subjects' tendency to be biased by the two dimensional projection of the three dimensional stimulus angles. Later experiments will use alternative responses, such as egocentric visual direction, and should resolve this question. In these experiments the subjects will be allowed to use a hand-held pointing device to indicate the visual direction of the target. These experiments will thus further test the quality of spatial information transfer that is accomplished when perspective displays are used as spatial information instruments.

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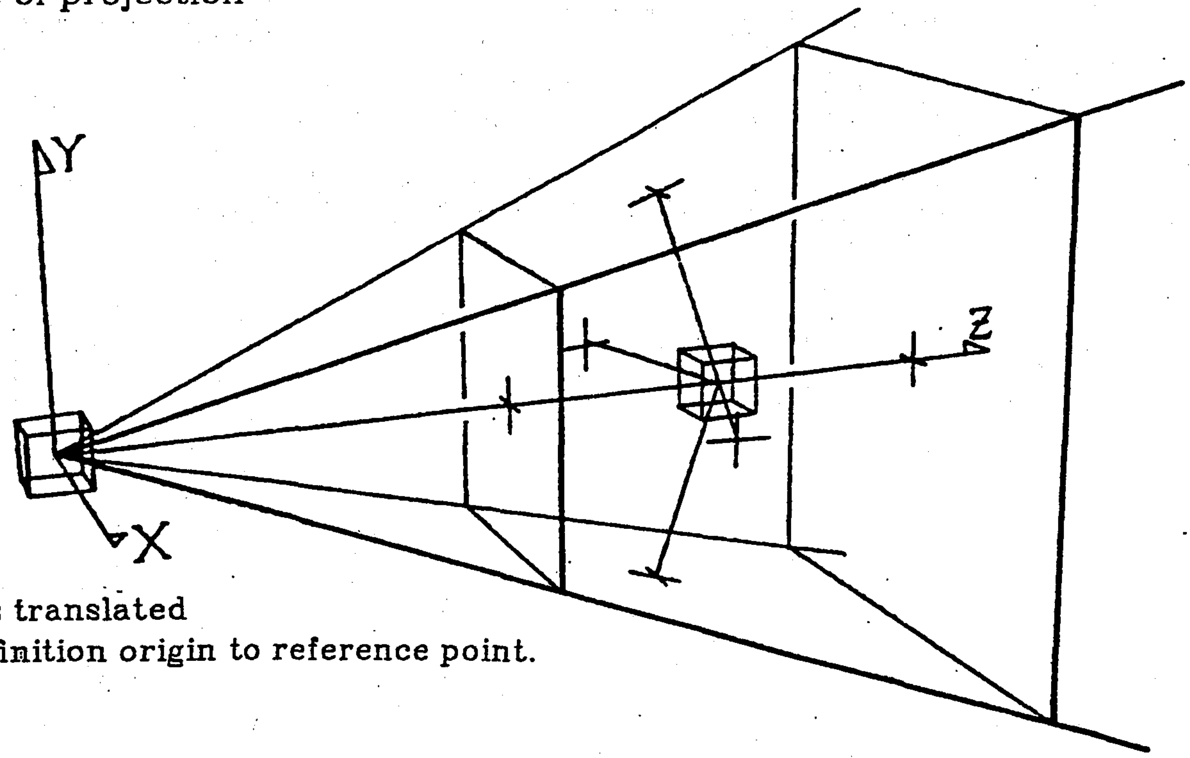
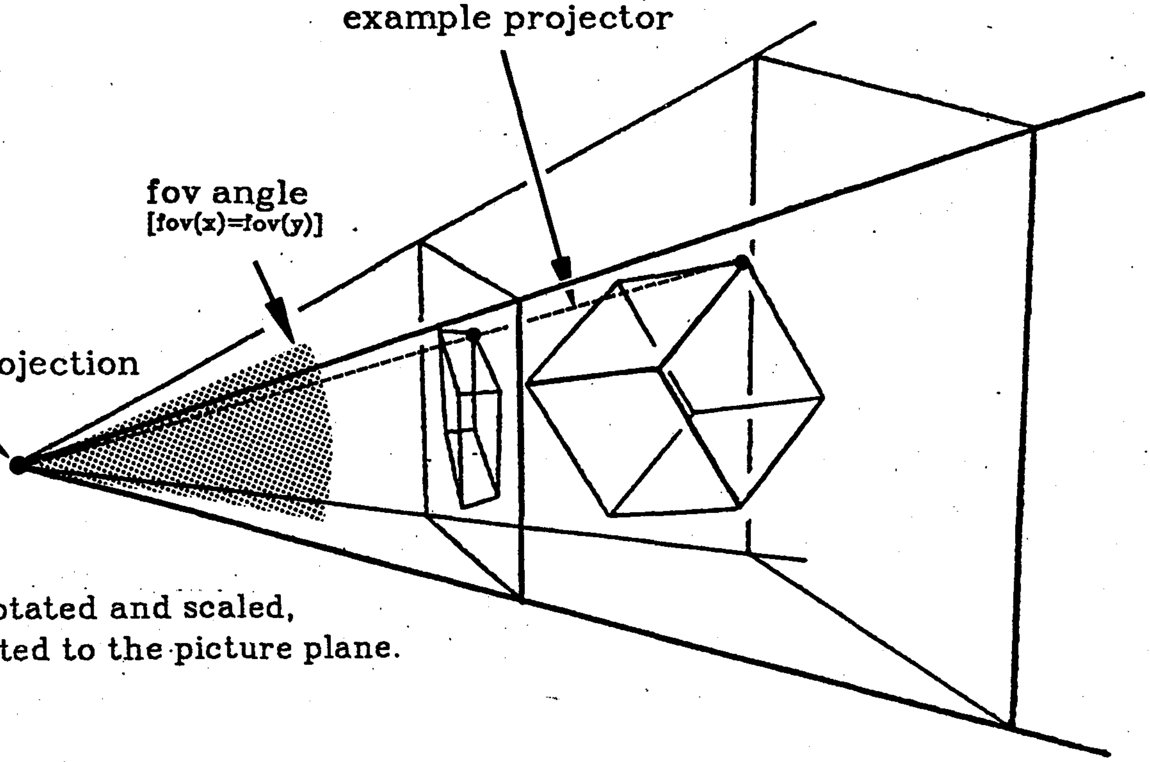
fig. 1
Example of projection



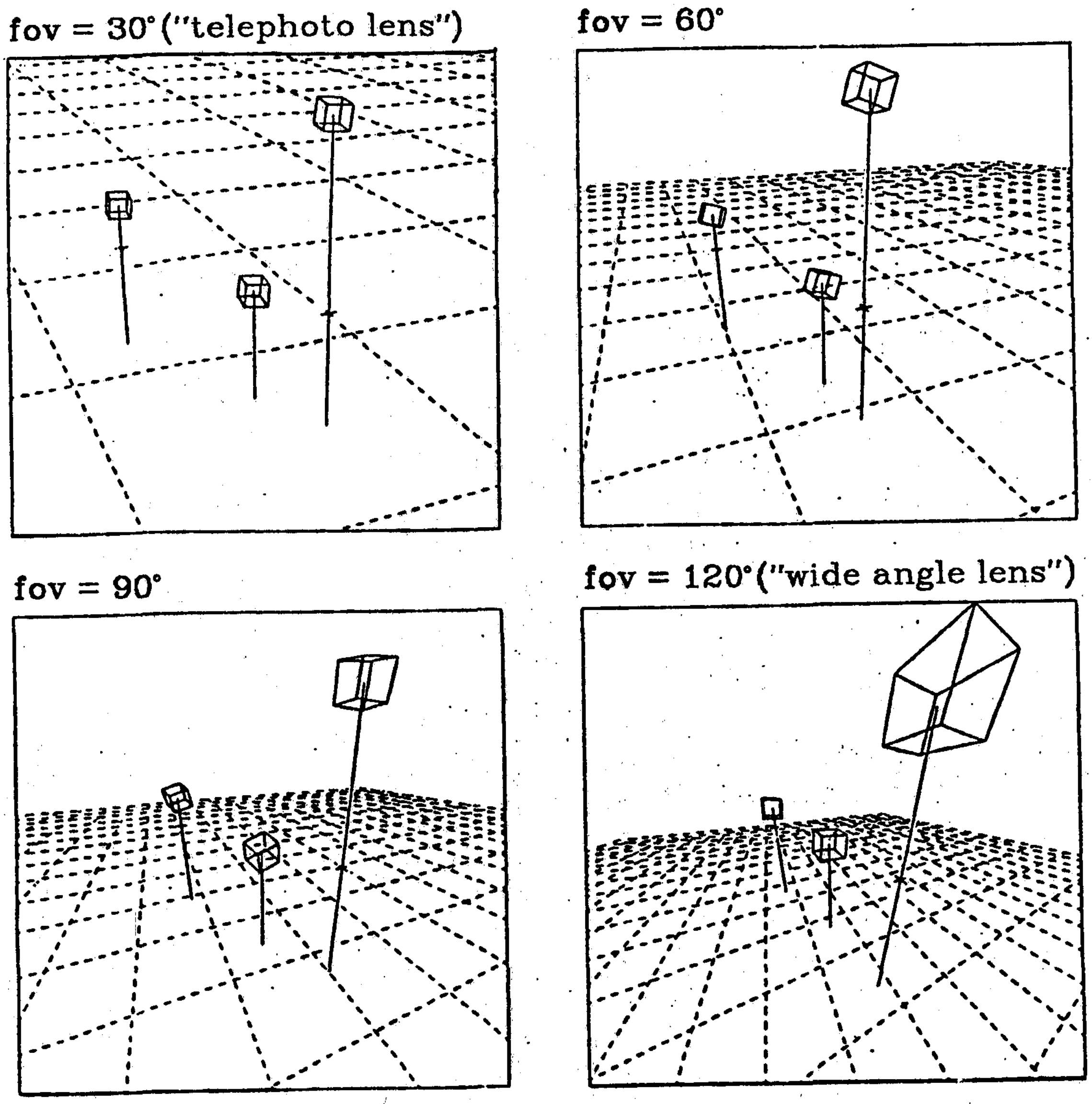
Object is translated
from definition origin to reference point.



Object is rotated and scaled,
and projected to the picture plane.

fov = visual angle of display screen as seen from center of projection

fig. 2
Field of View Effect
(constant viewing distance and direction)



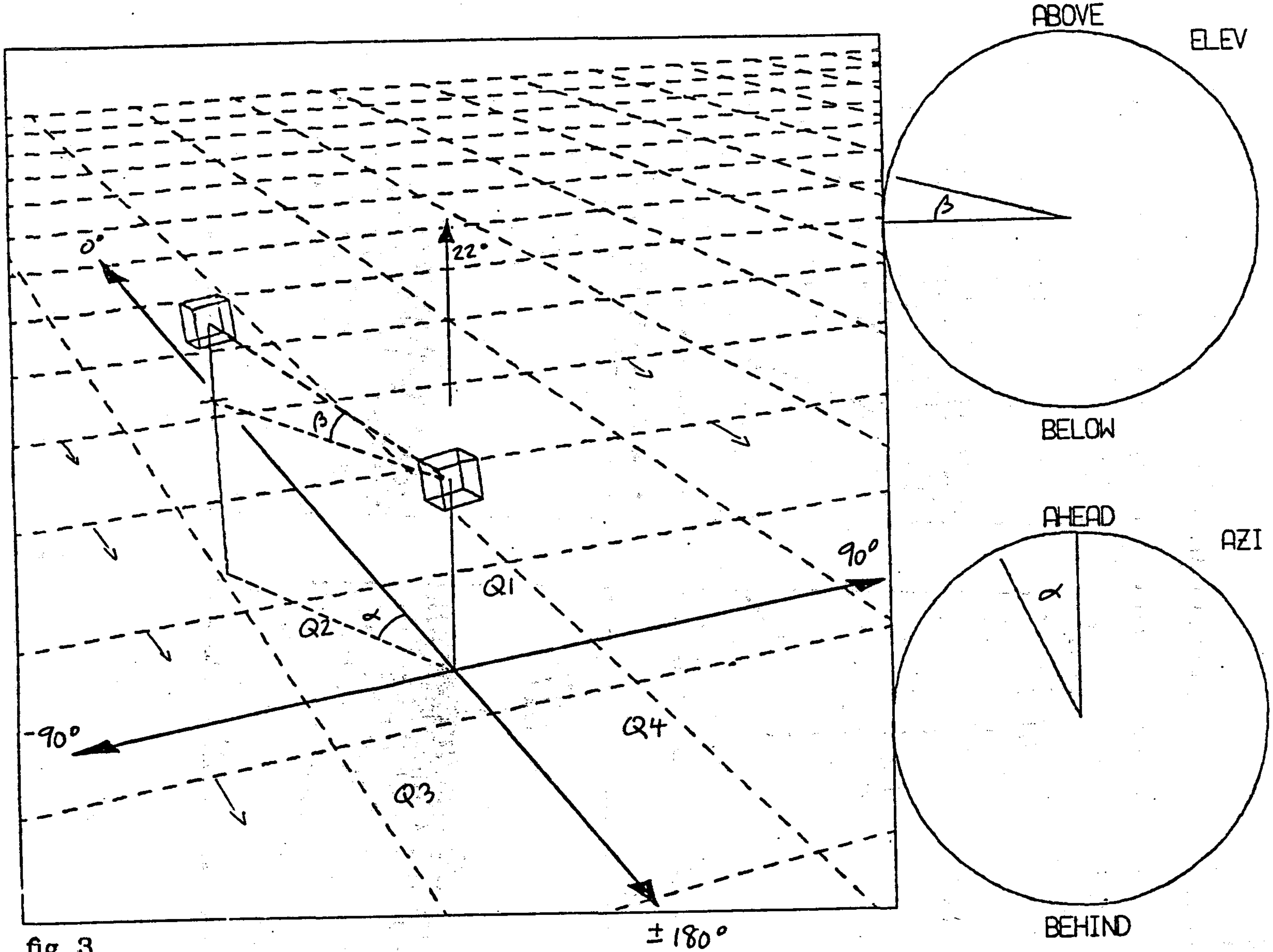
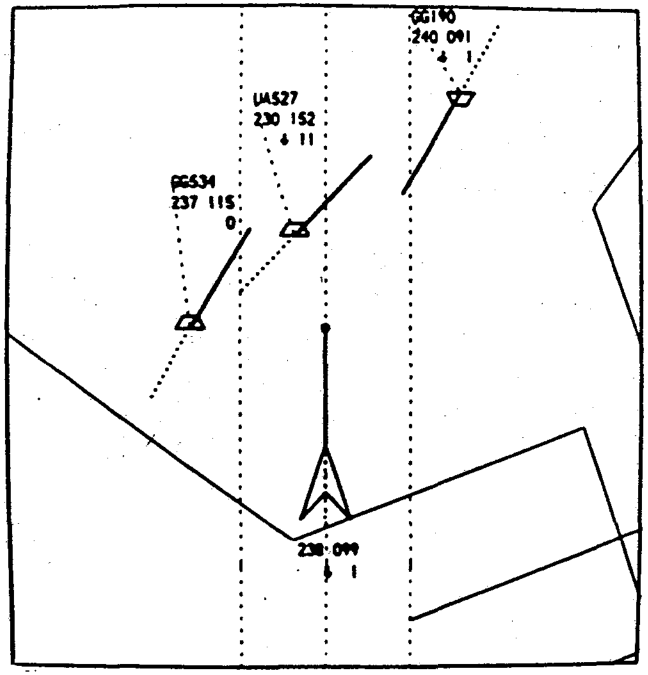


fig. 3
Diagram of Perspective Scene
Used in Experiment

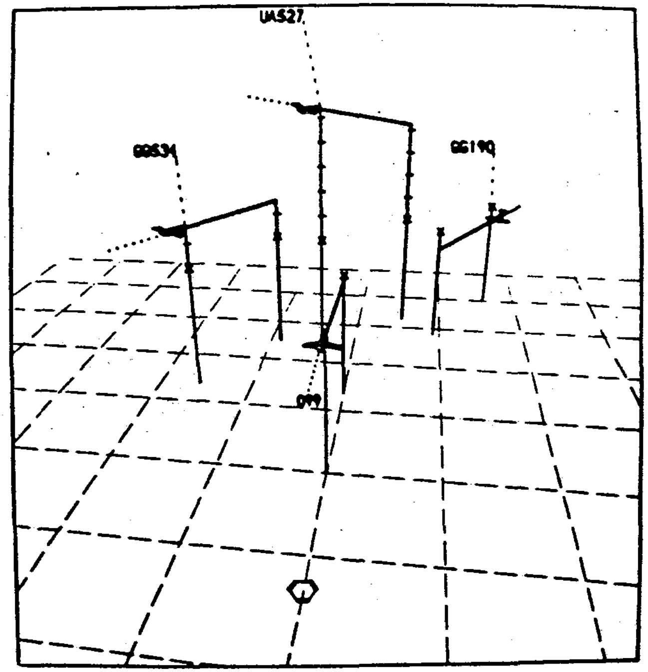
fov = 30 ue=-13667
elev= 22 uh= -3537
azi = 22 uy= -3537
hra= 3537 ul= -2714
vra= 3537 ur= 2714
seq 3 ub= -2714
tID 81 ut= 2714

fig. 4
Examples of Spatial Displays

PLAN-VIEW DISPLAY



PERSPECTIVE DISPLAY



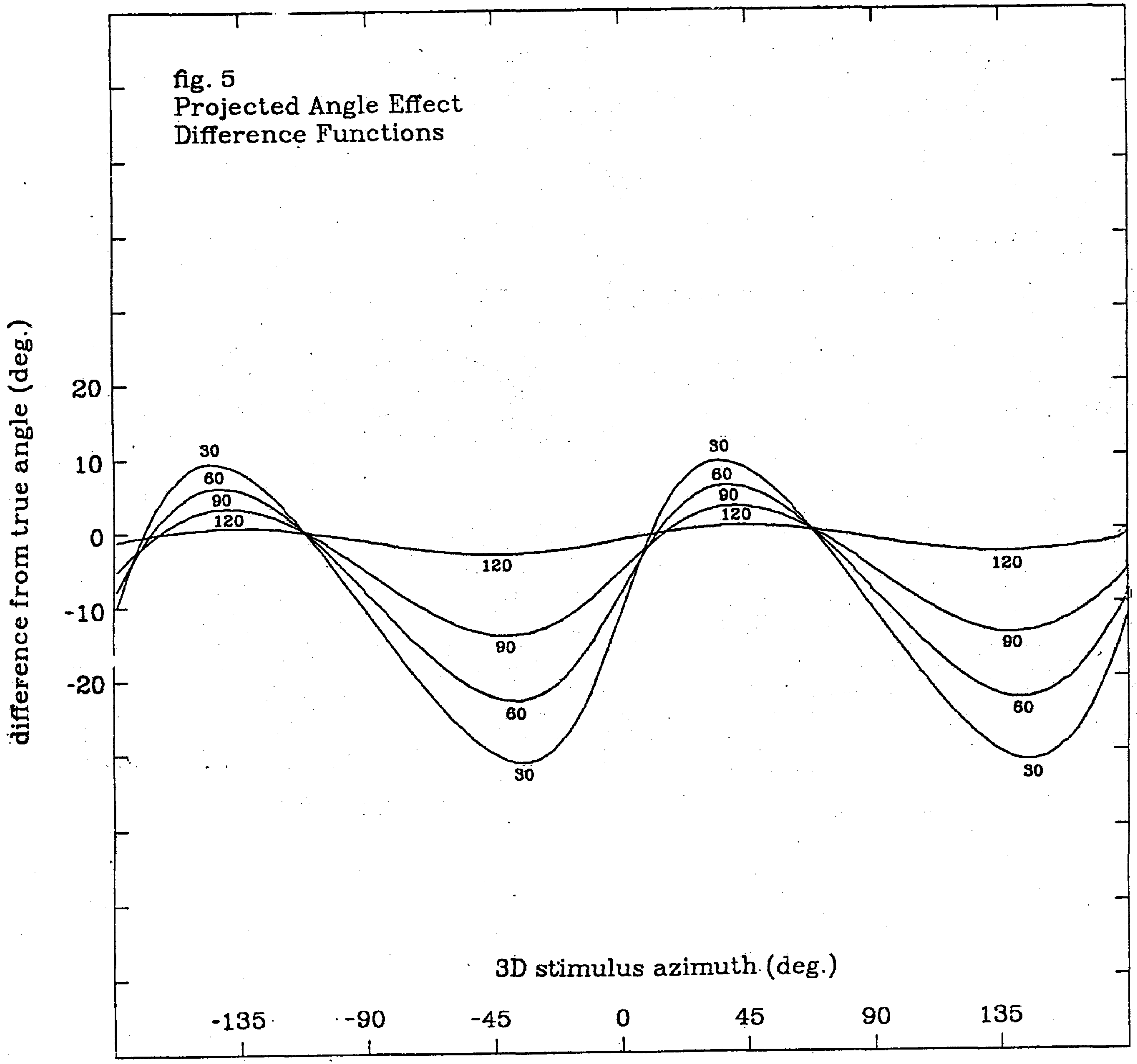
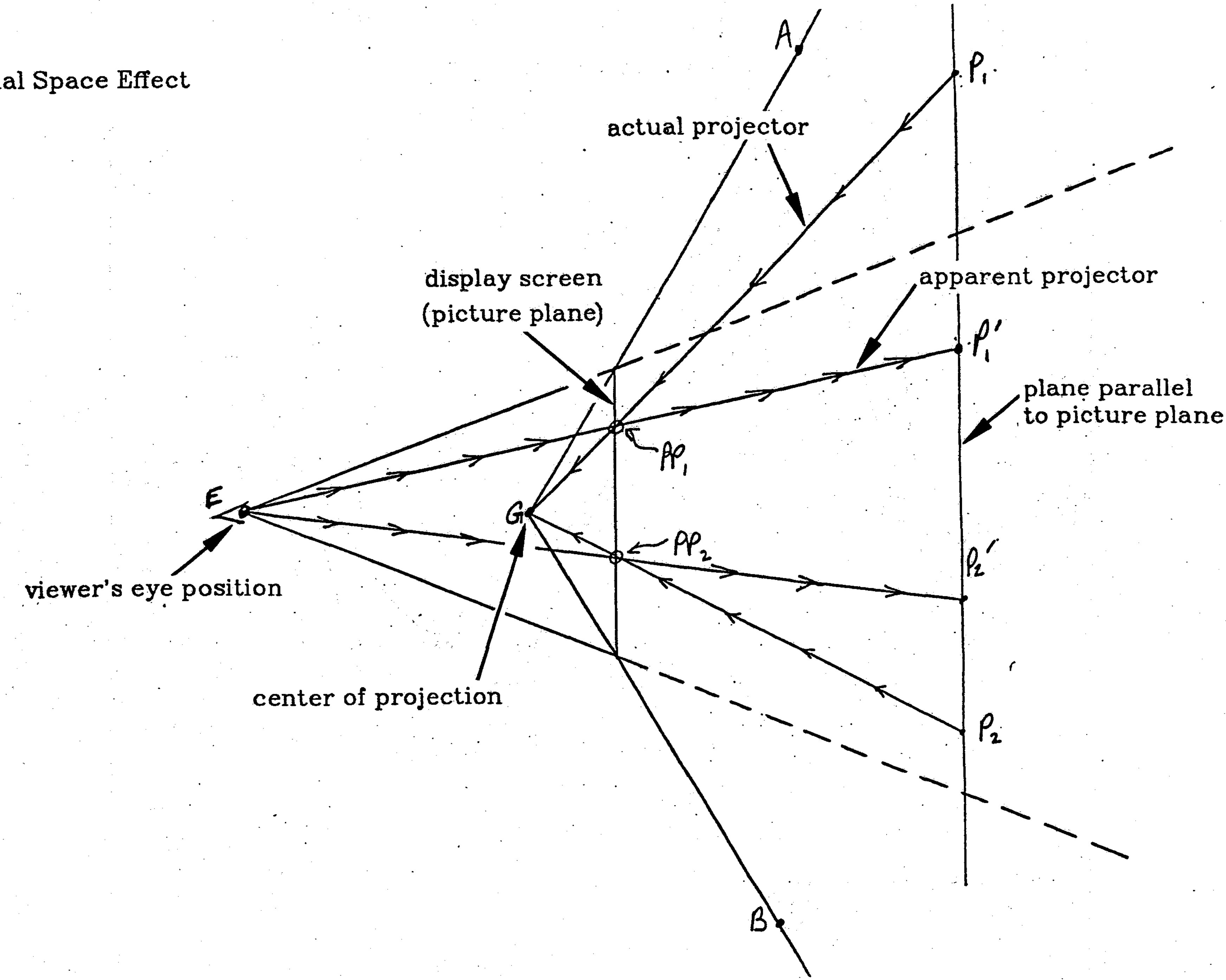


fig. 5
Projected Angle Effect
Difference Functions

fig. 6
Virtual Space Effect



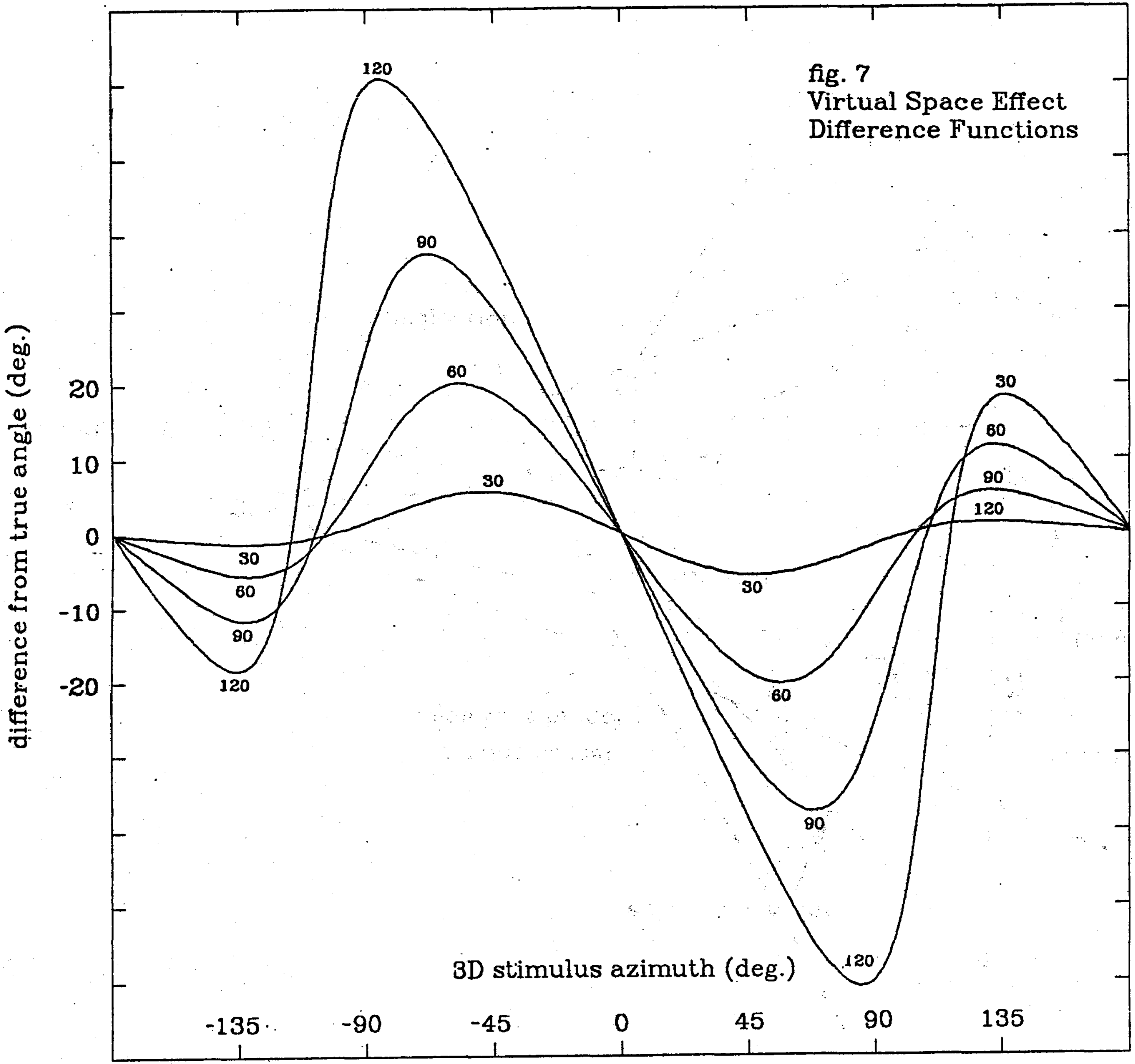


fig. 7
Virtual Space Effect
Difference Functions

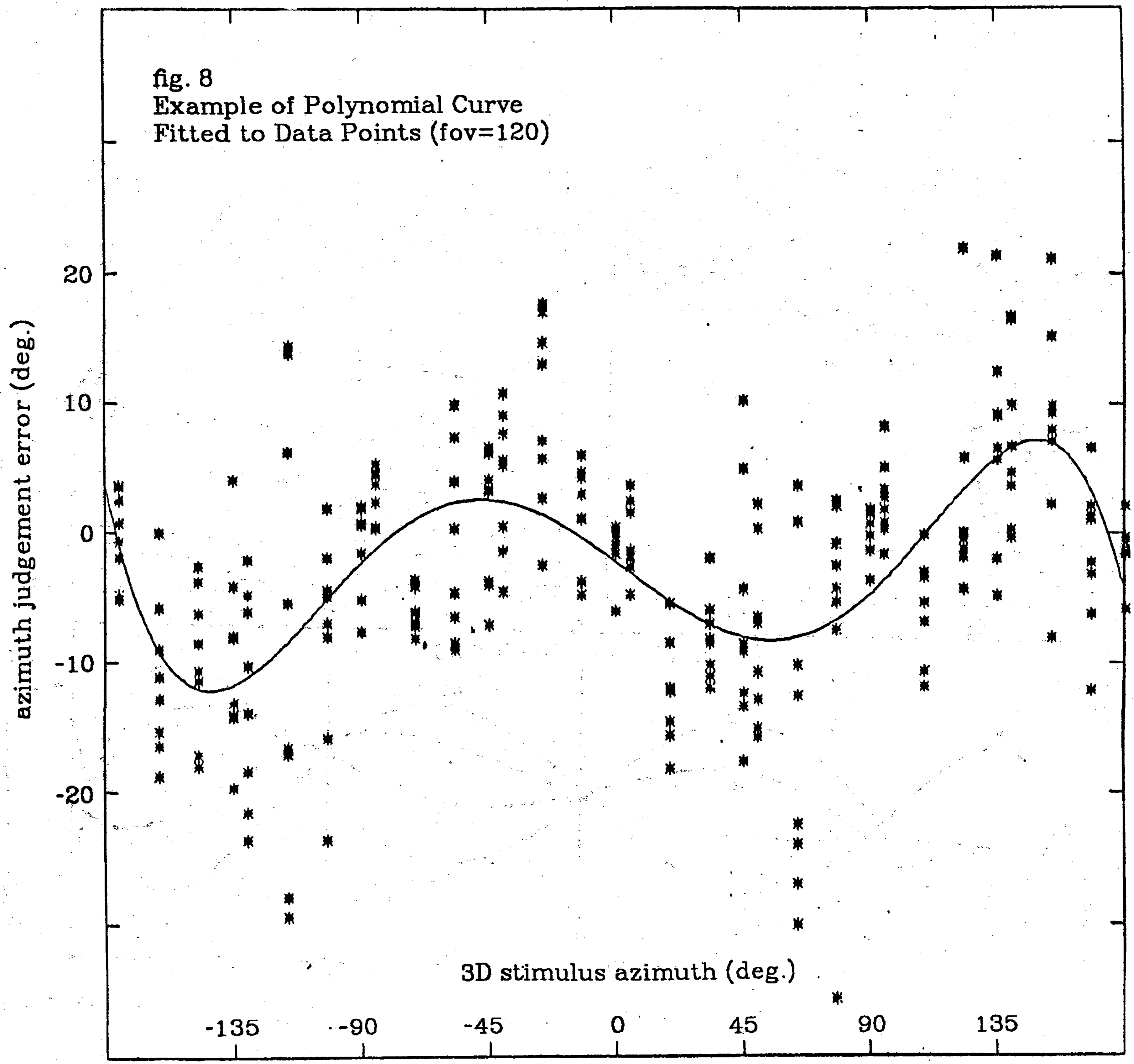


fig. 8
Example of Polynomial Curve
Fitted to Data Points (fov=120)

fig. 9
Data Summary Polynomials
and their Spatial Interpretation

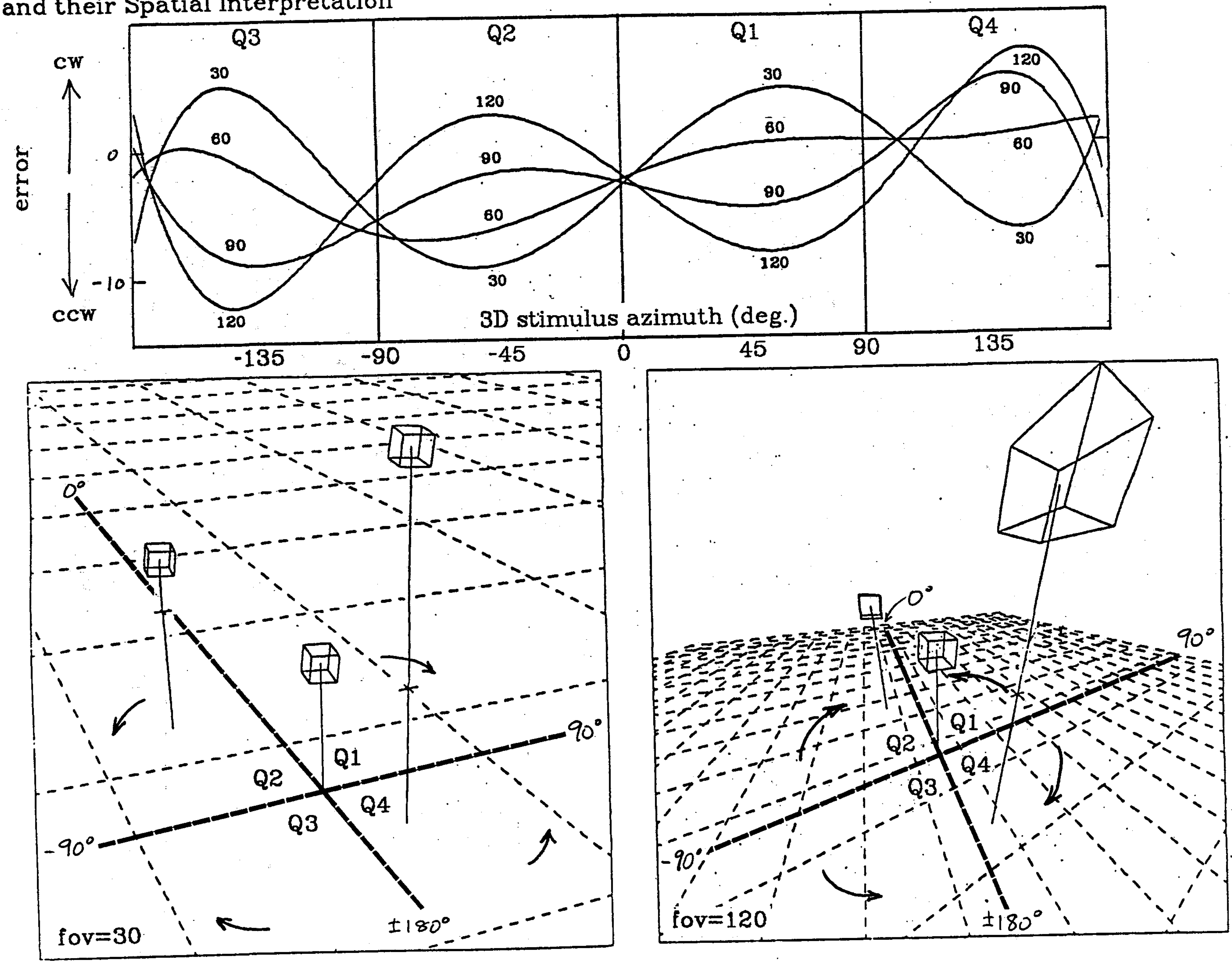


fig. 10
Comparison of Data Polynomials
and Composite Model Curves