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THE EFFECT OF SHAPE ON AIRCRAFT VULNERABLE AREA AND PROBABILITY OF KILL FOR AN ANTIAIRCRAFT ARTILLERY SIMULATION MODEL

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THESIS

GAW/MC/74-19 James P. VerStreate
Capt. USAF

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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Graduate Aerospace Engineering

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Preface

This report is the result of my attempts to analyze the effect of errors in vulnerable area due to the shape of an aircraft or component. A primary motivation was my interest in attaining a better understanding of the methods used to determine the vulnerability of a weapon system, an important factor in the design evaluation of aircraft.

I wish to thank Dr. D. W. Breuer, my thesis advisor, for his guidance throughout this effort. I would especially like to thank Mr. John H. Howard, Jr., for the use of his aircraft model programs, without which this study might not have been accomplished, his patient help in developing the computer program for drawing objects in a rotated system, and great motivation throughout this effort.

I also wish to thank my wife very much for her patience and understanding during the trying periods encountered while completing this study.

James P. VerStreate

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Abstract

An investigation is made to determine the effect of object shape on the calculation of 26 view vulnerable areas from six orthogonal views by the geometric projection method. Errors in vulnerable area are found for a parallelepiped, a pyramid, a cone, a cylinder, a sphere, a combination of these bodies, and two aircraft shapes - the OV-10 and the A-10. The P001 Antiaircraft Artillery Simulation Computer Program is used to determine probability of kill variation due to errors in vulnerable areas of the aircraft shapes. Errors in vulnerable area for the geometric bodies vary from 0% to 70% of actual area depending on the object and view. Vulnerable area variations average 6% of actual vulnerable area for the OV-10, 13% for the A-10 computer model, and 14% for the A-10 aircraft. These variations in vulnerable area result in cumulative probability of kill variations for flights against two weapon locations of 8.5% and 6.9% for the OV-10, 9.4% and 13.2% for the A-10 computer model, and 14.1% and 15.6% for the A-10 aircraft.

I. Introduction

Background

Aircraft survivability in a combat environment is an important factor in the evaluation of both preliminary aircraft designs and existing weapon systems. This concept has received increased emphasis as a result of the military experience in Southeast Asia. Several methods have been developed to determine the vulnerability of an aircraft to different types of hostile threats. These threats can be antiaircraft artillery, surface-to-air missiles, air-to-air missiles, or air-to-air artillery. These threats create damage due to impact by a projectile, by fragments from an exploding warhead, or by blast from the exploding warhead.

An integral part of a survivability analysis for projectile or fragment penetration is the computation of the vulnerable area of the target aircraft. Vulnerable area, A_v, is defined as that area of a target or component which, if hit by a specific threat, causes a specified kill of the target. It is normally expressed as

$$A_v = P_{kh} \times A_p \tag{1}$$

where P_{kh} is the probability of kill of a target given a random hit on the target and A_p is the presented area of the target projected on a plane perpendicular to the shotline of the threat.

In present methodology vulnerable areas are found either by using computer programs which require a detailed geometric description of the aircraft and its components as input, or by manual calculation from scaled engineering drawings of the aircraft major views. Although the computer method is more flexible, the cost and time necessary to develop a complete geometric target description is often not available. Therefore, the manual calculation method is frequently used. The major aircraft views available in detailed drawings are normally limited to three (top, front, and one side) or six orthogonal views (top, bottom, front, rear, and sides). Presented areas of critical components are measured from these drawings in order to calculate the associated vulnerable area for each of these six views of the aircraft. These vulnerable areas constitute the six faces of a theoretical "box."

The present antiaircraft computer simulation model requires an input of vulnerable areas of the aircraft for 26 views, composed of 45 degree increments in azimuth and elevation about the aircraft. Geometric projection of the six orthogonal vulnerable area faces is used to determine the remaining 20 oblique views of vulnerable area. This projection method does not account for shapes other than a "box" or for any component shielding on the oblique views. As a result, errors in vulnerable area are introduced, affecting probability of kill predictions.

Problem

The problem is to determine (1) the effect of object shape on the calculation of aircraft vulnerable areas and (2) the effect of errors in vulnerable area on the probability of kill, P_k, of an aircraft due to projectile or fragment penetration.

Scope

In this study aircraft vulnerable areas are computed from measured presented areas for 26 views using computer models of the OV-10 and A-10 aircraft. These areas are compared with vulnerable areas obtained by geometrically projecting the six major view vulnerable areas into 26 views. The difference between the measured and projected vulnerable areas determines the amount of error due to shielding and shape. Both the projected and measured sets of vulnerable areas for each aircraft are used in the Air Force Armament Laboratory P001 Antiaircraft Artillery (AAA) Simulation Computer Program to determine the variation in probability of kill obtained for a specified flight path and antiaircraft gun threat.

A computer program is developed by the author to plot five basic geometric shapes - a parallelepiped, a pyramid, a sphere, a cylinder, and a cone - in any orientation. The presented areas for 26 views of each shape are measured and compared with those obtained by geometric projection of the six major view areas to determine the error due to shape. A comparison of measured and projected sets of presented areas for a random combination of these shapes is made to determine the error caused by shape and shielding effects.

The study is limited to the investigation of shape variation of the two aircraft and five geometric bodies. The magnitude of variations that are found apply only to each specific case.

Assumptions

An underlying hypothesis to this problem is that there is error in the projection method of vulnerable area calculations for the P001 AAA Simulation Model. It is assumed that this error is due to shape and shielding of components that is unaccounted for by the geometric projection of six major view areas into 26 areas.

The probability of kill given a hit (P_{kh}) for the aircraft models and all geometric shapes is assumed to be one, so that presented areas are equal to vulnerable areas. This assumption is valid for the larger antiaircraft threats only. It is used to simplify the analysis and to provide a common basis for comparison of the magnitudes of vulnerable area variation and probability of kill for the shapes studied.

The OV-10 and the A-10 aircraft skin models are used as examples of the complex shapes of aircraft for the analysis. The results are not intended to reflect actual vulnerability statistics for either aircraft.

In the P001 AAA Computer Program the prediction of all tracking and gun firing errors is assumed to be correct. This allows any variation in probability of kill to be only a function of variation in vulnerable area.

II. Survivability Assessment Methodology

Survivability

Survivability is defined as the capability of a system to avoid and withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission (Ref 2:1). The survivability of a weapon system is dependent upon many parameters. The probability that a system will survive (P_s) in a given hostile environment is expressed mathematically by

$$P_s = 1 - P_k \qquad (2)$$

where P_k is the probability that the system will be killed. The probability of kill of a system is a function of its vulnerability to a hostile threat and the probability that it will be hit by that hostile threat. Approximate solutions to the probability of kill problem are found by developing attrition models which simulate the effect of a specified threat or damage mechanism against the weapon system. The weapon system is input to the attrition model in terms of its vulnerability to the threat, so the first step in the survivability assessment of a system is a vulnerability analysis.

Vulnerability

Vulnerability is defined as the characteristics of a system which cause it to suffer a definite degradation (incapability to perform the designated mission) as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment (Ref 2:2).

Kill Levels. There are four basic categories of damage that are used to assess the vulnerability of an aircraft in flight. These categories define the level of damage required to make the aircraft incapable of performing its mission. These are called "kill" categories and are named attrition, forced landing, mission, and mission available in decreasing order of magnitude. The attrition category is divided into five levels of kill. The first four are sequentially inclusive and time dependent. These kill levels are:

1. KK Kill - damage that causes the aircraft to disintegrate immediately upon being hit. An example of this could be a major structural hit.

2. K Kill - damage that causes an aircraft to fall out of manned control within 30 seconds after being hit. This could involve the pilot, structure, engine, or ammunition.

3. A Kill - damage that causes an aircraft to fall out of manned control within five minutes after being hit. This might involve hits in the engine, fuel system, or flight controls.

4. B Kill - damage that causes an aircraft to fall out of manned control within 30 minutes after being hit. This could include damage to the engine or fuel system components.

5. E Kill - damage that causes the aircraft to sustain additional levels of damage upon landing such that it is uneconomical to repair. This could involve hits on the landing gear, controls, or control surfaces.

The forced landing category covers damage which causes an aircraft to execute a forced landing. This could be caused by damage to hydraulic or fuel lines, the electrical system, or the engines.

The mission category includes that damage which prevents an aircraft from completing its designated mission and is divided into two levels:

1. Mission Abort - damage which causes loss of the mission, but not the aircraft.

2. Mission Kill - damage which causes an aircraft to fall out of manned control before completing its designated mission.

The lowest kill category is mission available, which includes all aircraft that require repairs before returning to mission ready status.

Critical Components. An aircraft is vulnerable to many kill mechanisms such as blast, fire, fragmentation, and penetration. The effect of these mechanisms on the critical components of the weapon system yield its vulnerability. Critical components are those components that are essential for stability, control, or flight of the vehicle within the limits of a specified kill level. Examples of critical components of an aircraft are the crewmembers, airframe, engines, fuel system, and flight controls. These components are called singly vulnerable if the loss of any one component results in the specified kill level. Multiply vulnerable components are those which require more than one to be lost in order for the aircraft to be killed. Redundant components such as crewmembers and engines are examples of multiply vulnerable components.

<u>P_{kh}</u>. Once kill levels, critical components, and damage mechanisms are specified, the level of damage that a component must sustain to prevent continued operation and the capability of the various damage mechanisms to inflict such damage can be determined. The predicted component damage is then used to determine the resultant target performance degradation. This results in component P_{kh} values, which are expressed as a function of velocity and mass.

<u>Vulnerable Area</u>. Vulnerable area is defined mathematically to be

$$A_v = \iint_{A_p} P(x,y)\,dy\,dx \tag{3}$$

where P(x,y) is the probability that the target is defeated by an impact at the point (x,y) in the plane in which the vulnerable area is to be measured and A_p is the presented area in that plane. Eq. (3) can be approximated by

$$A_v = P_{kh_1}A_{p_1} + P_{kh_2}A_{p_2} + \ldots + P_{kh_j}A_{p_j} \tag{4}$$

where the A_{p_j}'s are the projected areas of the critical components and the P_{kh_j}'s are the kill probabilities given a hit on these components (Ref 4:18).

Vulnerable area is a function of several parameters. First, it depends upon the characteristics of the attacking projectile. These characteristics include the striking velocity and size of the projectile, which determines its kinetic energy at impact. Second, the desired kill levels define the amount of damage to a critical component that is necessary to cause its loss and the subsequent kill of the aircraft. This damage is caused by a specified kinetic energy level of the projectile. Third, the encounter conditions between the projectile and the aircraft are required to completely describe the hostile environment. The relative orientation between the attack trajectory and the aircraft at the point of projectile impact in terms of azimuth and elevation angle determines the presented area to the threat. The altitude and range from the hostile weapon determines the projectile velocity. This velocity and the aircraft velocity determine the impact velocity. Finally, the aircraft characteristics describe the critical components, the criteria necessary to damage them, and their arrangement to determine the amount of shielding of one component by another. Shielding varies with the attack aspect of the projectile.

Presented area can be calculated manually through the use of engineering scaled drawings of the aircraft or photography of scaled models, or it can be calculated by computer. The manual method of calculation is accurate, but it is also time consuming and normally limited to the available aircraft major view drawings. Vulnerable area data for other views must be generated artificially from the major view data. The computer methods for finding vulnerable area require a detailed geometric description of the target aircraft and the accuracy of vulnerable area data is dependent upon the accuracy of this aircraft description.

Target Description

Target descriptions consist of basic information relative to dimensions, external configuration, location of components, thickness and composition of materials utilized in construction of the target and its components. Most target descriptions in use consist of shotline descriptions which are generated from a model of the target. This model may be in the form of engineering drawings or a three-dimensional geometric model of the target, which is used as input to shotline generating computer programs. The shotline is designed to predict the possible trajectory of some threat through a target. Each shotline is used to predict thickness and angles of intersection made with elements of the target. Shotline information can be obtained manually or by computer methods. MAGIC and SHOTGEN are two computer programs currently being used for this purpose. Both programs have similar output, but they differ in target modeling. The MAGIC target model is based on the combinatorial geometry method, which consists of describing target surfaces in terms of simple geometric bodies such as boxes, wedges, spheres, cylinders, cones, and ellipsoids. The SHOTGEN target model is based on the triangular approximation method in which all component surfaces are described with adjacent triangles.

Both of these target description models require extensive time to develop, and the MAGIC and SHOTGEN computer programs that use them can require up to two hours of computer time to generate the shotline output for two views of a complex aircraft such as the F-4. As a result, many vulnerability analyses are still accomplished manually.

Vulnerable Area Generation

If shotline data for projectiles or fragments is available, it can be used as input to the VAREA or COVART computer programs to determine vulnerable areas for any aspect of the target. The threat characteristics, component damage functions, and kill levels are specified and the kill contribution of each vulnerable component is computed using either a curve or a step function to relate the penetrator's striking mass and velocity to a conditional kill probability. Vulnerable area is developed by computing the conditional kill probability, P_{kh}, of each shotline and taking the product of P_{kh} and the area associated with each shotline. Summing all of the shotline vulnerable areas defines the target vulnerable area.

If vulnerable area calculations are accomplished manually, the results are normally based on the six major views of the target. The vulnerable areas of the critical components are summed for each view, including any component shielding. If any additional vulnerable area views are required, they are usually found by geometric projection of the adjacent major view vulnerable areas.

Threat Attrition Model

Once vulnerable area data has been found it is used as input to the appropriate threat attrition model to determine the probability of kill of the target. In order to find the probability of kill of the aircraft the probability of hitting it, P_h, must be evaluated. The probability of hit is expressed mathematically by

$$P_h = \iint_A P(x,y)dxdy \tag{5}$$

where A is the presented area of the aircraft and P(x,y) is a probability density function accounting for errors in gun tracking and firing (Ref 1:50). The probability of kill is then the probability that the projectile hits within the vulnerable area of the aircraft.

P001 Antiaircraft Artillery (AAA) Simulation Computer Program. This program, developed by the Air Force Armament Laboratory, is used to determine the probability of kill of a target aircraft flying a predefined flight path against specified AAA threats. The program analyzes the sources of random error which influence the effectiveness of the AAA. These errors include prediction of an aim point, firing process errors, and uncertainties and perturbations which arise externally to the weapon system. All of these sources of random error, which contribute to the distribution of projectile trajectories, are assessed by the program in order to locate the vulnerable area of the aircraft within this total distribution of trajectories and to compute a probability of kill.

The program requires vulnerable area data for 26 views of the aircraft, corresponding to 45 degree increments of azimuth and elevation about the aircraft. These combinations of azimuth and elevation locate points on an imaginary spherical surface surrounding the aircraft. A line from these points to the center of the aircraft represents a direction of view or a shotline of an impacting projectile. Azimuth is an angle in the horizontal plane referenced from the front of the aircraft on the X axis and is positive in a counterclockwise direction. Elevation is an angle in a vertical direction referenced from the X-Y plane and is positive above this plane. The orientation of the 26 views about the aircraft is illustrated in Fig. 1. As an example, view 23 represents a viewing aspect of the aircraft from 45 degrees azimuth and 45 degrees elevation on a sphere.

Vulnerable areas corresponding to eight striking velocities are input for each of the 26 views of the aircraft. This builds a three-dimensional array which is interpolated using impacting aspect and velocity of each shot at the aircraft to determine the vulnerable area exposed to that shot. Knowing this vulnerable area and the location of the aircraft with respect to the center of distribution of the projectile trajectories, the probability of kill of the aircraft is the summation of the probabilities of a projectile being located anywhere within this vulnerable area at the time of intercept (Ref 5:vii).

The P001 program uses a deterministic technique in which

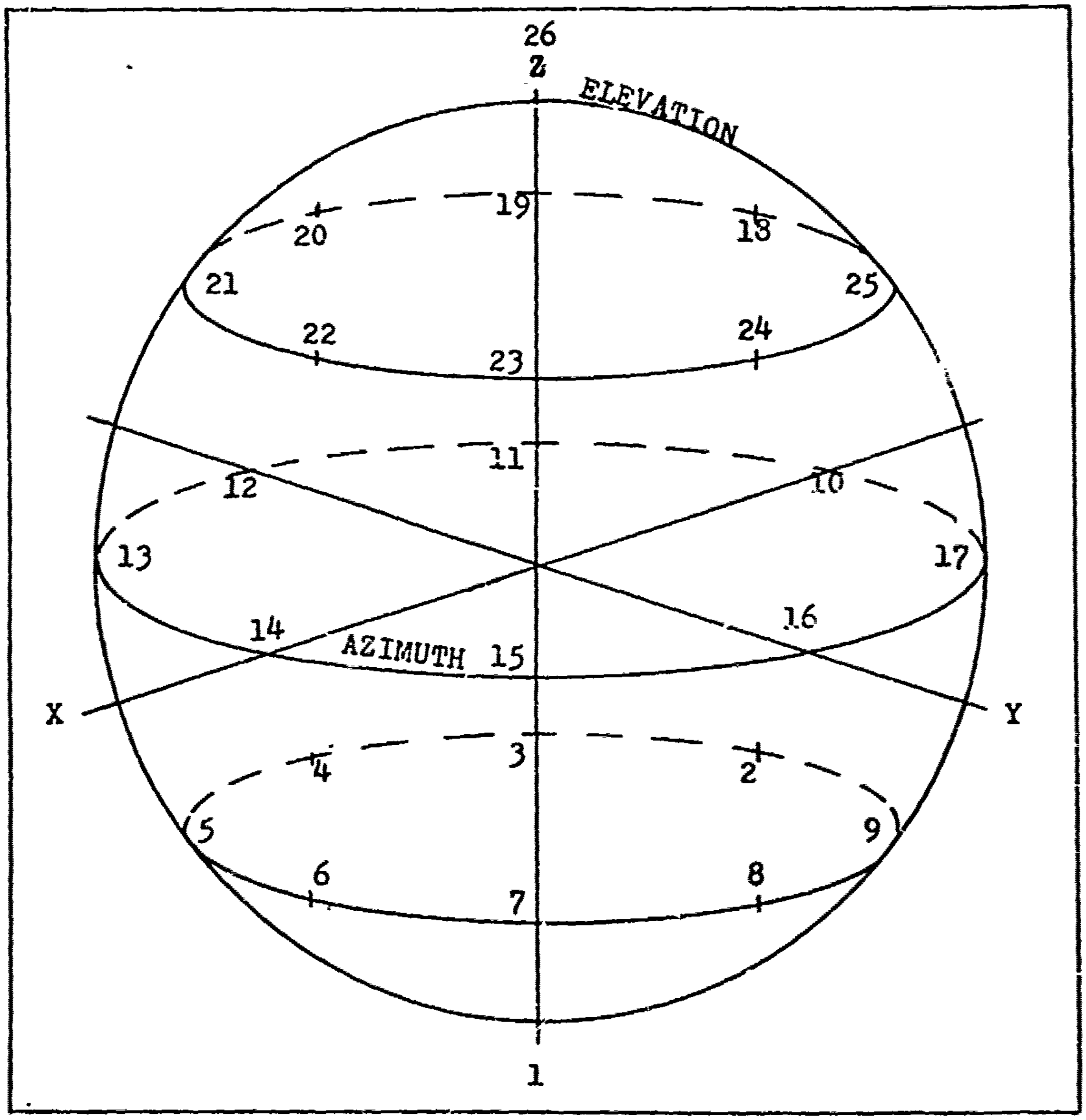

Figure 1. The 26 View Vulnerable Area System.

the distributions of the effects of all random errors are combined to form a probability distribution of projectile trajectories, centered about a "mean" aim point. This technique assumes that the respective distributions of the effects of random errors are Gaussian (Ref 6:1-3). Using the bivariate normal distribution of random effects, the interpolated vulnerable area for the projectile impact aspect, and the location of the aircraft, the single shot probability of kill (P_{kss}) is computed by the formula

$$P_{kss} = \frac{\frac{A_v}{2\pi}}{\sqrt{S_{f_1}^{\,2} + \frac{A_v}{2\pi}}\;\sqrt{S_{f_2}^{\,2} + \frac{A_v}{2\pi}}} \exp(A)$$

$$A = -\tfrac{1}{2}\left[\frac{f_1\text{bias}^2}{S_{f_1}^{\,2} + \frac{A_v}{2\pi}} + \frac{f_2\text{bias}^2}{S_{f_2}^{\,2} + \frac{A_v}{2\pi}}\right] \qquad \text{(Ref 6:2-51)} \qquad (6)$$

where A_v is the vulnerable area, $S_{f_1}^{\,2}$ and $S_{f_2}^{\,2}$ are total error variances, and $f_1$bias and $f_2$bias describe the aircraft's location. Any error in the interpolated value of vulnerable area due to the 26 view values input to the program will cause an error in probability of kill.

III. Procedure

General

The magnitude of error in vulnerable area produced by the geometric projection of various shapes is to be determined. Actual presented area data can be compared with projected area to evaluate this error. Data for 26 views of any aircraft is not generally available, but a computer program for rotating and plotting scaled models of two aircraft does exist and is used to obtain this data. Presented areas for some basic geometric bodies are found with the use of a computer program that plots them in any desired aspect. Finally, vulnerable area data can be used in P001 to determine the magnitude of error in probability of kill caused by error in vulnerable area.

Aircraft Computer Models

Scaled plots of the A-10 and OV-10 aircraft skin models are generated by a computer program. This program allows the scaled models to be rotated and plotted for any combination of azimuth and elevation. The basis for this rotation program is an Euler angle transformation matrix with azimuth angle representing a rotation about the Z axis and elevation angle angle representing a rotation about the Y axis. Azimuth is 0 on the X axis and positive in a counterclockwise direction to 180 degrees and elevation is 0 in the X-Y plane and positive above that plane as shown in Fig. 2. The aircraft is oriented in the reference frame with its longitudinal axis aligned with the X axis and its lateral axis aligned with the Y axis.

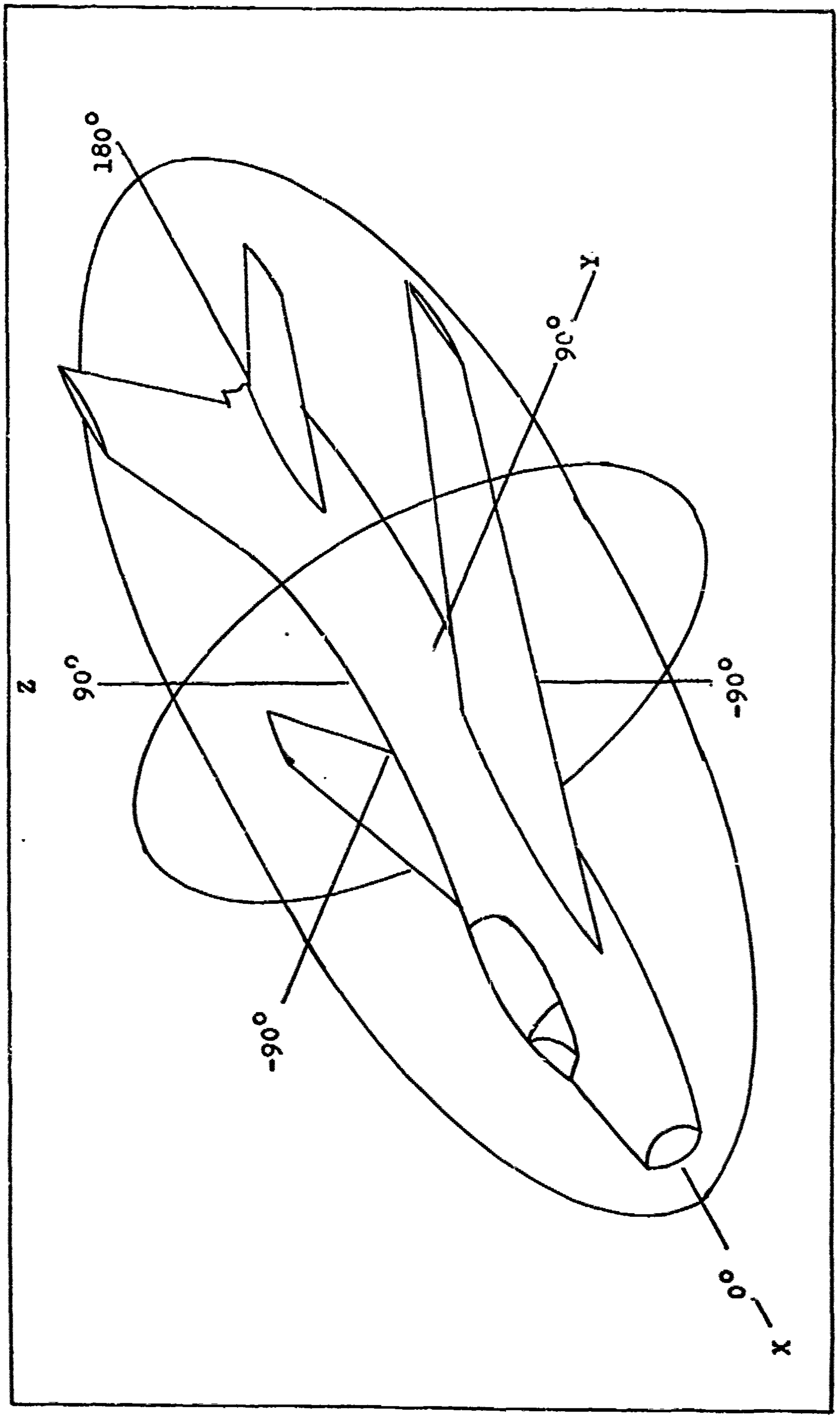

Figure 2. Reference System for Aircraft Program.

The desired values of azimuth and elevation for the required views are input to the program with the desired plot size of the aircraft. These views are plotted and labeled with azimuth, elevation, and scale factor. Examples of the OV-10 and A-10 plots are shown in Fig. 3 and Fig. 4.

Symmetry of the aircraft shape about the X-Z plane results in only nine distinct views necessary to completely represent the 26 views of the aircraft. These distinct views and the corresponding equivalent views using the numbering system of Fig. 1 are listed in Table I.

Table I.

Distinct Presented Area Views and the Equivalent Views for the 26 View System*

Distinct Views	Equivalent Views
1	26
2	22
3	[illegible], 21, 23
4	8, 20, 24
5	7, 19, 25
6	18
10	14
11	13, 15, 17
12	16

*Refer to Fig. 1 for information on the view numbering system.

Presented Area Measurement

Once the required aircraft views have been obtained in plotted form from the computer the presented areas are planimetered using a Hewlett Packard 9810 Calculator with an attached digitizer. The plot is placed on an electromagnetic digitizing

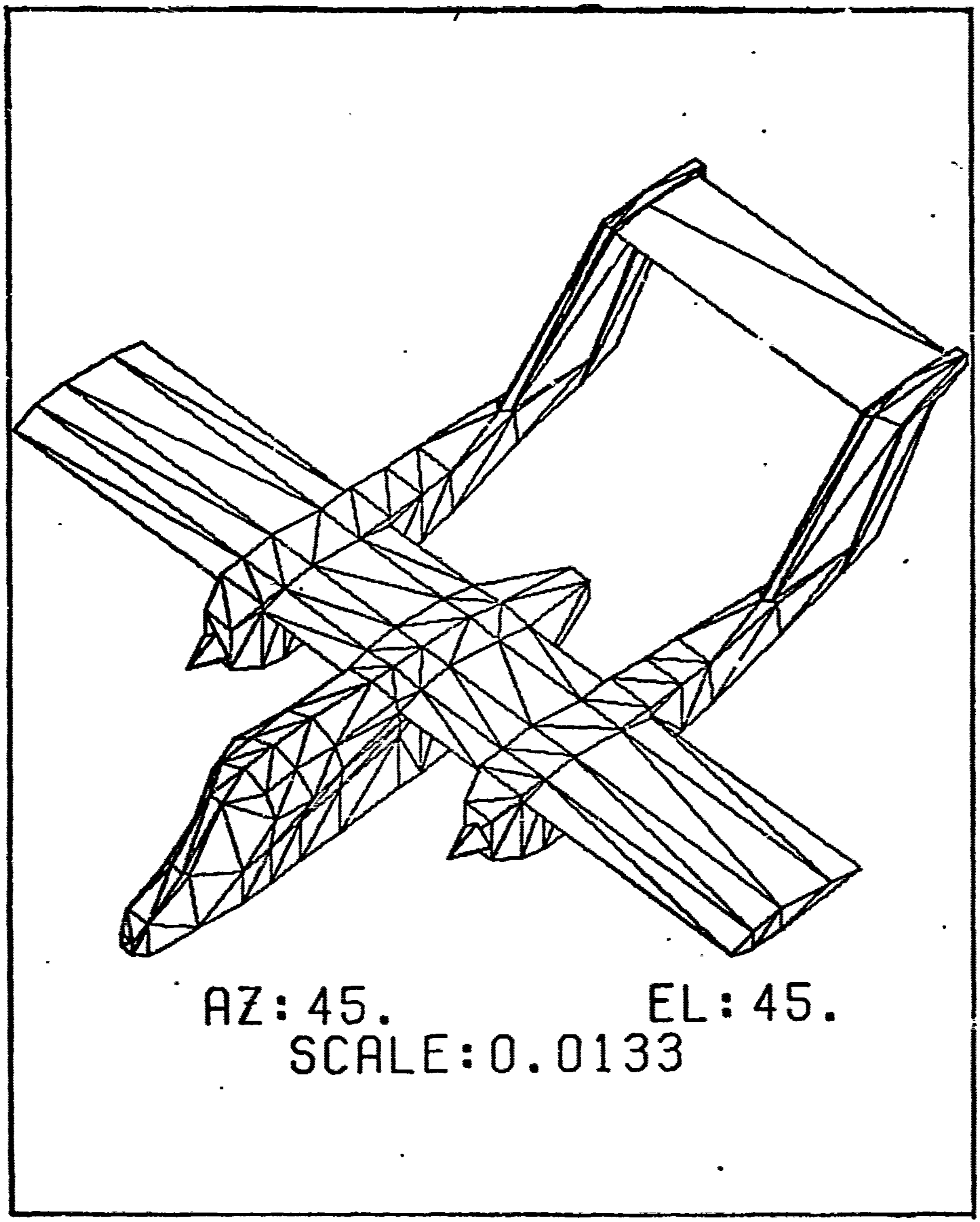

Figure 3. The OV-10 Computer Aircraft Model: View 23.

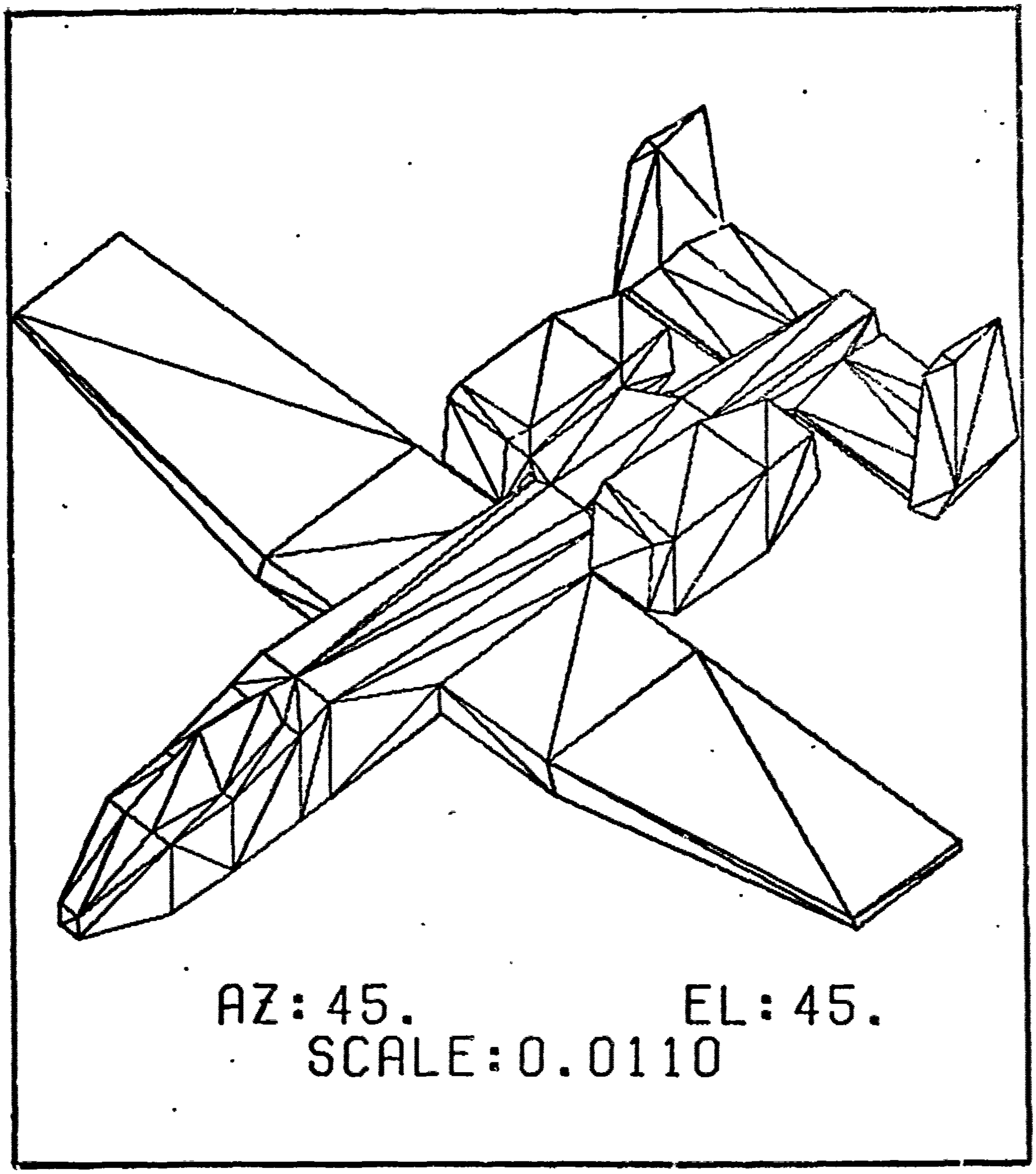

Figure 4. The A-10 Computer Aircraft Model: View 23.

surface and an electronic cursor is used to trace the outline of the aircraft. Points along this outline are recorded as X-Y coordinates to the calculator as the cursor crosshair is moved along the outline. The calculator, through one of the programs available to it, integrates the area between these identified points and designated X and Y axis baselines on the digitizing surface. After the aircraft outline is completely traced the total presented area in square inches is displayed by the calculator. The scale factor of the aircraft plot is then used to convert this presented area into actual area of the real aircraft for that view. The data obtained by this method is accurate within 2% of actual area.

Geometric Projection of Major Views

The presented areas for the major views of the aircraft, assuming symmetry, form a six-sided "box" that can be used to generate the remaining 20 views by geometric projection. The oblique views involve 45 degree projections only. A simple computer program is used to find the 26 view presented areas from those of the six major views. These results are then compared to the measured view data to determine the variation due to projection. The aircraft major view plots used to determine the presented areas for the expansion to 26 views are shown in Fig. 20 - 25 in Appendix C.

Probability of Kill Determination

The 26 view sets of vulnerable area, both measured and projected, for the OV-10 and A-10 models and the actual A-10 aircraft are used in the P001 AAA Simulation Program to obtain probability of kill. All other input parameters for each computer run remain the same so that the effect of vulnerable area differences on probability of kill can be determined.

The P001 program requires input information describing the time history of the flight path and its attitude in relation to a general reference system. Input is also required on the ground weapon location, characteristics, reaction and tracking times, weapon parameters and weapon projectile parameters. A typical aircraft dive bomb delivery flight path is used, which provides sufficient aircraft maneuvering to change the firing aspect of a gun throughout its firing range. The aircraft approaches the target at 15,000 feet altitude and 560 knots, performs a 45 degree dive delivery to 3500 feet above the target located at the origin of the reference system, climbs away from the target and returns to 15,000 feet.

One large antiaircraft gun is placed in one of two locations to fire at the aircraft during any one flight path. Gun location 1 is located with the target at the reference system origin. Gun location 2 is offset 500 meters in the Y direction from the origin. All gun and projectile parameters are automatically included in the program for several antiaircraft guns and the proper ones are called by a code used to identify the type of gun to be used (Ref 6:2-22). The reference system, flight path and gun locations are shown in Fig. 5.

The output of the P001 program includes vulnerable areas interpolated from the input set of vulnerable area data for each shot fired by the gun at the target, the probability of kill for that shot, and the cumulative probability of kill for the flight path. Since all conditions are the same for each computer run except the input vulnerable area set, the interpolated vulnerable areas for each shot can be compared for both the measured and projected vulnerable area data.

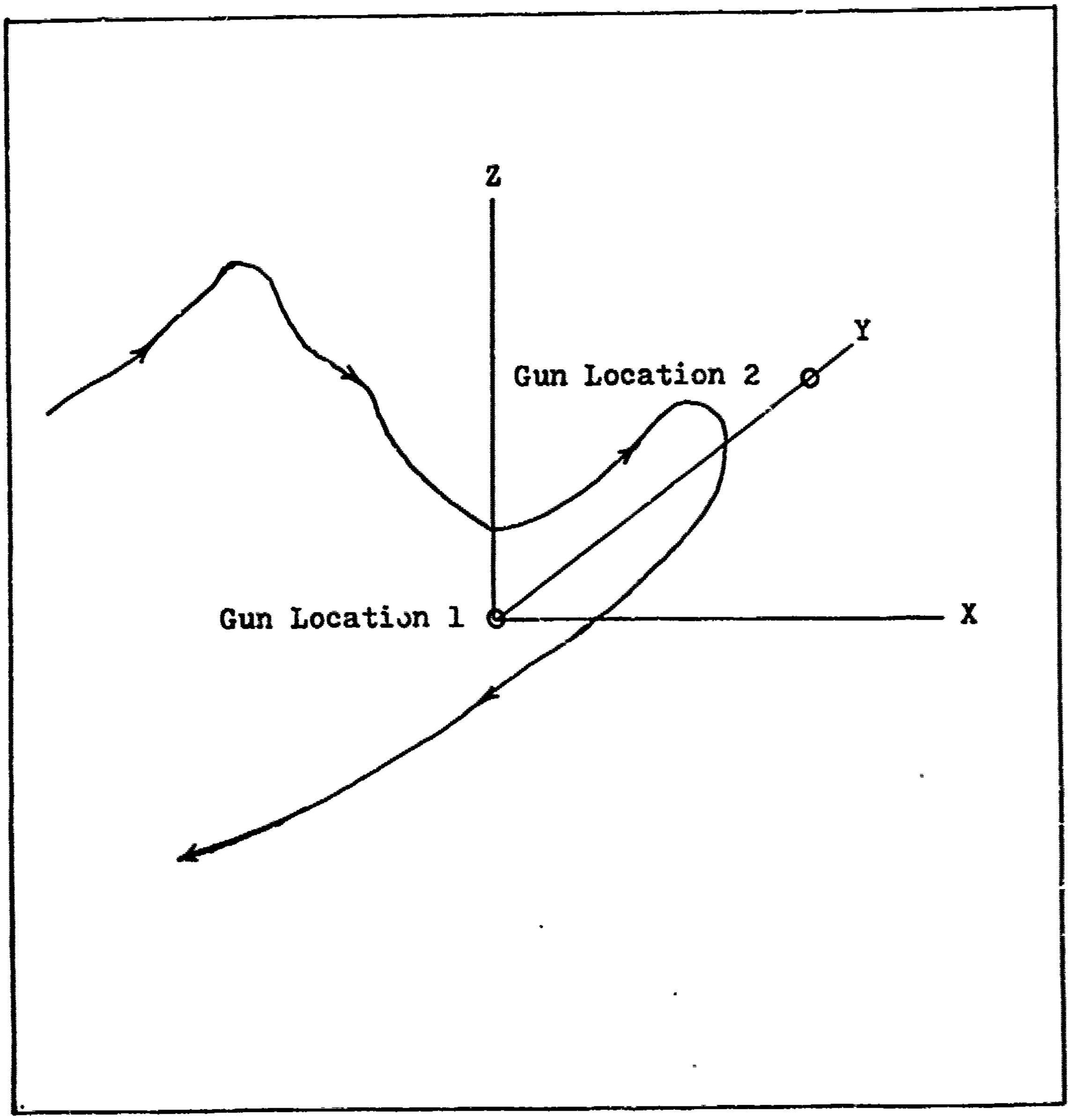

Figure 5. P001 Coordinate System with Aircraft Flight Path and Gun Locations.

Eq. (6) shows that the probability of kill is a function of vulnerable area, gun associated errors, and aircraft location. When comparing the probability of kill obtained with measured vulnerable area data to that obtained using projected vulnerable area data, the gun errors and aircraft location are constant for the same shot in the flight path. Therefore, any difference in the probability of kill is due to the difference between the measured and projected vulnerable area values for that shot. The vulnerable area terms in the denominator of Eq. (6) are small compared to the magnitude of the error variances, so the denominator is basically a constant. The exponent, A, is very small because the bias terms are also small when compared to the magnitude of the variance terms in that exponent. This makes the exponential term, e^A, approximately one. Therefore, the probability of kill is nearly a linear function of vulnerable area, and probability of kill variation is approximately equal to vulnerable area variation for each shot.

Geometric Shapes

A further investigation of area variation due to various shapes is conducted using five basic geometric bodies. These bodies are a parallelepiped, a pyramid, a cylinder, a cone, and a sphere. These are standard shapes and could be used individually or in some combination to simulate critical components of a weapon system.

A computer program was developed by the author to plot these shapes in any orientation with respect to a reference system to find their presented areas for 26 views. This program is described in Appendix B.

Presented areas are found from the plots of these individual shapes using the digitizer and the major view areas are projected to 26 views for comparison with the measured data to find the error due to projection.

A combination of the five geometric shapes is used for an analysis of area variation. Shielding of one component by another component is accounted for in measuring the areas of each rotated view. In this combination all five shapes are designed to have nearly equal volumes. The sphere is used as a control, since it has constant presented area for any aspect, and the volumes of all of the shapes are within 5% of the volume of the sphere. The combination of shapes is shown in Fig. 6 in their orientation and fixed positions on a plane. Other views are illustrated in Fig. 26 - 37 in Appendix C.

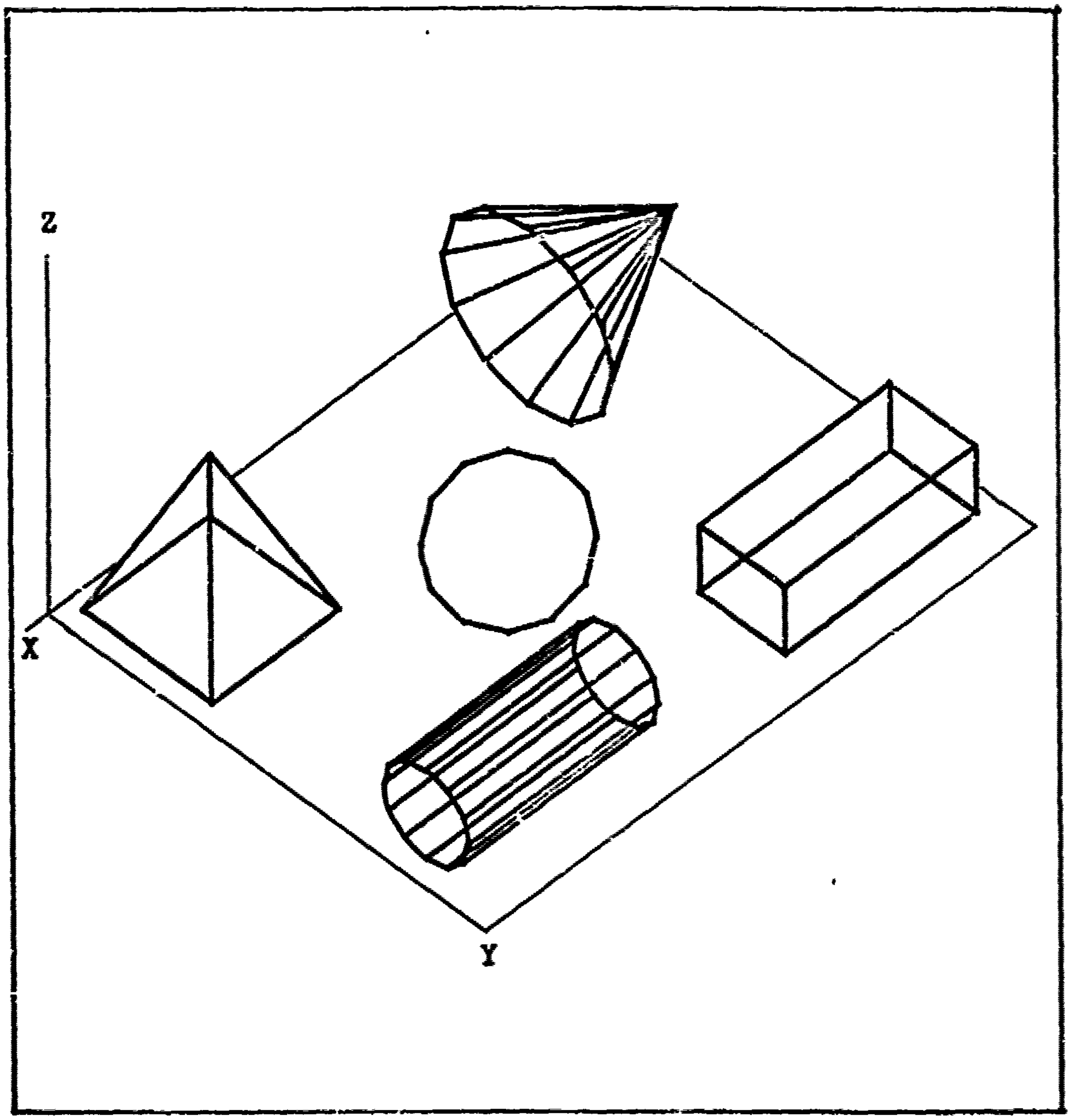

Figure 6. Combination of Geometric Shapes: View 23.

IV. Analysis, Discussion, and Results

Vulnerable Area Variation

The variation in vulnerable area is obtained by subtracting the measured area from the projected area for each of the 26 views and this difference is expressed as a percentage of the measured area. The results are given in graphic form in Fig. 7 - 11 for the geometric shapes and in Fig. 13 - 15 for the three aircraft considered. Fig. 12 illustrates the area variation for the combination of shapes. The lines used on the graphs are for emphasis of the 26 view data only and are not to be interpreted as continuous curves between each data point. The data on which these graphs are based is tabulated in Appendix A.

Influencing Factors. Several factors influence vulnerable area and its variation. These are true length representation in the projection of surfaces, shielding, probability of kill given a hit variation, and orientation of objects.

A source of error in the projection method is the loss of true length representation of lines or surfaces. When an object is projected on a plane, true length is not preserved unless the projecting plane is parallel to the object surface. When presented areas are obtained for the six orthogonal major views of an aircraft or component, the surfaces of that body are projected on the planes of a theoretical box. When the areas on these six planes are then projected to a view in a non-parallel plane, area representation is no longer accurate, if true length was not maintained in the original projection to six faces. For example, the parallelepiped used in the geometric shape analysis is oriented such that its sides are parallel to the projecting surfaces of the six major views. Therefore, the areas of its sides project accurately and true length is preserved. When these views are then used as projecting surfaces to obtain 26 views, no error in area is generated. This is illustrated by the results of Fig. 7. The other shapes do illustrate error because some of their surfaces are not parallel to the original six projecting planes.

Another source of error in area representation occurs because of shielding. When the presented areas are measured for the six major views, any shielding of components is automatically included. Shielding is dependent on the viewing aspect. When these six major views are projected to generate other views, the resulting areas for those generated views include only the shielding of the major projecting views, and any shielding that may exist in the actual view that is being generated is not considered. Shielding is not a factor in the five individual geometric shapes studied, but it is a factor in the aircraft and combination of shapes computations.

The probability of kill given a hit can influence vulnerable area variation. Different values of P_{kh} may be assigned to various parts of an object because of material differences or construction. These P_{kh}'s are used to compute the vulnerable areas from presented areas for each view. If this occurs

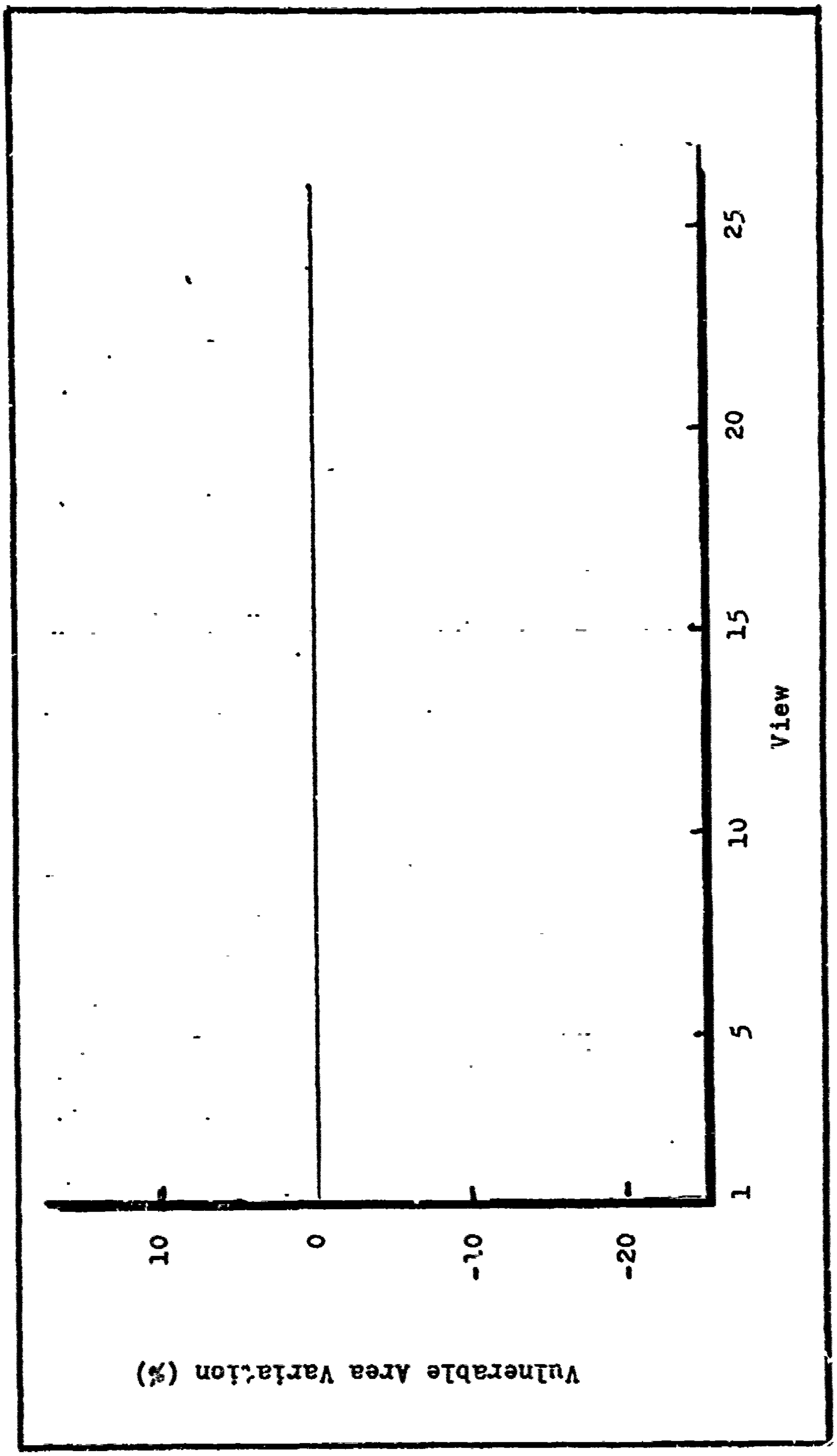

Figure 7. Variation Between Measured and Projected Vulnerable Area as a Percentage of Measured Vulnerable Area for the 26 Views of a Parallelepiped.

on a major view, any projection of this plane includes this P_{kh} relationship and does not account for a different P_{kh} that may exist for the view being generated.

A change in orientation of the object with respect to the reference system changes the six major view areas and the 26 view areas will differ from those of any other orientation. In this study the results are applicable only to the particular objects and their assumed orientation.

Geometric Shapes. Area presentation is accurately generated for all projections on the level elevation plane for the pyramid or cylinder, as Fig. 8 and 9 illustrate, because the projecting surfaces maintain the true length relationship in the plane of projection. However, substantial error is generated in the 45 degree elevation views because some of the projecting planes do not have the true length preserved.

A 41% error in vulnerable area occurs in views 4, 8, 20, and 24 of the sphere. The areas of these views are found from the projection of two major view planes. A 71% error occurs in views generated by the projection of three orthogonal planes, as illustrated in Fig. 10. This error should be 73.2% and the difference is caused by the 2% inaccuracy of the planimetering process. The cone has a similar pattern of area variation in Fig. 11 with error magnitudes almost equal to those of the sphere.

The area variation illustrated for these basic geometric shapes is characteristic of their orientation in the reference system and their size relationship of length, width, and

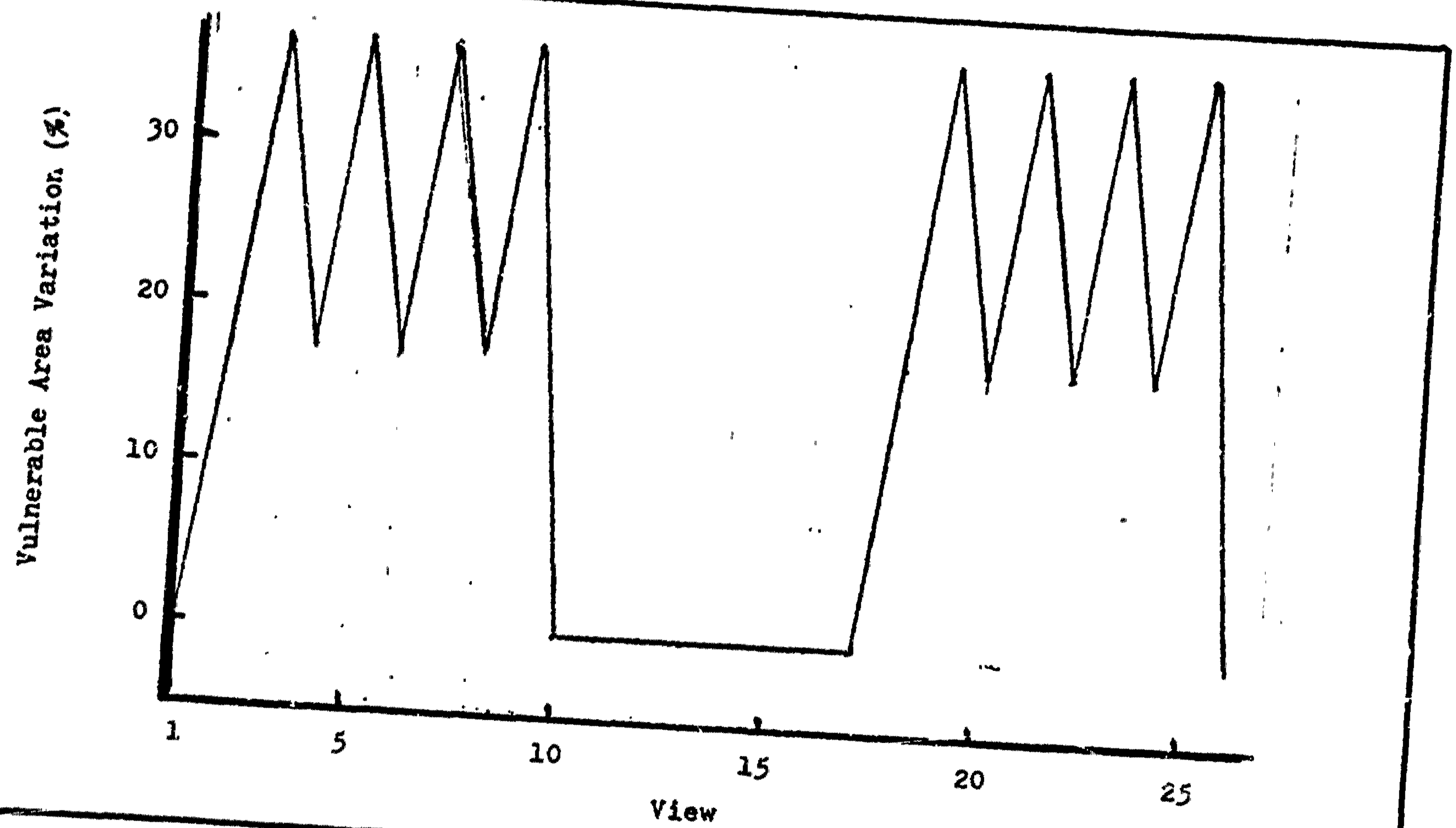

Figure 8. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of a Pyramid.

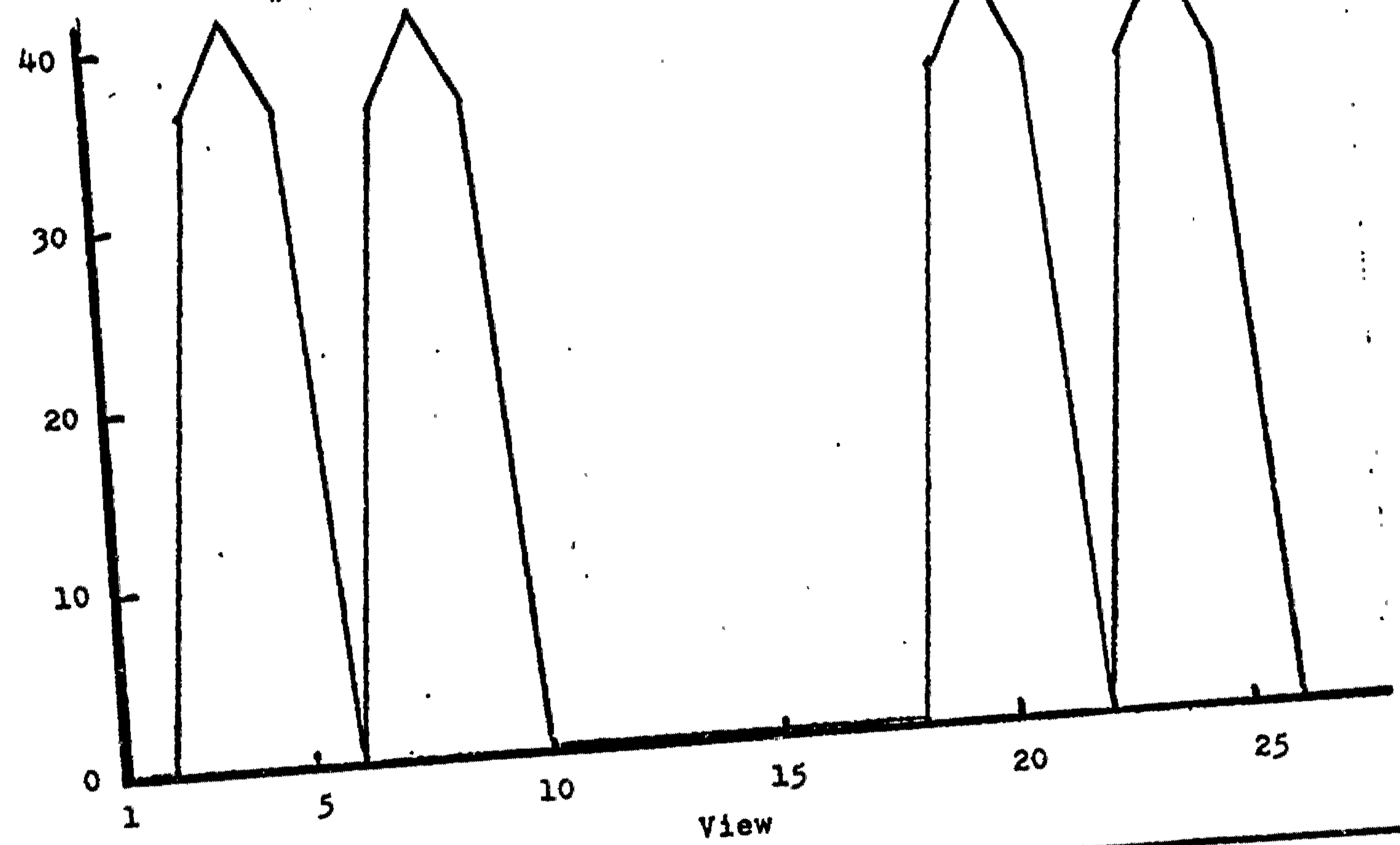

Figure 9. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of a Cylinder.

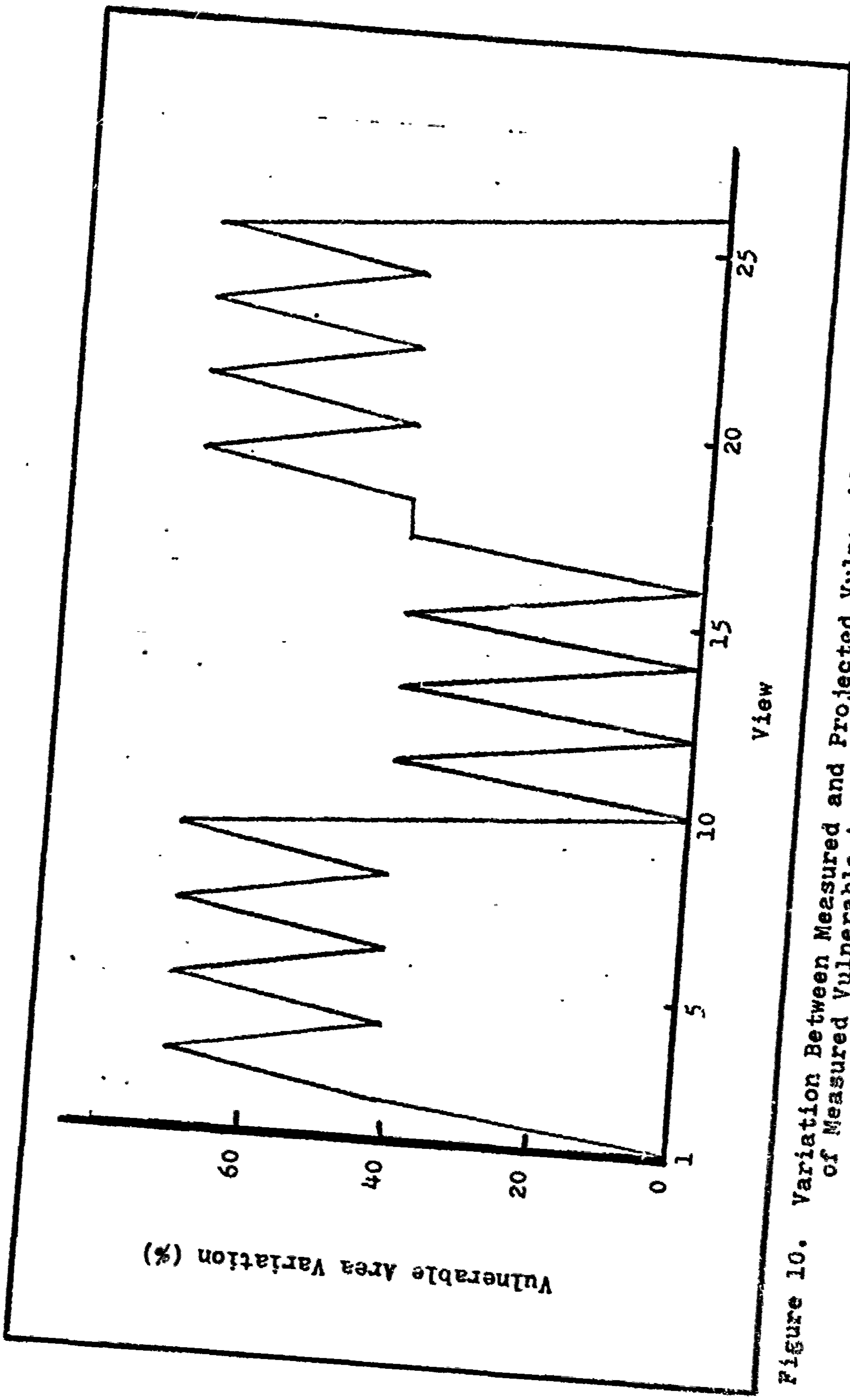

Figure 10. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of a Sphere.

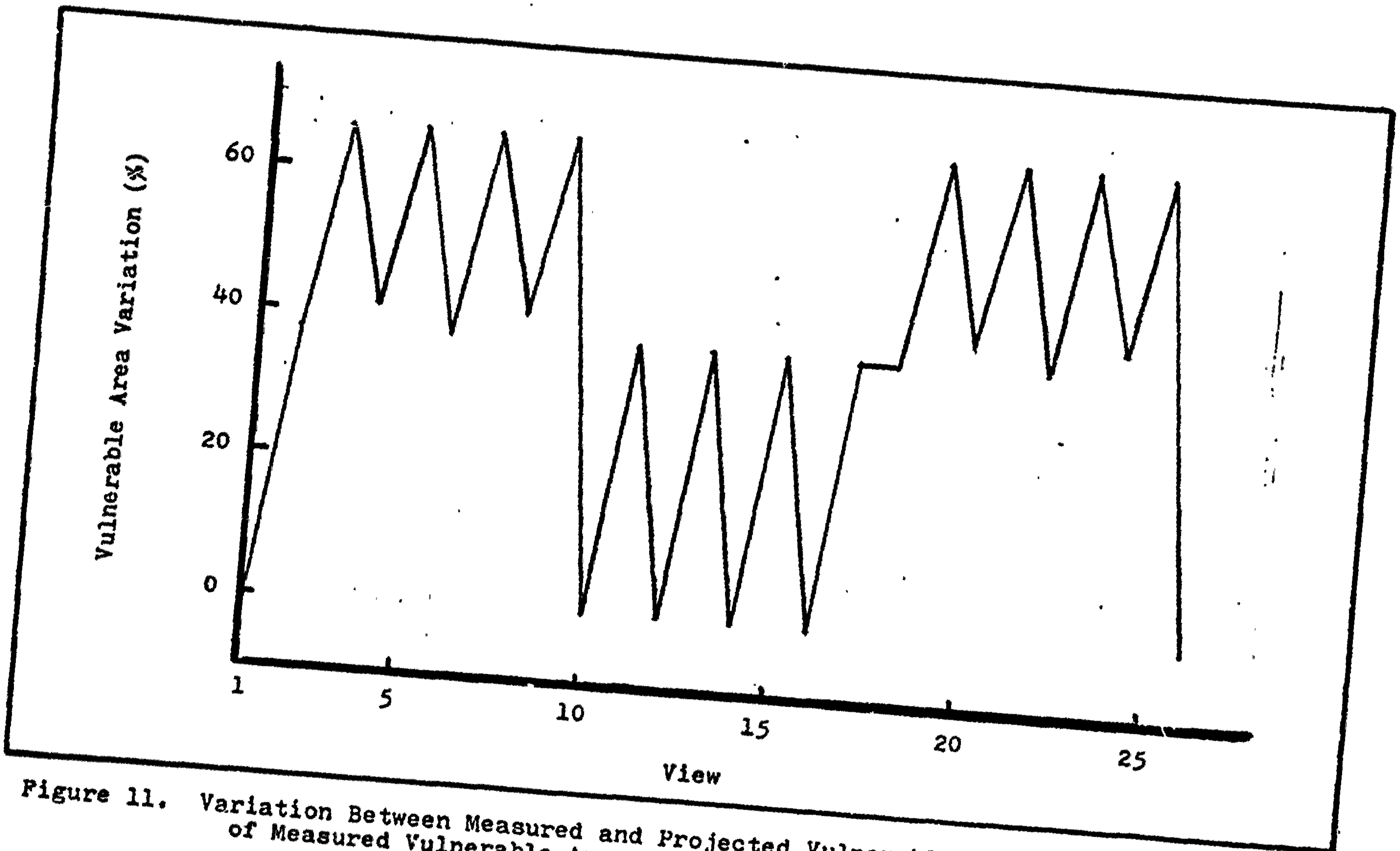

Figure 11. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of a Cone.

height. A change in any of these parameters would result in different area for each view and different variation due to projection.

Combination of Shapes. The five basic geometric shapes were combined as shown in Fig. 7 to analyze a system involving both shape and shielding effects. The results are shown in Fig. 12. Only 13 distinct views are required to describe the 26 views for area measurement due to symmetry. These views are illustrated in Fig. 26 - 37 in Appendix C.

Fig. 12 illustrates two results. First, it shows the amount of vulnerable area variation due to projection, which includes the effects of shielding and shape. Second, the dotted line represents the percent of actual presented area of each view that is shielded. Since the geometric figures are located in the same horizontal plane, most of the shielding effect occurs in those views in that plane. Views 11 and 15, which show the greatest area variation due to projection, also contain the largest amount of shielded area. Both shape and shielding cause this variation. Views 10 and 12, the two major views that are projected to determine the area of view 11, contain 35% and 29% shielded area respectively, which contributes to the error in view 11 area.

Twelve of the 26 views show a vulnerable area error of 20% or more due to shape and shielding effects. These errors would be a source for uncertainty, if used for probability of kill calculations.

Aircraft. The area variation for the aircraft studied

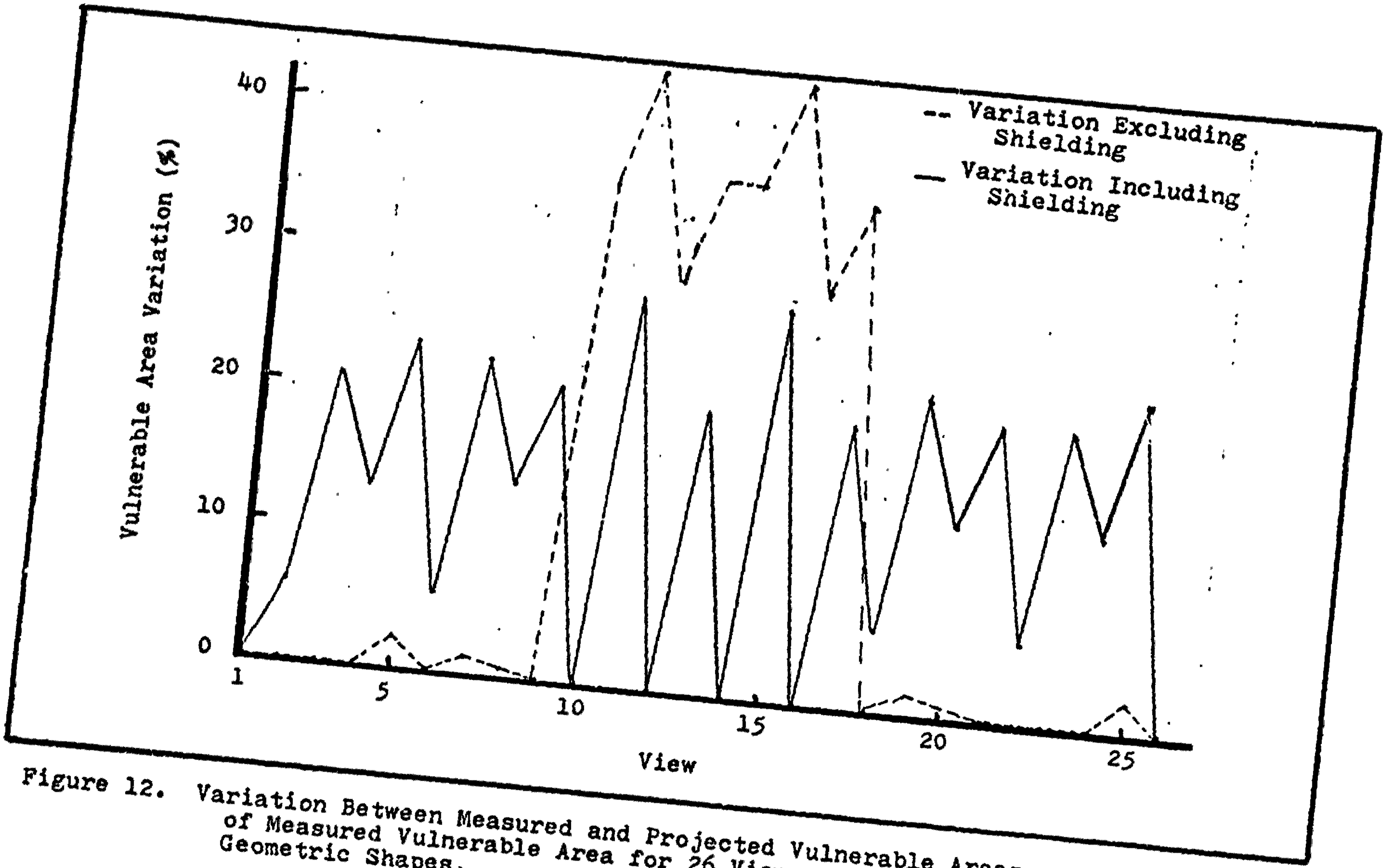

Figure 12. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of the Combination of Geometric Shapes.

is caused both by shape and shielding effect. The OV-10 has the largest errors generated in views 2, 6, 18, and 22, as shown in Fig. 13, which are 45 degrees above and below the nose and tail of the aircraft. The error is generated primarily because of shape, since there is very little shielding in these views or in the major views used to determine these areas.

Only 3% error occurs in views 11, 13, 15, and 17, the 45 degree views in the level elevation plane. There is considerable shielding in these views as well as in views 12 and 14, the side views used to generate the areas of these views. This shielding effect in the side view seems to balance the shielding that exists in the actual 45 degree views, resulting in little error.

The A-10 computer model error in vulnerable areas is illustrated in Fig. 14. This aircraft is modeled with less curvature of surface than the OV-10 model. As such, the major views will project with less error due to shape than with the OV-10. Also, there is little shielding effect in the major views, except for the engines and the vertical tail surfaces in the side view as shown in Fig. 24 in Appendix C.

The largest errors in area presentation occur in views 11, 13, 15, and 17, the non-major views in the level elevation plane. These views contain large shielding effects, which are not compensated for in the projection of the two major views used to generate these views geometrically. The same effect occurs in views 5, 7, 19, and 25, which show sig-

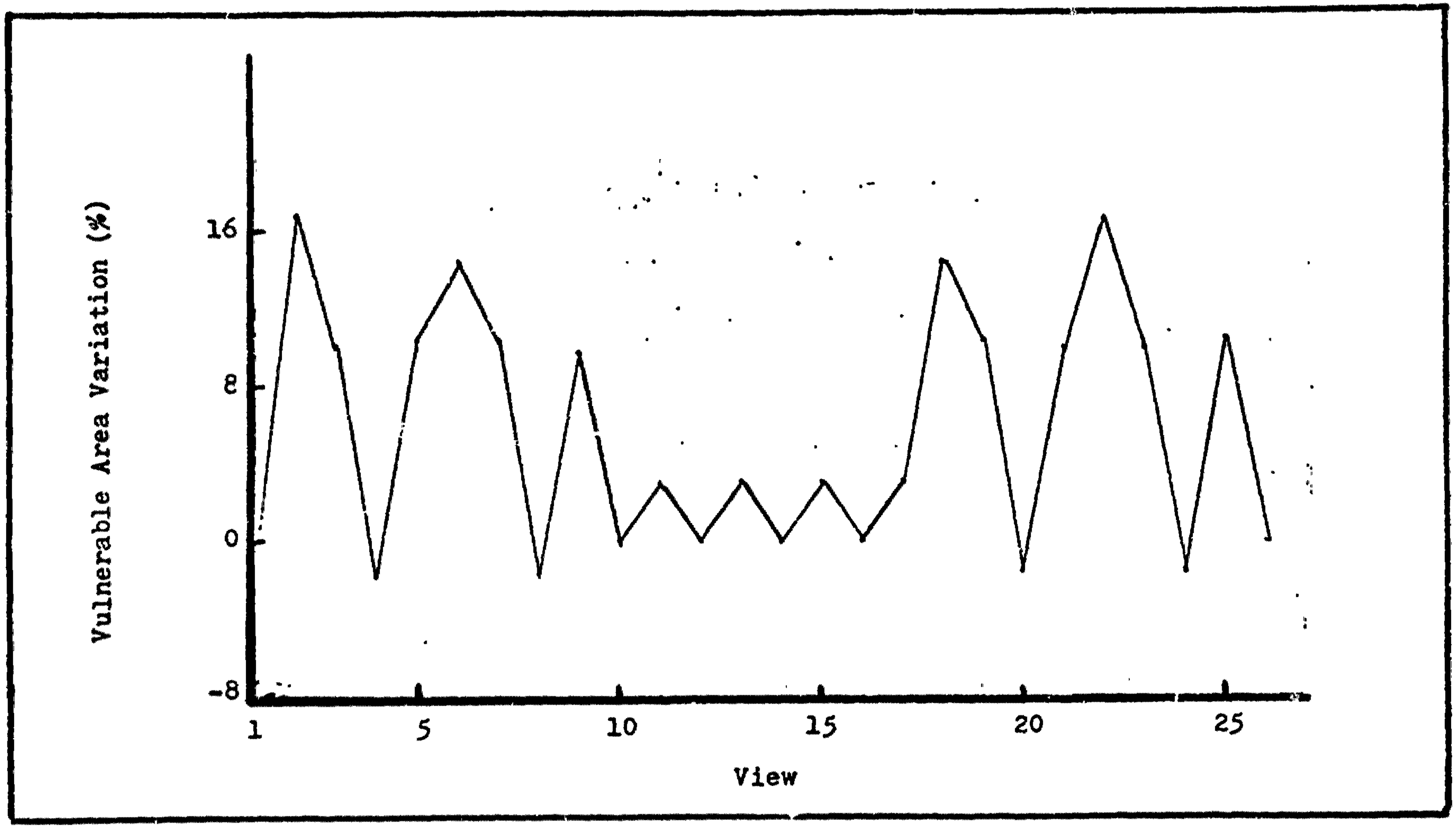

Figure 13. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of the OV-10 Computer Model.

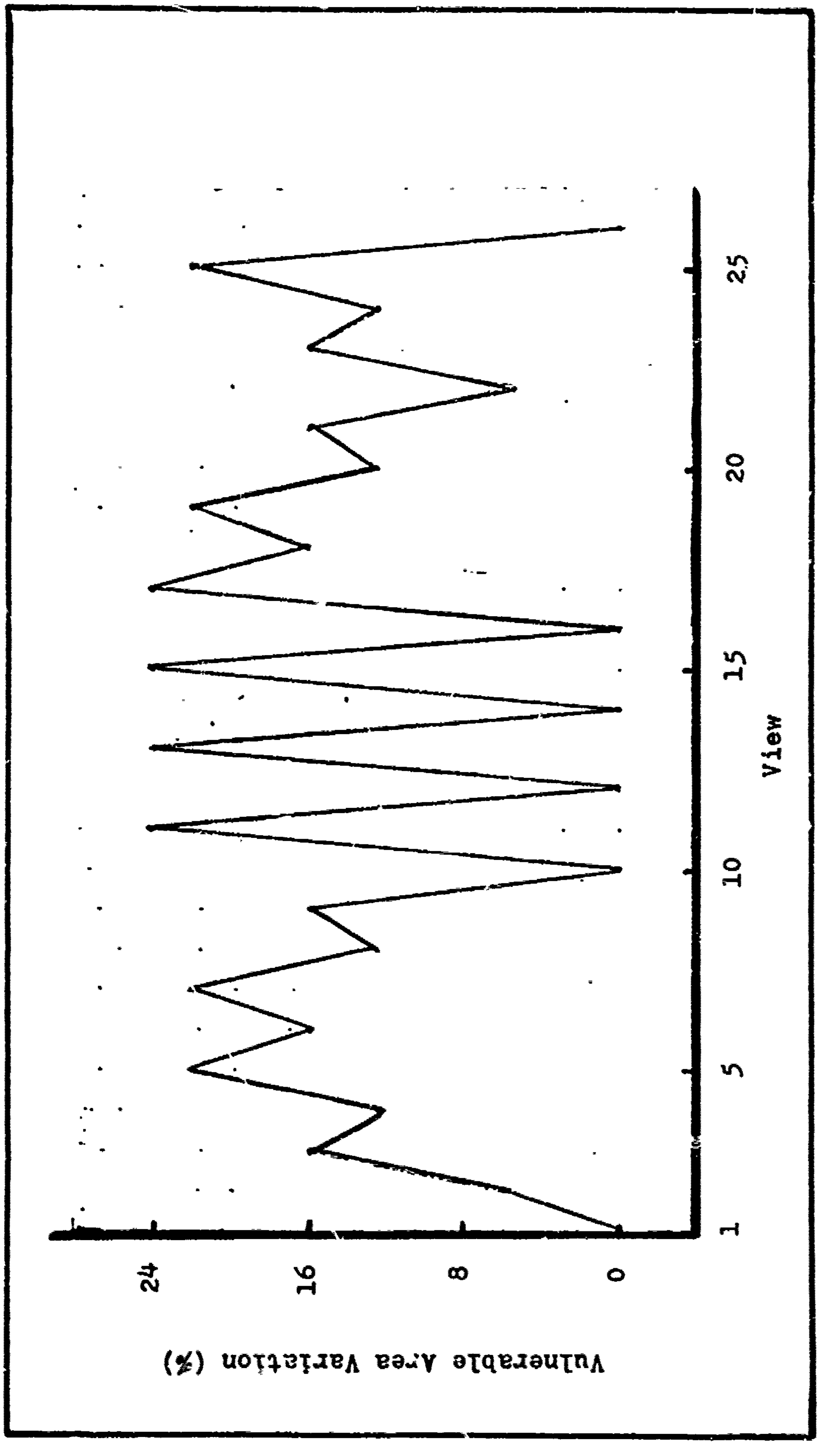

Figure 14. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of the A-10 Computer Model.

nificant error in area.

The actual A-10 aircraft area variation presented in Fig. 15 shows the same general form as that of the A-10 computer model, as would be expected, but the magnitudes of error are somewhat different because of the variation in areas between the actual aircraft and the computer model. This variation occurs because the model is only an approximation and the actual A-10 dimensions used are for a different series aircraft than was used for the model. This accounts for the differences in magnitude of variation between Fig. 14 and 15.

Probability of Kill Variation

The probability of kill variation for each shot is shown in Fig. 16, 17, and 18. All three figures show the same general trend because the given conditions of flight path, gun location, and gun type were used. The hump in the curves represents the dive delivery portion of the flight path with a peak at shot number 18 coinciding with the point of closest approach to the target.

In addition to individual shot probability of kill, the cumulative probability of kill for the flight path is computed by the P001 program. The results for the three aircraft are given in Table II.

The vulnerable area of the A-10 is approximately twice that of the OV-10 for all views and the cumulative probability of kill results reflect this relationship. This does not necessarily relate to the cumulative probability of kill variation, however. The larger A-10 does show a greater variation

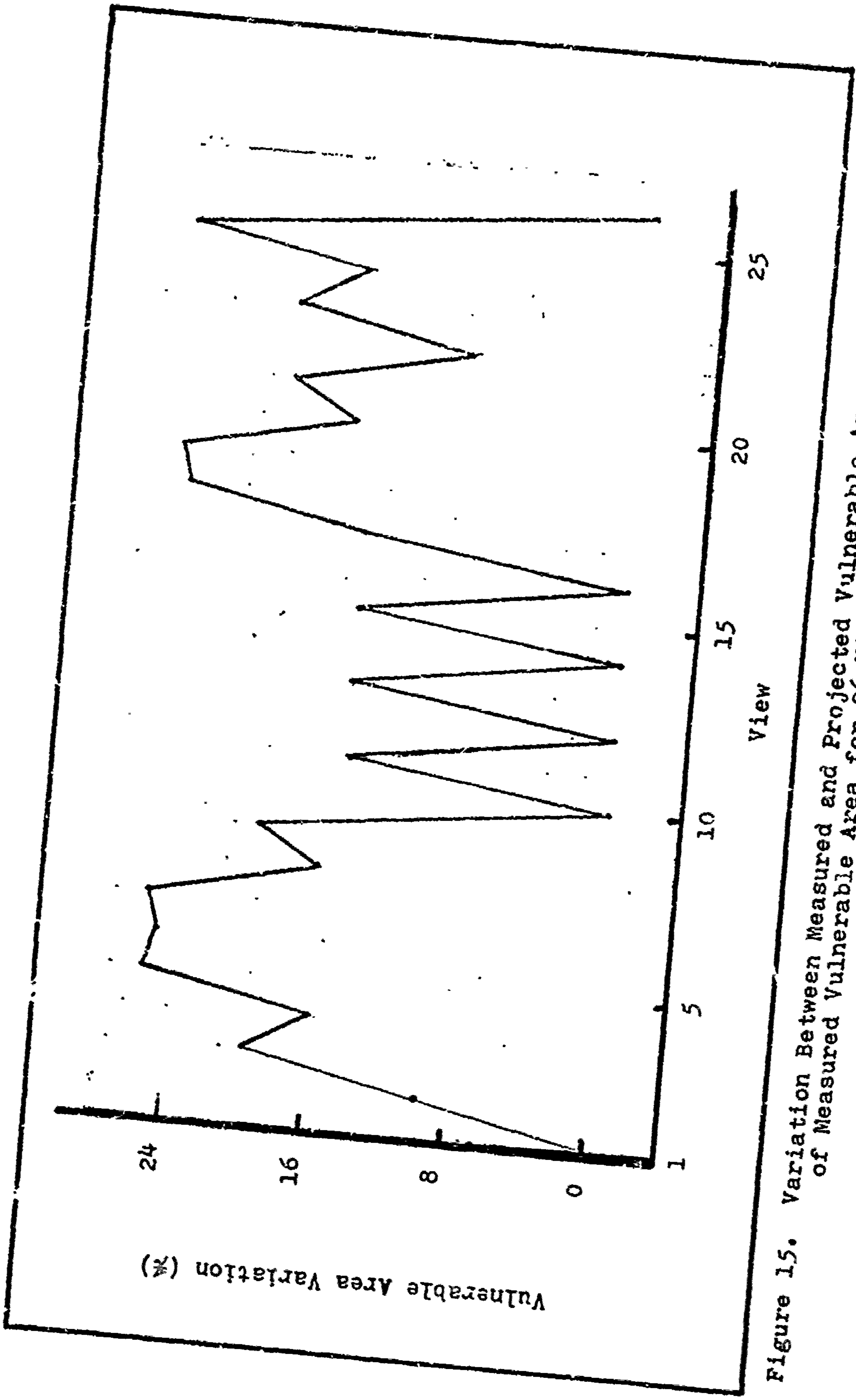

Figure 15. Variation Between Measured and Projected Vulnerable Areas as a Percentage of Measured Vulnerable Area for 26 Views of the A-10 Aircraft.

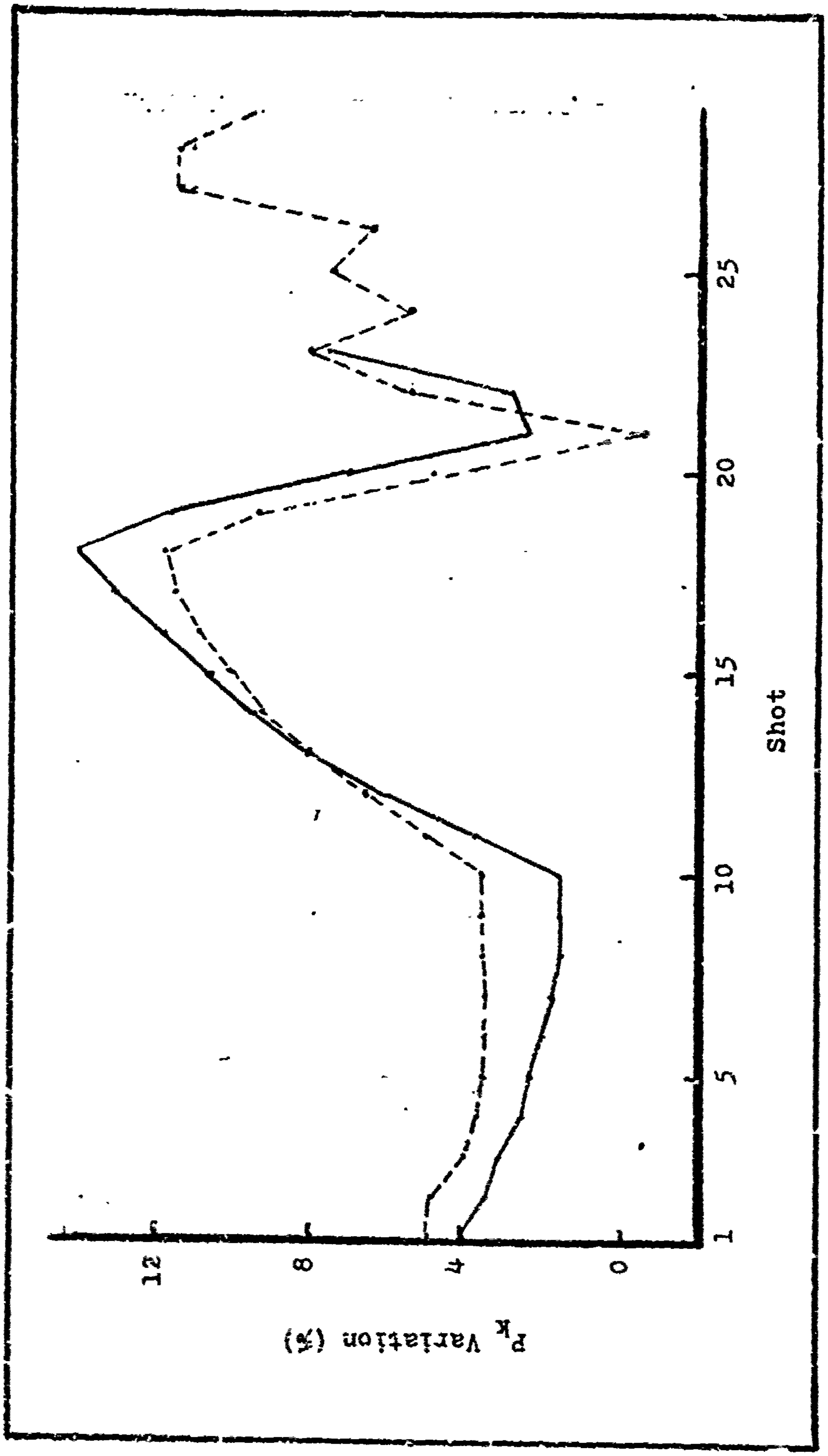

Figure 16. P_k Variation for the OV-10 Computer Modeled Aircraft for Each Gunshot Throughout a Flight Path for Two Different Gun Locations.

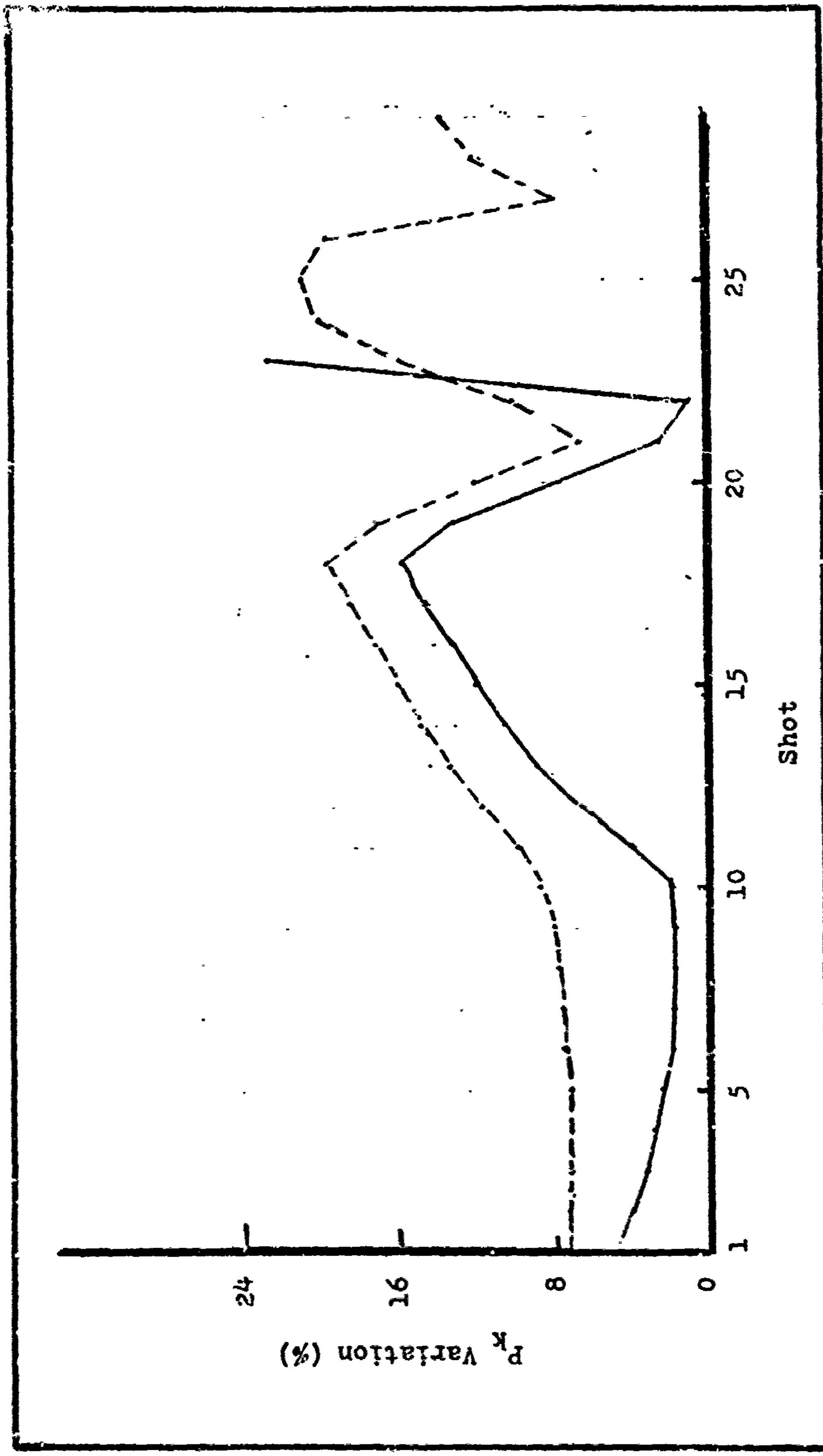

Figure 17. P_k Variation for the A-10 Computer Modeled Aircraft for Each Gunshot Throughout a Flight Path for Two Different Gun Locations.

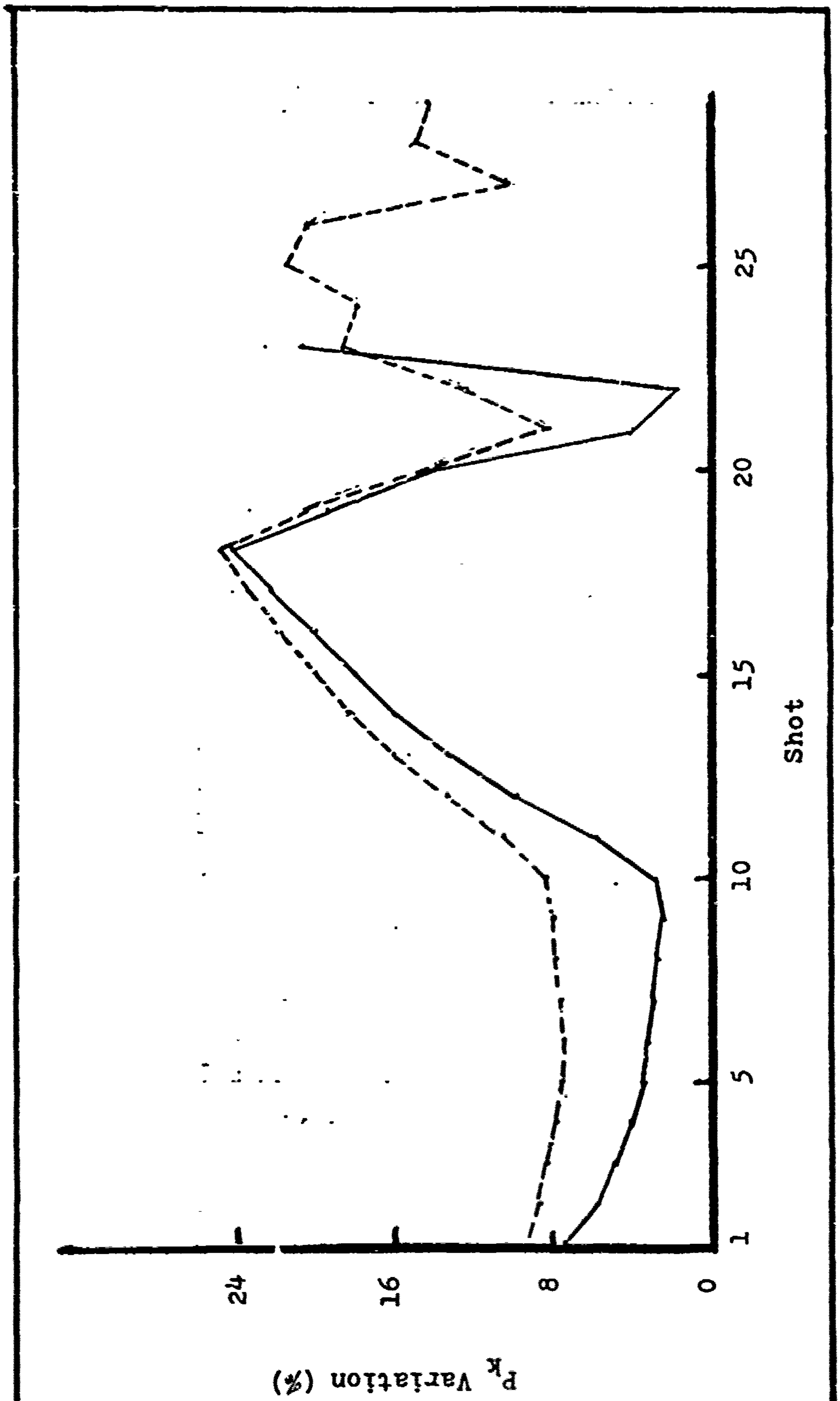

Figure 18. P_k Variation for the A-10 Aircraft for Each Gunshot Throughout a Flight Path for Two Different Gun Locations.

Table II.

Cumulative Probability of Kill Variation Per Flight for Measured vs. Projected Vulnerable Area of the Aircraft

Vulnerable Area	OV-10 Model		A-10 Model		A-10	
	Gun Location					
	1	2	1	2	1	2
Projected	.00733	.00875	.0139	.0164	.0143	.0170
Measured	.00675	.00818	.0127	.0145	.0125	.0145
P_k Variation (%)	8.5	6.9	9.4	13.2	14.1	15.6

in cumulative probability of kill than the OV-10, which is a direct consequence of the greater probability of kill variation per shot as shown in Fig. 16 and 17. The difference in vulnerable areas for the A-10 computer model and the actual aircraft data results in a large change in probability of kill variation for gun location 1, but not for gun location 2. The larger aircraft do display larger variations in both individual shot probability of kill and cumulative probability of kill.

The average error for the OV-10 26 view projected vulnerable area is 6%. This results in a cumulative probability of kill variation of 8.5% and 6.9%, respectively, for flights against gun locations 1 and 2. During these flights the maximum variation in single shot probability of kill is 14% and 12%.

It sh[illegible]ld be noted that the cumulative probability of kill varia[illegible]on [illegible] based only on those vulnerable area views required for interpolation during the flight path used in this study, and may not include all 26 views in this average variation.

The A-10 computer model average error for 26 view projected vulnerable area is 13%. This error results in cumulative probability of kill errors of 9.4% and 13.2% for the two flights, with maximum single shot probability of kill errors during these flights of 22.5% and 20.6%.

The A-10 aircraft average error for 26 view projected vulnerable area is 14%. This error results in cumulative probability of kill errors of 14.1% and 15.6% for the two flights, with maximum single shot probability of kill errors during these flights of 24.2% and 24.9%.

V. Conclusions and Recommendations

An investigation of the effect of certain shapes on the error in 26 view vulnerable area calculated by the geometric projection method has been conducted. It can be concluded that, while individual view vulnerable area variation can be very large, the average variation is approximately one-half this maximum value for the five basic shapes, the combination of shapes, and the aircraft shapes considered. The combination of geometric shapes and the aircraft vulnerable area variation averages are less than 15% of actual area. The results of the effect of vulnerable area variation on probability of kill show that the cumulative probability of kill variation is approximately equal to the average variation in vulnerable area. For the aircraft considered this variation in probability of kill is 16% or less.

Recommendations for further study of vulnerable area effects are as follows: (1) An analysis of the amount and effect of vulnerable area variation on the probability of kill of a complete operational weapon system could be conducted to compare with current estimates of system vulnerability, (2) The sensitivity of lumped vulnerable area vs. distributed vulnerable area on probability of kill of a weapon system could be investigated, and (3) A study of the sensitivity of probability of kill to antiaircraft gun tracking and firing errors for the P001 Computer Program could be conducted to compare the magnitude of its effect with that of vulnerable area variation.

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APPENDIX A

The Tabular Results of Vulnerable Area Variation for the Aircraft and Geometric Shapes and the Probability of Kill Variation for the Aircraft

Table III.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Parallelepiped

View	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	3.35	3.35	0
2	3.15	3.15	0
3	4.18	4.18	0
4	4.14	4.14	0
5	4.18	4.18	0
6	3.15	3.15	0
7	4.18	4.18	0
8	4.14	4.14	0
9	4.18	4.18	0
10	1.16	1.16	0
11	2.56	2.56	0
12	2.51	2.51	0
13	2.56	2.56	0
14	1.16	1.16	0
15	2.56	2.56	0
16	2.51	2.51	0
17	2.56	2.56	0
18	3.15	3.15	0
19	4.18	4.18	0
20	4.14	4.14	0
21	4.18	4.18	0
22	3.15	3.15	0
23	4.18	4.18	0
24	4.14	4.14	0
25	4.18	4.18	0
26	3.35	3.35	0

Table IV.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Pyramid

View	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	3.35	3.35	0
2	3.19	3.74	17.44
3	3.16	4.32	36.50
4	3.19	3.74	17.44
5	3.16	4.32	36.50
6	3.19	3.74	17.44
7	3.16	4.32	36.50
8	3.19	3.74	17.44
9	3.16	4.32	36.50
10	1.95	1.95	0
11	2.76	2.76	0
12	1.95	1.95	0
13	2.76	2.76	0
14	1.95	1.95	0
15	2.76	2.76	0
16	1.95	1.95	0
17	2.76	2.76	0
18	3.19	3.[illegible]	17.44
19	3.16	4.32	36.50
20	3.19	3.74	17.44
21	3.16	4.32	36.50
22	3.19	3.74	17.44
23	3.16	4.32	36.50
24	3.19	3.74	17.44
25	3.16	4.32	36.50
26	3.35	3.35	0

Table V.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Cylinder

View	Vulnerable Area (M^2) Measured	Projected	% Variation
1	3.35	3.35	0
2	3.19	3.19	0
3	3.39	4.62	36.23
4	3.35	4.73	41.41
5	3.39	4.62	36.23
6	3.19	3.19	0
7	3.39	4.62	36.23
8	3.35	4.73	41.41
9	3.39	4.62	36.23
10	1.17	1.17	0
11	3.19	3.19	0
12	3.35	3.35	0
13	3.19	3.19	0
14	1.17	1.17	0
15	3.19	3.19	0
16	3.35	3.35	0
17	3.19	3.19	0
18	3.19	3.19	0
19	3.39	4.62	36.23
20	3.35	4.73	41.41
21	3.39	4.62	36.23
22	3.19	3.19	0
23	3.39	4.62	36.23
24	3.35	4.73	41.41
25	3.39	4.62	36.23
26	3.35	3.35	0

Table VI.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Sphere

View	Vulnerable Area (M^2) Measured	Projected	% Variation
1	2.63	2.63	0
2	2.63	3.72	41.42
3	2.63	4.48	70.69
4	2.63	3.72	41.42
5	2.63	4.48	70.69
6	2.63	3.72	41.42
7	2.63	4.48	70.69
8	2.63	3.72	41.42
9	2.63	4.48	70.69
10	2.63	2.63	0
11	2.63	3.72	41.42
12	2.63	2.63	0
13	2.63	3.72	41.42
14	2.63	2.63	0
15	2.63	3.72	41.42
16	2.63	2.63	0
17	2.63	3.72	41.42
18	2.63	3.72	41.42
19	2.63	4.48	70.69
20	2.63	3.72	41.42
21	2.63	4.48	70.69
22	2.63	3.72	41.42
23	2.63	4.48	70.69
24	2.63	3.72	41.42
25	2.63	4.48	70.69
26	2.63	2.63	0

Table VII.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Cone

View	Vulnerable Area (M^2) Measured	Projected	% Variation
1	2.60	2.60	0
2	3.73	5.14	37.83
3	3.29	5.47	66.26
4	2.60	3.67	41.45
5	3.29	5.47	66.26
6	3.73	5.14	37.83
7	3.29	5.47	66.26
8	2.60	3.67	41.45
9	3.29	5.47	66.26
10	4.67	4.67	0
11	3.73	5.14	37.83
12	2.60	2.60	0
13	3.73	5.14	37.83
14	4.67	4.67	0
15	3.73	5.14	37.83
16	2.60	2.60	0
17	3.73	5.14	37.83
18	3.73	5.14	37.83
19	3.29	5.48	66.26
20	2.60	3.68	41.45
21	3.29	5.46	66.26
22	3.73	5.14	37.83
23	3.29	5.48	66.26
24	2.60	3.68	41.45
25	3.29	5.48	66.26
26	2.60	2.60	0

Table VIII.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the Combination of Shapes

View	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	15.26	15.26	0
2	15.89	16.80	5.70
3	16.69	20.18	20.75
4	15.90	17.96	12.95
5	16.29	20.10	23.40
6	15.89	16.80	5.70
7	16.43	20.10	22.34
8	15.77	17.96	13.84
9	16.64	20.10	20.80
10	8.49	8.49	0
11	10.35	13.17	27.30
12	10.13	10.13	0
13	10.97	13.17	20.05
14	8.49	8.49	0
15	10.34	13.17	27.30
16	10.13	10.13	0
17	10.97	13.17	20.05
18	15.89	16.80	5.70
19	16.43	20.10	22.34
20	15.77	17.96	13.84
21	16.64	20.10	20.80
22	15.90	16.80	5.70
23	16.64	20.10	20.75
24	15.90	17.96	12.95
25	16.29	20.10	23.40
26	15.26	15.26	0

Table IX.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the OV-10 Computer Model

View	Vulnerable Area (M^2)		% Variation
	Measured	Projected	
1	40.87	40.87	0
2	29.50	34.41	16.64
3	36.60	40.22	9.89
4	39.95	39.39	-1.40
5	36.39	40.22	10.52
6	30.09	34.41	14.36
7	36.39	40.[illegible]	10.52
8	39.95	39.39	-1.40
9	36.60	40.22	9.89
10	7.80	7.80	0
11	15.52	16.00	3.09
12	14.83	14.83	0
13	15.52	16.00	3.09
14	7.80	7.80	0
15	15.52	16.00	3.09
16	14.83	14.83	0
17	15.52	16.00	3.09
18	30.09	34.41	14.36
19	36.39	40.22	10.52
20	39.95	39.39	-1.40
21	36.60	40.22	9.89
22	29.50	34.41	16.64
23	36.60	40.22	9.89
24	39.95	39.39	-1.40
25	36.39	40.22	10.52
26	40.87	40.87	0

Table X.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the A-10 Computer Model

View	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	77.94	77.94	0
2	62.19	65.63	5.53
3	65.26	75.62	15.87
4	65.39	73.59	12.54
5	61.95	75.62	22.07
6	56.57	65.63	16.02
7	61.95	75.62	22.07
8	65.39	73.59	12.54
9	65.26	75.62	15.87
10	14.88	14.88	0
11	23.34	29.00	24.25
12	26.13	26.13	0
13	23.34	29.00	24.25
14	14.88	14.88	0
15	23.34	29.00	24.[illegible]
16	26.13	26.13	[illegible]
17	23.34	29.00	24.25
18	56.57	65.63	16.02
19	61.95	75.62	22.07
20	65.39	73.59	12.54
21	65.26	75.62	15.87
22	62.19	65.63	5.53
23	65.26	75.62	15.87
24	65.39	73.59	12.54
25	61.95	75.62	22.07
26	77.94	77.94	0

Table XI.

Percentage Variation Between Measured and Projected Vulnerable Areas for 26 Views of the A-10 Aircraft

View	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	79.99	79.99	0
2	61.32	67.30	9.75
3	65.78	78.59	19.47
4	66.39	76.98	15.95
5	62.62	78.59	25.50
6	53.89	67.30	24.88
7	62.66	78.59	25.50
8	66.39	76.98	15.95
9	65.78	78.59	19.47
10	15.19	15.19	0
11	27.13	31.16	14.85
12	28.87	28.87	0
13	27.13	31.16	14.85
14	15.19	15.19	0
15	27.13	31.16	14.85
16	28.87	28.87	0
17	27.13	31.16	14.85
18	53.89	67.30	24.88
19	62.62	78.59	25.50
20	66.39	76.98	15.95
21	65.78	78.59	19.47
22	61.32	67.30	9.75
23	65.78	78.59	19.47
24	66.39	76.98	15.95
25	62.62	78.59	25.50
26	79.99	79.99	0

Table XII.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using OV-10 Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 1

Shot	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	10.07	10.48	4.07
2	9.59	9.92	3.44
3	9.25	9.52	2.92
4	8.99	9.21	2.45
5	8.80	9.00	2.27
6	8.68	8.85	1.96
7	8.59	8.74	1.75
8	8.53	8.67	1.64
9	8.47	8.61	1.65
10	8.54	8.68	1.64
11	9.59	9.94	3.65
12	11.24	11.91	5.96
13	13.21	14.26	7.95
14	15.36	16.82	9.51
15	17.36	19.21	10.66
16	19.98	22.34	11.81
17	23.72	26.81	13.03
18	27.98	31.89	13.97
19	31.78	35.42	11.45
20	34.86	37.27	6.91
21	38.57	39.49	2.39
22	38.41	39.47	2.76
23	22.70	24.39	7.44

Table XIII.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using OV-10 Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 2

Shot	Vulnerable Area (M^2) Measured	Projected	% Variation
1	11.11	11.66	4.95
2	10.80	11.28	4.81
3	10.61	11.03	3.96
4	10.47	10.86	3.72
5	10.41	10.78	3.55
6	10.40	10.76	3.46
7	10.43	10.78	3.36
8	10.48	10.84	3.44
9	10.56	10.93	3.50
10	10.75	11.14	3.63
11	11.83	12.41	4.90
12	13.62	14.52	6.61
13	15.76	17.03	8.06
14	18.20	19.89	9.29
15	20.51	22.58	10.09
16	23.47	26.06	10.82
17	27.62	30.79	11.48
18	32.27	36.08	11.81
19	35.94	39.26	9.24
20	38.45	40.33	4.89
21	40.35	40.04	-0.77
22	38.25	40.33	5.44
23	33.77	36.51	8.11
24	22.10	23.31	5.48
25	28.22	30.30	7.37
26	28.05	29.86	6.45
27	33.49	37.25	11.23
28	27.98	31.14	11.29
29	21.99	23.98	9.05

Table XIV.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using A-10 Computer Model Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 1

Shot	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	18.98	19.96	5.16
2	18.14	18.91	4.24
3	17.54	18.16	3.53
4	17.07	17.57	2.93
5	16.74	17.16	2.45
6	16.53	16.89	2.18
7	16.37	16.69	1.95
8	16.25	16.55	1.85
9	16.15	16.42	1.67
10	16.27	16.57	1.84
11	18.24	18.97	4.00
12	21.32	22.72	6.57
13	25.00	27.20	8.80
14	29.01	32.09	10.62
15	32.76	36.65	11.87
16	37.66	42.61	13.14
17	44.66	51.13	14.49
18	52.61	60.82	15.61
19	59.90	67.55	12.77
20	66.01	71.07	7.67
21	73.37	75.31	2.64
22	74.52	75.27	1.01
23	36.90	45.21	22.52

Table XV.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using A-10 Computer Model Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 2

Shot	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	20.59	22.14	7.53
2	19.92	21.39	7.38
3	19.49	20.90	7.23
4	19.18	20.56	7.19
5	19.01	20.38	7.21
6	18.94	20.33	7.34
7	18.94	20.37	7.55
8	18.98	20.45	7.74
9	19.07	20.60	8.02
10	19.36	21.00	8.47
11	21.30	23.41	9.91
12	24.53	27.40	11.70
13	28.38	32.16	13.32
14	32.75	37.59	14.78
15	36.82	42.67	15.89
16	42.00	49.16	17.05
17	49.20	58.20	18.29
18	57.10	68.20	19.44
19	63.44	74.16	16.90
20	68.00	76.14	11.97
21	70.92	75.51	6.47
22	69.10	76.10	10.13
23	59.07	68.42	15.83
24	35.84	42.96	19.87
25	46.81	56.45	20.59
26	46.49	55.57	19.53
27	65.52	70.70	7.91
28	52.42	58.71	12.00
29	39.59	44.93	13.49

Table XVI.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using A-10 Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 1

Shot	Vulnerable Area (M^2)		% Variation
	Measured	Projected	
1	19.09	20.44	7.60
2	18.28	19.34	5.80
3	17.70	18.56	4.86
4	17.25	17.96	4.12
5	16.93	17.54	3.60
6	16.72	17.25	3.17
7	16.57	17.05	2.90
8	16.46	16.90	2.67
9	16.37	16.77	2.44
10	16.48	16.92	2.67
11	18.31	19.39	5.90
12	21.17	23.24	9.78
13	24.58	27.84	13.26
14	28.31	32.86	16.07
15	31.79	37.54	18.09
16	36.34	43.66	20.14
17	42.84	52.41	22.34
18	50.22	62.36	24.17
19	57.96	69.28	19.53
20	65.43	72.91	11.43
21	74.41	77.28	3.86
22	75.94	77.25	1.73
23	39.42	47.59	20.73

Table XVII.

Percentage Variation Between P001 Calculated Vulnerable Areas Per Shot Using A-10 Measured vs. Projected Vulnerable Area Data for a Flight Against Gun Location 2

Shot	Vulnerable Area (M^2) Measured	Vulnerable Area (M^2) Projected	% Variation
1	20.82	22.75	9.27
2	20.26	22.01	8.64
3	19.90	21.52	8.14
4	19.65	21.18	7.79
5	19.53	21.01	7.58
6	19.50	20.97	7.54
7	19.54	21.03	7.63
8	19.61	21.13	7.75
9	19.74	21.30	7.90
10	20.06	21.72	8.28
11	21.91	24.21	10.50
12	24.97	28.32	13.42
13	28.63	33.24	16.10
14	32.80	38.84	18.41
15	36.72	44.10	20.10
16	41.73	50.81	21.76
17	48.71	60.17	23.53
18	56.47	70.53	24.90
19	63.71	76.76	20.48
20	69.19	78.86	13.98
21	72.38	78.31	8.19
22	70.13	78.84	12.42
23	60.11	71.32	18.65
24	38.55	45.47	17.95
25	48.70	59.16	21.48
26	48.41	58.31	20.45
27	65.54	72.85	11.15
28	52.95	60.85	14.92
29	40.94	46.82	14.36

APPENDIX B

A Computer Program for Rotating and Plotting Geometric Shapes

APPENDIX B

A Computer Program for Rotating and Plotting Geometric Shapes

General

A computer program is developed for use with the Hewlett Packard Model 9810 Calculator and attached Model 9862A Calculator Plotter to locate a specified geometric shape in any desired orientation in a three-dimensional coordinate system, to rotate about the system to any aspect of azimuth and elevation, and to plot the shape for that aspect. This capability is needed to produce the necessary 26 views of these geometric shapes, so that the presented areas can be accurately measured for comparison with projected area data. The program is based upon Euler angle transformations. These transformations are used both to initially orient a shape through rotation from a base orientation in the computer program and to rotate about the coordinate system in azimuth and elevation to any desired aspect.

Five geometric shapes are included in the program - a parallelepiped, a pyramid, a sphere, a cylinder, and a cone. The axis system used and the five shapes are shown in their basic orientation with respect to the axis system in Fig. 6.

Transformations

In order to be able to orient any of the shapes in the program in a different attitude than its base orientation, the figure must first be moved to the origin. This is done by the use of the negative identity matrix. Multiplying this matrix times the base coordinates of the figure translates it to the origin. The operation is

$$\begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{Bmatrix} X_c \\ Y_c \\ Z_c \end{Bmatrix} + \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix} = \begin{Bmatrix} -X_c+X \\ -Y_c+Y \\ -Z_c+Z \end{Bmatrix} \tag{7}$$

where X_c, Y_c, and Z_c are the coordinates of the lower left corner of the parallelepiped or pyramid, or the coordinates of the center of the circular base of the cone or cylinder. X, Y, and Z represent any other point in the figure.

Now that the figure is at the origin it can be rotated about any or all of the axes to a new orientation. This operation involves multiplying by a transformation matrix made up of rotations of angle ψ about the Z axis, $-\theta$ about the Y axis, and ϕ about the X axis (Ref 2:332-336). The rotation about the Y axis is made negative to agree with the convention of the system rotation matrix used later in the program. This rotation matrix is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} =$$

$$\begin{bmatrix} \cos\psi\cos\theta & \sin\psi\cos\theta & \sin\theta \\ -\sin\psi\cos\phi & \cos\psi\cos\phi & \cos\theta\sin\phi \\ -\cos\psi\sin\theta\sin\phi & -\sin\psi\sin\theta\sin\phi & \\ -\sin\psi\sin\phi & -\cos\psi\sin\phi & \cos\theta\cos\phi \\ -\cos\psi\sin\theta\cos\phi & -\sin\psi\sin\theta\cos\phi & \end{bmatrix} \tag{8}$$

Now the shape is rotated by multiplying by the A matrix:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{12} & a_{22} & a_{23} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{Bmatrix} -X_c+X \\ -Y_c+Y \\ -Z_c+Z \end{Bmatrix} =$$

$$\begin{Bmatrix} a_{11}(-X_c+X) + a_{12}(-Y_c+Y) + a_{13}(-Z_c+Z) \\ a_{21}(-X_c+X) + a_{22}(-Y_c+Y) + a_{23}(-Z_c+Z) \\ a_{31}(-X_c+X) + a_{32}(-Y_c+Y) + a_{33}(-Z_c+Z) \end{Bmatrix} \tag{9}$$

Once the object is rotated it must now be translated back to its original location with respect to the origin. This is done by adding the base coordinates to the rotated coordinates of Eq. (9). The coordinates now become

$$\begin{Bmatrix} a_{11}(-X_c+X) + a_{12}(-Y_c+Y) + a_{13}(-Z_c+Z) + X_c \\ a_{21}(-X_c+X) + a_{22}(-Y_c+Y) + a_{23}(-Z_c+Z) + Y_c \\ a_{31}(-X_c+X) + a_{32}(-Y_c+Y) + a_{33}(-Z_c+Z) + Z_c \end{Bmatrix} = \begin{Bmatrix} g_1 \\ g_2 \\ g_3 \end{Bmatrix} \tag{10}$$

The final operation is to rotate the system to the desired aspect of azimuth (α) and elevation (β). This requires the following matrix:

$$\begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} = \begin{bmatrix} \cos\alpha\cos\beta & \sin\alpha\cos\beta & \sin\beta \\ -\sin\beta & \cos\alpha & 0 \\ -\cos\alpha\sin\beta & -\sin\alpha\sin\beta & \cos\beta \end{bmatrix} \tag{11}$$

Here the convention is that ψ is positive counterclockwise and θ is positive in a clockwise rotation to agree with the normal sign convention for azimuth and elevation about the aircraft. When the matrix of Eq. (11) premultiplies Eq. (10), the resulting 3 x 1 matrix contains the coordinates of the rotated system. They are

$$X_T = b_{11}g_1 + b_{12}g_2 + b_{13}g_3 \tag{12}$$

$$Y_T = b_{21}g_1 + b_{22}g_2 + b_{23}g_3 \tag{13}$$

$$Z_T = b_{31}g_1 + b_{32}g_2 + b_{33}g_3 \tag{14}$$

These operations are programmed so that the geometric shapes can be plotted randomly. This allows modeling to be done, since the shapes can be placed in any position to correspond to a critical component in an aircraft. In this way any view can be obtained and the presented area found simply and quickly.

Program Operations

A simplified program flow chart is shown in Fig. 19. The base coordinates of the figure to be drawn are entered first. Then ψ, θ, and ϕ are input to perform the necessary rotations of the base figure at the origin in order to represent the desired attitude. For example, the base attitude of the cone in the program is with the axis parallel to the -X axis. If a cone is to be represented with its axis parallel to the Z axis, the base cone must be rotated 90 degrees about

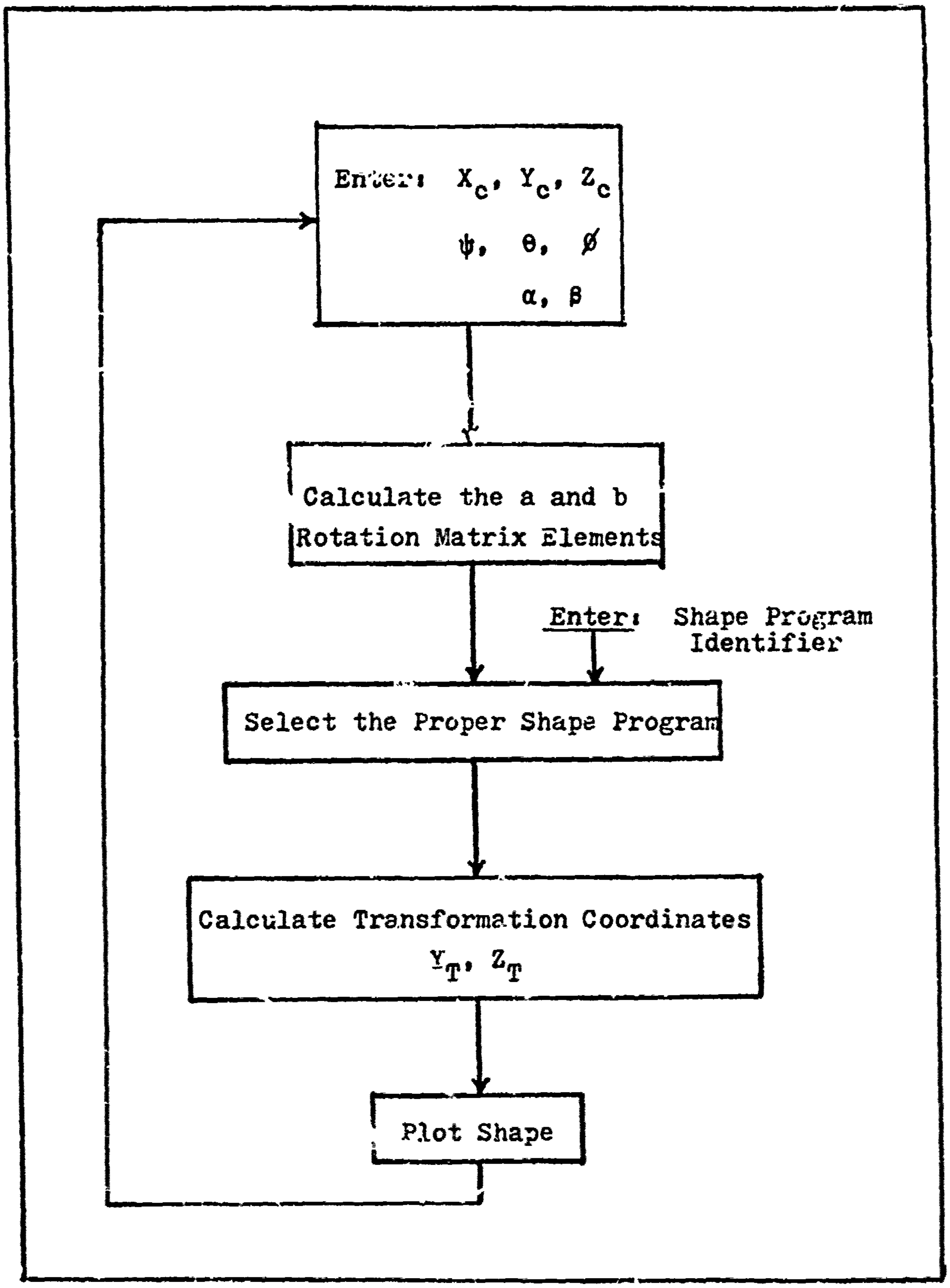

Figure 19. Geometric Shape Program Flow Chart.

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the Y axis, or θ = 90 degrees.

Next, α and β are entered into the program to rotate the observer to the desired viewing aspect. The a and b matrices are automatically calculated once the angle data is entered. There is a subprogram for each geometric shape and these subprograms are identified by a numerical designator. When this designator is entered into the calculator, the associated shape subprogram is selected. The necessary parameters for the particular shape are entered and the program calculates the transformed coordinates and plots the figure.

The parameters needed for the parallelepiped are length (ΔX), width (ΔY), and height (ΔZ). The parallelepiped is automatically drawn using a sequence of counters to direct the plotting pen to draw the three orthogonal edges of the figure from four of the eight corners of the figure.

The pyramid subprogram requires five parameters. These are the base length (ΔX), base width (ΔY), height to apex (h), X coordinate of the apex (X_A), and the Y coordinate of the apex (Y_A). The pyramid is automatically drawn following the input of this data.

The cone parameters are the radius of the base (r) and the height (h), while the cylinder requires radius (r) and length (l). These two subprograms are similar in operation because they involve a circle drawing sequence for the bases of each figure. The Y and Z coordinates around the circle are incremented by 30 degrees. Smaller increments can be used to obtain the desired fineness of curvature.

The sphere subprogram is just a circle drawing sequence, since the sphere projects as a circle in all views. The sphere parameter is the radius (r). When plotting this figure the circle must be rotated about the origin to the proper aspect such that when the system is rotated in azimuth and elevation to a selected aspect the circle will be parallel to this aspect plane. This is accomplished by entering values of ψ and θ that are opposite in sign to the aspect α and β angles. An exception to this algorithm occurs when the desired aspect is 90 degrees in azimuth and some non-zero value of elevation. In this case, the negative value of azimuth is entered as ψ, but now the negative rotation of aspect elevation must be entered as ϕ to obtain the correct representation of the circle.

A subprogram is also included which transforms input x, y,z position coordinates through a desired azimuth and elevation rotation and displays the X and Y transformed coordinate values. This feature is used to determine the minimum and maximum values of X and Y for a particular aspect. These values are required to be input to the calculator prior to plotting a figure and are used to correctly compute the scale factor for the plot.

This program is very flexible and can be used for a variety of purposes. The geometric shapes can be combined to form complex shapes for rotation and translation in a system. Other geometric shapes could be added to those already in the program. It could be used in limited vulnerability studies of aircraft components to determine presented area accurately and to show shielding effects by other components for any view.

A program listing is included in this section.

```
0000--XTO---23
0001-- 7 ---07
0002--XTO---23
0003-- 1 ---01
0004-- 0 ---00
0005-- 3 ---03
0006--YTO---40
0007-- 6 ---06
0008--YTO---40
0009-- 1 ---01
0010-- 0 ---00
0011-- 2 ---02
0012-- DN---25
0013--YTO---40
0014-- 5 ---05
0015--YTO---40
0016-- 1 ---01
0017-- 0 ---00
0018-- 1 ---01
0019--STP---41
0020--XTO---23
0021-- 1 ---01
0022-- 0 ---00
0023--YTO---40
0024-- 9 ---11
0025-- DN---25
0026--YTO---40
0027-- 8 ---10
0028--STP---41
0029--XTO---23
0030-- 1 ---01
0031-- 2 ---02
0032--YTO---40
0033-- 1 ---01
0034-- 1 ---01
0035--XFR---67
0036-- 8 ---10
0037-- H ---73
0038-- UP---27
0039--XFR---67
0040-- 9 ---11
0041-- H ---73
0042-- X ---36
0043--YTO---40
0044-- 1 ---01
0045-- 3 ---03
0046--XFR---67
0047-- 8 ---10
0048-- M ---70
0049-- UP---27
0050--XFR---67
0051-- 9 ---11
0052-- H ---73
0053-- X ---36
0054--YTO---40
0055-- 1 ---01
0056-- 4 ---04
0057--XFR---67
0058-- 9 ---11
0059-- M ---70
0060--XTO---23
0061-- 1 ---01
0062-- 5 ---05
0063-- UP---27
0064--XFR---67
0065-- 1 ---01
0066-- 0 ---00
0067-- M ---70
0068-- X ---36
0069--XFR---67
0070-- 8 ---10
0071-- H ---73
0072--CHS---32
0073-- X ---36
0074--XFR---67
0075-- 1 ---01
0076-- 0 ---00
0077-- H ---73
0078-- UP---27
0079--XFR---67
0080-- 8 ---10
0081-- M ---70
0082--CHS---32
0083-- X ---36
0084-- DN---25
0085-- + ---33
0086--YTO---40
0087-- 1 ---01
0088-- 6 ---06
0089--XFR---67
0090-- 9 ---11
0091-- M ---70
0092-- UP---27
0093--XFR---67
0094-- 1 ---01
0095-- 0 ---00
0096-- M ---70
0097-- X ---36
0098--XFR---67
0099-- 8 ---10
0100-- H ---70
0101--CHS---32
0102-- X ---36
0103--XFR---67
0104-- 1 ---01
0105-- 0 ---00
0106-- H ---73
0107-- UP---27
0108--XFR---67
0109-- 8 ---10
0110-- H ---73
0111-- X ---36
0112-- DN---25
0113-- + ---33
0114--YTO---40
0115-- 1 ---01
0116-- 7 ---07
0117--XFR---67
0118-- 9 ---11
0119-- H ---73
0120-- UP---27
0121--XFR---67
0122-- 1 ---01
0123-- 0 ---00
0124-- M ---70
0125-- X ---36
0126--YTO---40
0127-- 1 ---01
0128-- 8 ---10
0129-- UP---27
0130--XFR---67
0131-- 8 ---10
0132-- M ---70
0133-- X ---36
0134--XFR---67
0135-- 8 ---10
0136-- H ---73
0137--CHS---32
0138-- UP---27
0139--XFR---67
0140-- 9 ---11
0141-- M ---70
0142-- X ---36
0143--XFR---67
0144-- 1 ---01
0145-- 0 ---00
0146-- H ---73
0147-- X ---36
0148-- DN---25
0149-- + ---33
0150--YTO---40
0151-- 1 ---01
0152-- 9 ---11
0153--XFR---67
0154-- 1 ---01
0155-- 0 ---00
0156-- H ---73
0157-- UP---27
0158--XFR---67
0159-- 9 ---11
0160-- M ---70
0161-- X ---36
```

```
0162--XFR---67
0163-- 8 ---10
0164-- M ---70
0165--CHS---32
0166-- X ---36
0167--XFR---67
0168-- 1 ---01
0169-- 0 ---00
0170-- M ---70
0171-- UP---27
0172--XFR---67
0173-- 8 ---10
0174-- N ---73
0175--CHS---32
0176-- X ---36
0177-- DN---25
0178-- + ---33
0179--YTO---40
0180-- 2 ---02
0181-- 0 ---00
0182--XFR---67
0183-- 9 ---11
0184-- N ---73
0185-- UP---27
0186--XFR---67
0187-- 1 ---01
0188-- 0 ---00
0189-- N ---73
0190-- X ---36
0191--YTO---40
0192-- 2 ---02
0193-- 1 ---01
0194--XFR---67
0195-- 1 ---01
0196-- 1 ---01
0197-- N ---73
0198-- UP---27
0199--XFR---67
0200-- 1 ---01
0201-- 2 ---02
0202-- N ---73
0203-- X ---36
0204--YTO---40
0205-- 2 ---02
0206-- 2 ---02
0207-- UP---27
0208--XFR---67
0209-- 1 ---01
0210-- 1 ---01
0211-- M ---70
0212-- X ---36
0213--YTO---40
0214-- 2 ---02
0215-- 3 ---03
0216--XFR---67
0217-- 1 ---01
0218-- 2 ---02
0219-- M ---70
0220--XTO---23
0221-- 2 ---02
0222-- 4 ---04
0223--XFR---67
0224-- 1 ---01
0225-- 1 ---01
0226-- M ---70
0227--CHS---32
0228--XTO---23
0229-- 2 ---02
0230-- 5 ---05
0231--XFR---67
0232-- 1 ---01
0233-- 1 ---01
0234-- N ---73
0235--XTO---23
0236-- 2 ---02
0237-- 6 ---06
0238--CLX---37
0239--XTO---23
0240-- 2 ---02
0241-- 7 ---07
0242--XFR---67
0243-- 1 ---01
0244-- 1 ---01
0245-- N ---73
0246--CHS---32
0247-- UP---27
0248--XFR---67
0249-- 1 ---01
0250-- 2 ---02
0251-- M ---70
0252-- X ---36
0253--YTO---40
0254-- 2 ---02
0255-- 8 ---10
0256-- UP---27
0257--XFR---67
0258-- 1 ---01
0259-- 1 ---01
0260-- M ---70
0261--CHS---32
0262-- X ---36
0263--YTO---40
0264-- 2 ---02
0265-- 9 ---11
0266--XFR---67
0267-- 1 ---01
0268-- 2 ---02
0269-- N ---73
0270--XTO---23
0271-- 3 ---03
0272-- 0 ---00
0273--PSE---57
0274--CNT---47
0275--CNT---47
0276--STP---41
0277--XTO---23
0278-- 3 ---03
0279-- 4 ---04
0280-- UP---27
0281--CLX---37
0282-- 1 ---01
0283--X=Y---50
0284-- 0 ---00
0285-- 5 ---05
0286-- 6 ---06
0287-- 8 ---10
0288--CLX---37
0289-- 2 ---02
0290--X=Y---50
0291-- 1 ---01
0292-- 0 ---00
0293-- 1 ---01
0294-- 9 ---11
0295--CLX---37
0296-- 3 ---03
0297--X=Y---50
0298-- 1 ---01
0299-- 3 ---03
0300-- 9 ---11
0301-- 8 ---10
0302--CLX---37
0303-- 4 ---04
0304--X=Y---50
0305-- 1 ---01
0306-- 5 ---05
0307-- 1 ---01
0308-- 2 ---02
0309--CLX---37
0310-- 5 ---05
0311--X=Y---50
0312-- 1 ---01
0313-- 6 ---06
0314-- 9 ---11
0315-- 9 ---11
0316--CLX---37
0317-- 6 ---06
0318--X=Y---50
0319-- 1 ---01
0320-- 7 ---07
0321-- 6 ---06
0322-- 1 ---01
0323--PSE---57
```

```
0324--CHT---47
0325--CHT---47
0326--LBL---51
0327-- # ---56
0328--XFR---67
0329-- 1 ---01
0330-- 3 ---03
0331-- UP---27
0332--XFR---67
0333-- 3 ---03
0334-- 1 ---01
0335-- X ---36
0336--XFR---67
0337-- 1 ---01
0338-- 4 ---04
0339-- UP---27
0340--XFR---67
0341-- 3 ---03
0342-- 2 ---02
0343-- X ---36
0344-- DN---25
0345-- + ---33
0346--XFR---67
0347-- 1 ---01
0348-- 5 ---05
0349-- UP---27
0350--XFR---67
0351-- 3 ---03
0352-- 3 ---03
0353-- X ---36
0354-- DN---25
0355-- + ---33
0356--XFR---67
0357-- 5 ---05
0358-- + ---33
0359--YTO---40
0360-- 2 ---02
0361-- 2 ---02
0362--XFR---67
0363-- 1 ---01
0364-- 6 ---06
0365-- UP---27
0366--XFR---67
0367-- 3 ---03
0368-- 1 ---01
0369-- X ---36
0370--XFR---67
0371-- 1 ---01
0372-- 7 ---07
0373-- UP---27
0374--XFR---67
0375-- 3 ---03
0376-- 2 ---02
0377-- X ---36
0378-- DN---25
0379-- + ---33
0380--XFR---67
0381-- 1 ---01
0382-- 8 ---10
0383-- UP---27
0384--XFR---67
0385-- 3 ---03
0386-- 3 ---03
0387-- X ---36
0388-- DN---25
0389-- + ---33
0390--XFR---67
0391-- 6 ---06
0392-- + ---33
0393--YTO---40
0394-- 2 ---02
0395-- 3 ---03
0396--XFR---67
0397-- 1 ---01
0398-- 9 ---11
0399-- UP---27
0400--XFR---67
0401-- 3 ---03
0402-- 1 ---01
0403-- X ---36
0404--XFR---67
0405-- 2 ---02
0406-- 0 ---00
0407-- UP---27
0408--XFR---67
0409-- 3 ---03
0410-- 2 ---02
0411-- X ---36
0412-- DN---25
0413-- + ---33
0414--XFR---67
0415-- 2 ---02
0416-- 1 ---01
0417-- UP---27
0418--XFR---67
0419-- 3 ---03
0420-- 3 ---03
0421-- X ---36
0422-- DN---25
0423-- + ---33
0424--XFR---67
0425-- 7 ---07
0426-- + ---33
0427--YTO---40
0428-- 2 ---02
0429-- 4 ---04
0430--XFR---67
0431-- 2 ---02
0432-- 5 ---05
0433-- UP---27
0434--XFR---67
0435-- 2 ---02
0436-- 2 ---02
0437-- X ---36
0438--XFR---67
0439-- 2 ---02
0440-- 6 ---06
0441-- UP---27
0442--XFR---67
0443-- 2 ---02
0444-- 3 ---03
0445-- X ---36
0446-- DN---25
0447-- + ---33
0448--XFR---67
0449-- 2 ---02
0450-- 7 ---07
0451-- UP---27
0452--XFR---67
0453-- 2 ---02
0454-- 4 ---04
0455-- X ---36
0456-- DN---25
0457-- + ---33
0458--YTO---40
0459-- 5 ---05
0460-- 1 ---01
0461--XFR---67
0462-- 2 ---02
0463-- 8 ---10
0464-- UP---27
0465--XFR---67
0466-- 2 ---02
0467-- 2 ---02
0468-- X ---36
0469--XFR---67
0470-- 2 ---02
0471-- 9 ---11
0472-- UP---27
0473--XFR---67
0474-- 2 ---02
0475-- 3 ---03
0476-- X ---36
0477-- DN---25
0478-- + ---33
0479--XFR---67
0480-- 3 ---03
0481-- 0 ---00
0482-- UP---27
0483--XFR---67
0484-- 2 ---02
0485-- 4 ---04
```

```
0486-- % ---36
0487-- DN---25
0488-- + ---33
0489--XFR---67
0490-- 5 ---05
0491-- 1 ---01
0492--PSE---57
0493--IFG---43
0494-- 0 ---00
0495-- 5 ---05
0496-- 0 ---00
0497-- 8 ---10
0498-- K ---55
0499--FMT---42
0500-- DN---25
0501--FMT---42
0502-- UP---27
0503--GTO---44
0504-- 0 ---00
0505-- 5 ---05
0506-- 1 ---01
0507-- 1 ---01
0508-- K ---55
0509--FMT---42
0510-- UP---27
0511--S/R---77
0512--CNT---47
0513--CNT---47
0514--LBL---51
0515-- 1 ---01
0516--XFR---67
0517-- 4 ---04
0518-- UP---27
0519--XFR---67
0520-- 2 ---02
0521-- K ---55
0522--FMT---42
0523-- UP---27
0524--S/R---77
0525--CNT---47
0526--CNT---47
0527--LBL---51
0528-- 2 ---02
0529-- UP---27
0530-- 3 ---03
0531-- 0 ---00
0532-- % ---36
0533-- DN---25
0534-- UP---27
0535-- M ---70
0536--XTO---23
0537-- 5 ---05
0538-- 2 ---02
0539-- DN---25
0540-- N ---73
0541--XTO---23
0542-- 5 ---05
0543-- 3 ---03
0544-- UP---27
0545--XFR---67
0546-- 1 ---01
0547-- 0 ---00
0548-- 4 ---04
0549-- % ---36
0550--YTO---40
0551-- 3 ---03
0552-- 2 ---02
0553--XFR---67
0554-- 5 ---05
0555-- 2 ---02
0556-- UP---27
0557--XFR---67
0558-- 1 ---01
0559-- 0 ---00
0560-- 4 ---04
0561-- % ---36
0562--YTO---40
0563-- 3 ---03
0564-- 3 ---03
0565--S/R---77
0566--CNT---47
0567--[illegible]T---47
0568--[illegible]---20
0569--[illegible]--06
0570-- U[illegible]7
0571--[illegible]--32
0572-- 1 ---01
0373-- E ---60
0574--CL[illegible]--37
0575--XTO---23
0576-- 3 ---03
0577-- 1 ---01
0578--XTO---23
0579-- 3 ---03
0580-- 2 ---02
0581--XTO---23
0582-- 3 ---03
0583-- 3 ---03
0584--STP---41
0585--XTO---23
0586-- 1 ---01
0587-- 0 ---00
0588-- 4 ---04
0589--STP---41
0590--XTO---23
0591-- 1 ---01
0592-- 0 ---00
0593-- 5 ---05
0594--STP---41
0595--XTO---23
0596-- 1 ---01
0597-- 0 ---00
0598-- 6 ---06
0599--SFL---54
0600--GTO---44
0601--S/R---77
0602--LBL---51
0603-- π ---56
0604--CNT---47
0605--CLX---37
0606-- 0 ---00
[illegible]07-- UP---27
0608-- 1 ---01
0609-- E ---60
0610-- C ---61
0611--X>Y---53
0612-- 1 ---01
0613-- 0 ---00
0614-- 0 ---00
0615-- 7 ---07
0616-- UP---27
0617-- 0 ---00
0618--X<Y---52
0619-- 0 ---00
0620-- 6 ---06
0621-- 4 ---04
0622-- 5 ---05
0623--XFR---67
0624-- 3 ---03
0625-- 1 ---01
0626-- UP---27
062[illegible]--XFR---67
0628-- 1 ---01
0629-- 0 ---00
0630-- 4 ---04
0631-- + ---33
0632--YTO---40
0633-- 3 ---03
0634-- 1 ---01
0635--GTO---44
0636--S/R---77
0637--LBL---51
0638-- π ---56
0639--CNT---47
0640--GTO---44
0641-- 0 ---00
0642-- 6 ---06
0643-- 0 ---00
0644-- 5 ---05
0645--CLX---37
0646-- 1 ---01
0647--X<Y---52
```

```
0648-- 0 ---00
0649-- 6 ---06
0650-- 7 ---07
0651-- 5 ---05
0652--XFR---67
0653-- 3 ---03
0654-- 1 ---01
0655-- UP---27
0656--XFR---67
0657-- 1 ---01
0658-- 0 ---00
0659-- 4 ---04
0660-- - ---34
0661--YTO---40
0662-- 3 ---03
0663-- 1 ---01
0664--SFL---54
0665--GTO---44
0666--S/R---77
0667--LBL---51
0668-- π ---56
0669--CNT---47
0670--GTO---44
0671-- 0 ---00
0672-- 6 ---06
0673-- 0 ---00
0674-- 5 ---05
0675--CLX---37
0676-- 2 ---02
0677--X<Y---52
0678-- 0 ---00
0679-- 7 ---07
0680-- 0 ---00
0681-- 4 ---04
0682--XFR---67
0683-- 3 ---03
0684-- 2 ---02
0685-- UP---27
0686--XFR---67
0687-- 1 ---01
0688-- 0 ---00
0689-- 5 ---05
0690-- ÷ ---33
0691--YTO---40
0692-- 3 ---03
0693-- 2 ---02
0694--GTO---44
0695--S/R---77
0696--LBL---51
0697-- π ---56
0698--CNT---47
0699--GTO---44
0700-- 0 ---00
0701-- 6 ---06
0702-- 0 ---00
0703-- 5 ---05
0704--CLX---37
0705-- 3 ---03
0706--X<Y---52
0707-- 0 ---00
0708-- 7 ---07
0709-- 3 ---03
0710-- 4 ---04
0711--XFR---67
0712-- 3 ---03
0713-- 2 ---02
0714-- UP---27
0715--XFR---67
0716-- 1 ---01
0717-- 0 ---00
0718-- 5 ---05
0719-- - ---34
0720--YTO---40
0721-- 3 ---03
0722-- 2 ---02
0723--SFL---54
0724--GTO---44
0725--S/R---77
0726--LBL---51
0727-- π ---56
0728--CNT---47
0729--GTO---44
0730-- 0 ---00
0731-- 6 ---06
0732-- 0 ---00
0733-- 5 ---05
0734--CLX---37
0735-- 4 ---04
0736--X<Y---52
0737-- 0 ---00
0738-- 7 ---07
0739-- 6 ---06
0740-- 3 ---03
0741--XFR---67
0742-- 3 ---03
0743-- 3 ---03
0744-- UP---27
0745--XFR---67
0746-- 1 ---01
0747-- 0 ---00
0748-- 6 ---06
0749-- ÷ ---33
0750--YTO---40
0751-- 3 ---03
0752-- 3 ---03
0753--GTO---44
0754--S/R---77
0755--LBL---51
0756-- π ---56
0757--CNT---47
0758--GTO---44
0759-- 0 ---00
0760-- 6 ---06
0761-- 0 ---00
0762-- 5 ---05
0763--CLX---37
0764-- 5 ---05
0765--X<Y---52
0766-- 0 ---00
0767-- 7 ---07
0768-- 9 ---11
0769-- 3 ---03
0770--XFR---67
0771-- 3 ---03
0772-- 3 ---03
0773-- UP---27
0774--XFR---67
0775-- 1 ---01
0776-- 0 ---00
0777-- 6 ---06
0778-- - ---34
0779--YTO---40
0780-- 3 ---03
0781-- 3 ---03
0782--SFL---54
0783--GTO---44
0784--S/R---77
0785--LBL---51
0786-- π ---56
0787--CNT---47
0788--GTO---44
0789-- 0 ---00
0790-- 6 ---06
0791-- 0 ---00
0792-- 5 ---05
0793--CLX---37
0794-- 6 ---06
0795-- UP---27
0796--CHS---32
0797-- 7 ---07
0798-- E ---60
0799-- C ---61
0800--CLX---37
0801-- 1 ---01
0802-- 2 ---02
0803--X<Y---52
0804-- 0 ---00
0805-- 8 ---10
0806-- 6 ---06
0807-- 9 ---11
0808--XFR---67
0809-- 1 ---01
```

```
0810-- 0 ---00
0811-- 2 ---02
0812-- UP---27
0813--XFR---67
0814-- 1 ---01
0815-- 0 ---00
0816-- 5 ---05
0817-- + ---33
0818--YTO---40
0819-- 1 ---01
0820-- 0 ---00
0821-- 2 ---02
0822--CHS---32
0823--XTO---23
0824-- 1 ---01
0825-- 0 ---00
0826-- 5 ---05
0827--XFR---67
0828-- 6 ---06
0829-- - ---34
0830--YTO---40
0831-- 3 ---03
0832-- 2 ---02
0833--XFR---67
0834-- 1 ---01
0835-- 0 ---00
0836-- 3 ---03
0837-- UP---27
0838--XFR---67
0839-- 1 ---01
0840-- 0 ---00
0841-- 6 ---06
0842-- + ---33
0843--YTO---40
0844-- 1 ---01
0845-- 0 ---00
0846-- 3 ---03
0847--CHS---32
0848--XTO---23
0849-- 1 ---01
0850-- 0 ---00
0851-- 6 ---06
0852--XFR---67
0853-- 7 ---07
0854-- - ---34
0855--YTO---40
0856-- 3 ---03
0857-- 3 ---03
0858--SFL---54
0859--GTO---44
0860--S/R---77
0861--LBL---51
0862-- π ---56
0863--CNT---47
```

```
0864--GTO---44
0865-- 0 ---00
0866-- 6 ---06
0867-- 0 ---00
0868-- 5 ---05
0869--CLX---37
0870-- 1 ---01
0871-- 8 ---10
0872--X<Y---52
0873-- 0 ---00
0874-- 9 ---11
0875-- 3 ---03
0876-- 8 ---10
0877--XFR---67
0878-- 1 ---01
0879-- 0 ---00
0880-- 1 ---01
0881-- UP---27
0882--XFR---67
0883-- 1 ---01
0884-- 0 ---00
0885-- 4 ---04
0886-- + ---33
0887--YTO---40
0888-- 1 ---01
0889-- 0 ---00
0890-- 1 ---01
0891--CHS---32
0892--XTO---23
0893-- 1 ---01
0894-- 0 ---00
0895-- 4 ---04
0896--XFR---67
0897-- 5 ---05
0898-- - ---34
0899--YTO---40
0900-- 3 ---03
0901-- 1 ---01
0902--XFR---67
0903-- 1 ---01
0904-- 0 ---00
0905-- 2 ---02
0906-- UP---27
0907--XFR---67
0908-- 1 ---01
0909-- 0 ---00
0910-- 5 ---05
0911-- + ---33
0912--YTO---40
0913-- 1 ---01
0914-- 0 ---00
0915-- 2 ---02
0916--CHS---32
0917--XTO---23
```

```
0918-- 1 ---01
0919-- 0 ---00
0920-- 5 ---05
0921--XFR---67
0922-- 6 ---06
0923-- - ---34
0924--YTO---40
0925-- 3 ---03
0926-- 2 ---02
0927--SFL---54
0928--GTO---44
0929--S/R---77
0930--LBL---51
0931-- π ---56
0932--CNT---47
0933--GTO---44
0934-- 0 ---00
0935-- 6 ---06
0936-- 0 ---00
0937-- 5 ---05
0938--CLX---37
0939-- 2 ---02
0940-- 4 ---04
0941--X<Y---52
0942-- 1 ---01
0943-- 0 ---00
0944-- 0 ---00
0945-- 7 ---07
0946--XFR---67
0947-- 1 ---01
0948-- 0 ---00
0949-- 2 ---02
0950-- UP---27
0951--XFR---67
0952-- 1 ---01
0953-- 0 ---00
0954-- 5 ---05
0955-- + ---33
0956--YTO---40
0957-- 1 ---01
0958-- 0 ---00
0959-- 2 ---02
0960--CHS---32
0961--XTO---23
0962-- 1 ---01
0963-- 0 ---00
0964-- 5 ---05
0965--XFR---67
0966-- 6 ---06
0967-- - ---34
0968--YTO---40
0969-- 3 ---03
0970-- 2 ---02
0971--XFR---67
```

```
0972-- 1 ---01
0973-- 0 ---00
0974-- 3 ---03
0975-- UP---27
0976--XFR---67
0977-- 1 ---01
0978-- 0 ---00
0979-- 6 ---06
0980-- + ---33
0981--YTO---40
0982-- 1 ---01
0983-- 0 ---00
0984-- 3 ---03
0985--CHS---32
0986--XTO---23
0987-- 1 ---01
0988-- 0 ---00
0989-- 6 ---06
0990--XFR---67
0991-- 7 ---07
0992-- - ---34
0993--YTO---40
0994-- 3 ---03
0995-- 3 ---03
0996--SFL---54
0997--GTO---44
0998--S/R---77
0999--LBL---51
1000-- π ---56
1001--CNT---47
1002--GTO---44
1003-- 0 ---00
1004-- 6 ---06
1005-- 0 ---00
1006-- 5 ---05
1007--GTO---44
1008--S/R---77
1009--LBL---51
1010-- 1 ---01
1011--CNT---47
1012--GTO---44
1013-- 1 ---01
1014-- 8 ---10
1015-- 9 ---11
1016-- 7 ---07
1017--CNT---47
1018--CNT---47
1019--CLR---20
1020-- 8 ---10
1021-- UP---27
1022--CHS---32
1023-- 1 ---01
1024-- E ---60
1025--CLX---37
1026--XTO---23
1027-- 3 ---03
1028-- 1 ---01
1029--XTO---23
1030-- 3 ---03
1031-- 2 ---02
1032--XTO---23
1033-- 3 ---03
1034-- 3 ---03
1035--STP---41
1036--XTO---23
1037-- 1 ---01
1038-- 0 ---00
1039-- 4 ---04
1040--STP---41
1041--XTO---23
1042-- 1 ---01
1043-- 0 ---00
1044-- 5 ---05
1045--STP---41
1046--XTO---23
1047-- 1 ---01
1048-- 0 ---00
1049-- 6 ---06
1050--STP---41
1051--XTO---23
1052-- 1 ---01
1053-- 0 ---00
1054-- 7 ---07
1055--STP---41
1056--XTO---23
1057-- 1 ---01
1058-- 0 ---00
1059-- 8 ---10
1060--SFL---54
1061--GTO---44
1062--S/R---77
1063--LBL---51
1064-- π ---56
1065--CNT---47
1066--CLX---37
1067-- 0 ---00
1068-- UP---27
1069-- 1 ---01
1070-- E ---60
1071-- C ---61
1072--X>Y---53
1073-- 1 ---01
1074-- 3 ---03
1075-- 8 ---10
1076-- 6 ---06
1077-- UP---27
1078-- 0 ---00
1079--X<Y---52
1080-- 1 ---01
1081-- 1 ---01
1082-- 0 ---00
1083-- 6 ---06
1084--XFR---67
1085-- 3 ---03
1086-- 1 ---01
1087-- UP---27
1088--XFR---67
1089-- 1 ---01
1090-- 0 ---00
1091-- 4 ---04
1092-- + ---33
1093--YTO---40
1094-- 3 ---03
1095-- 1 ---01
1096--GTO---44
1097--S/R---77
1098--LBL---51
1099-- π ---56
1100--CNT---47
1101--GTO---44
1102-- 1 ---01
1103-- 0 ---00
1104-- 6 ---06
1105-- 6 ---06
1106--CLX---37
1107-- 1 ---01
1108--X<Y---52
1109-- 1 ---01
1110-- 1 ---01
1111-- 3 ---03
1112-- 5 ---05
1113--XFR---67
1114-- 3 ---03
1115-- 2 ---02
1116-- UP---27
1117--XFR---67
1118-- 1 ---01
1119-- 0 ---00
1120-- 5 ---05
1121-- + ---33
1122--YTO---40
1123-- 3 ---03
1124-- 2 ---02
1125--GTO---44
1126--S/R---77
1127--LBL---51
```

```
1128-- π ---56
1129--CNT---47
1130--GTO---44
1131-- 1 ---01
1132-- 0 ---00
1133-- 6 ---06
1134-- 6 ---06
1135--CLX---37
1136-- 2 ---02
1137--X<Y---52
1138-- 1 ---01
1139-- 1 ---01
1140-- 6 ---06
1141-- 4 ---04
1142--XFR---67
1143-- 3 ---03
1144-- 1 ---01
1145-- UP---27
1146--XFR---67
1147-- 1 ---01
1148-- 0 ---00
1149-- 4 ---04
1150-- - ---34
1151--YTO---40
1152-- 3 ---03
1153-- 1 ---01
1154--GTO---44
1155--S/R---77
1156--LBL---51
1157-- π ---56
1158--CNT---47
1159--GTO---44
1160-- 1 ---01
1161-- 0 ---00
1162-- 6 ---06
1163-- 6 ---06
1164--CLX---37
1165-- 3 ---03
1166--X<Y---52
1167-- 1 ---01
1168-- 1 ---01
1169-- 9 ---11
1170-- 3 ---03
1171--XFR---67
1172-- 3 ---03
1173-- 2 ---02
1174-- UP---27
1175--XFR---67
1176-- 1 ---01
1177-- 0 ---00
1178-- 5 ---05
1179-- - ---34
1180--YTO---40
1181-- 3 ---03
1182-- 2 ---02
1183--GTO---44
1184--S/R---77
1185--LBL---51
1186-- π ---56
1187--CNT---47
1188--GTO---44
1189-- 1 ---01
1190-- 0 ---00
1191-- 6 ---06
1192-- 6 ---06
1193--CLX---37
1194-- 4 ---04
1195--X<Y---52
1196-- 1 ---01
1197-- 2 ---02
1198-- 3 ---03
1199-- 9 ---11
1200--XFR---67
1201-- 1 ---01
1202-- 0 ---00
1203-- 7 ---07
1204-- UP---27
1205--XFR---67
1206-- 5 ---05
1207-- - ---34
1208--YTO---40
1209-- 3 ---03
1210-- 1 ---01
1211--XFR---67
1212-- 1 ---01
1213-- 0 ---00
1214-- 8 ---10
1215-- UP---27
1216--XFR---67
1217-- 6 ---06
1218-- - ---34
1219--YTO---40
1220-- 3 ---03
1221-- 2 ---02
1222--XFR---67
1223-- 1 ---01
1224-- 0 ---00
1225-- 6 ---06
1226--XTO---23
1227-- 3 ---03
1228-- 3 ---03
1229--GTO---44
1230--S/R---77
1231--LBL---51
1232-- π ---56
1233--CNT---47
1234--GTO---44
1235-- 1 ---01
1236-- 0 ---00
1237-- 6 ---06
1238-- 6 ---06
1239--CLX---37
1240-- 5 ---05
1241--X<Y---52
1242-- 1 ---01
1243-- 2 ---02
1244-- 7 ---07
1245-- 9 ---11
1246-- 0 ---00
1247--XTO---23
1248-- 3 ---03
1249-- 1 ---01
1250--XFR---67
1251-- 1 ---01
1252-- 0 ---00
1253-- 5 ---05
1254  XTO---23
1255-- 3 ---03
1256-- 2 ---02
1257--XFR---67
1258-- 3 ---03
1259-- 3 ---03
1260-- UP---27
1261--XFR---67
1262-- 1 ---01
1263-- 0 ---00
1264-- 6 ---06
1265-- - ---34
1266--YTO---40
1267-- 3 ---03
1268-- 3 ---03
1269--GTO---44
1270--S/R---77
1271--LBL---51
1272-- π ---56
1273--CNT---47
1274--GTO---44
1275-- 1 ---01
1276-- 0 ---00
1277-- 6 ---06
1278-- 6 ---06
1279--CLX---37
1280-- 6 ---06
1281--X<Y---52
1282-- 1 ---01
1283-- 3 ---03
1284-- 0 ---00
1285-- 9 ---11
1286--XFR---67
1287-- 1 ---01
1288-- 0 ---00
1289-- 4 ---04
```

```
1290-- UP---27
1291--XFR---67
1292-- 3 ---03
1293-- 1 ---01
1294-- + ---33
1295--YTO---40
1296-- 3 ---03
1297-- 1 ---01
1298--SFL---54
1299--GTO---44
1300--S/R---77
1301--LBL---51
1302-- π ---56
1303--CNT---47
1304--GTO---44
1305-- 1 ---01
1306-- 0 ---00
1307-- 6 ---06
1308-- 6 ---06
1309--CLX---37
1310-- 7 ---07
1311--X<Y---52
1312-- 1 ---01
1313-- 3 ---03
1314-- 6 ---06
1315-- 0 ---00
1316--XFR---67
1317-- 1 ---01
1318-- 0 ---00
1319-- 7 ---07
1320-- UP---27
1321--XFR---67
1322-- 5 ---05
1323-- - ---34
1324--YTO---40
1325-- 3 ---03
1326-- 1 ---01
1327--XFR---67
1328-- 1 ---01
1329-- 0 ---00
1330-- 8 ---10
1331-- UP---27
1332--XFR---67
1333-- 6 ---06
1334-- - ---34
1335--YTO---40
1336-- 3 ---03
1337-- 2 ---02
1338--XFR---67
1339-- 1 ---01
1340-- 0 ---00
1341-- 6 ---06
1342-- UP---27
1343--XFR---67
1344-- 3 ---03
1345-- 3 ---03
1346-- + ---33
1347--YTO---40
1348-- 3 ---03
1349-- 3 ---03
1350--GTO---44
1351--S/R---77
1352--LBL---51
1353-- π ---56
1354--CNT---47
1355--GTO---44
1356-- 1 ---01
1357-- 0 ---00
1358-- 6 ---06
1359-- 6 ---06
1360--CLX---37
1361-- 8 ---10
1362--XFR---67
1363-- 1 ---01
1364-- 0 ---00
1365-- 4 ---04
1366--XTO---23
1367-- 3 ---03
1368-- 1 ---01
1369--CLX---37
1370--XTO---23
1371-- 3 ---03
1372-- 2 ---02
1373--XTO---23
1374-- 3 ---03
1375-- 3 ---03
1376--GTO---44
1377--S/R---77
1378--LBL---51
1379-- π ---56
1380--CNT---47
1381--GTO---44
1382-- 1 ---01
1383-- 0 ---00
1384-- 6 ---06
1385-- 6 ---06
1386--GTO---44
1387--S/R---77
1388--LBL---51
1389-- 1 ---01
1390--CNT---47
1391--GTO---44
1392-- 1 ---01
1393-- 8 ---10
1394-- 9 ---11
1395-- 7 ---07
1396--CNT---47
1397--CNT---47
1398--CLX---37
1399--XTO---23
1400-- 3 ---03
1401-- 1 ---01
1402--XTO---23
1403-- 3 ---03
1404-- 3 ---03
1405--STP---41
1406--XTO---23
1407-- 1 ---01
1408-- 0 ---00
1409-- 4 ---04
1410--XTO---23
1411-- 3 ---03
1412-- 2 ---02
1413--STP---41
1414--XTO---23
1415-- 1 ---01
1416-- 0 ---00
1417-- 5 ---05
1418--CLR---20
1419-- 1 ---01
1420-- 3 ---03
1421-- UP---27
1422-- 0 ---00
1423-- 0 ---00
1424-- E ---60
1425--SFL---54
1426--GTO---44
1427--S/R---77
1428--LBL---51
1429-- π ---56
1430--CNT---47
1431--CLX---37
1432-- 0 ---00
1433-- UP---27
1434-- 1 ---01
1435-- E ---60
1436-- C ---61
1437--X=Y---50
1438-- 1 ---01
1439-- 5 ---05
1440-- 0 ---00
1441-- 0 ---00
1442-- C ---61
1443--GTO---44
1444--S/R---77
1445--LBL---51
1446-- 2 ---02
1447--CNT---47
1448--GTO---44
1449--S/R---77
1450--LBL---51
1451-- π ---56
```

```
1452--CNT---47
1453-- 0 ---00
1454--XTO---23
1455-- 3 ---03
1456-- 2 ---02
1457--XTO---23
1458-- 3 ---03
1459-- 3 ---03
1460--XFR---67
1461-- 1 ---01
1462-- 0 ---00
1463-- 5 ---05
1464--XTO---23
1465-- 3 ---03
1466-- 1 ---01
1467--GTO---44
1468--S/R---77
1469--LBL---51
1470-- π ---56
1471--CNT---47
1472--SFL---54
1473--CLX---37
1474--XTO---23
1475-- 3 ---03
1476-- 1 ---01
1477--XFR---67
1478-- 1 ---01
1479-- 0 ---00
1480-- 4 ---04
1481--XTO---23
1482-- 3 ---03
1483-- 2 ---02
1484-- C ---61
1485--GTO---44
1486--S/R---77
1487--LBL---51
1488-- 2 ---02
1489--CNT---47
1490--GTO---44
1491--S/R---77
1492--LBL---51
1493-- π ---56
1494--CNT---47
1495--GTO---44
1496-- 1 ---01
1497-- 4 ---04
1498-- 3 ---03
1499-- 1 ---01
1500--GTO---44
1501--S/R---77
1502--LBL---51
1503-- 1 ---01
1504--CNT---47
1505--GTO---44
1506-- 1 ---01
1507-- 8 ---10
1508-- 9 ---11
1509-- 7 ---07
1510--CNT---47
1511--CNT---47
1512--CLX---37
1513--XTO---23
1514-- 3 ---03
1515-- 1 ---01
1516--XTO---23
1517-- 3 ---03
1518-- 3 ---03
1519--STP---41
1520--XTO---23
1521-- 1 ---01
1522-- 0 ---00
1523-- 4 ---04
1524--XTO---23
1525-- 3 ---03
1526-- 2 ---02
1527--STP---41
1528--XTO---23
1529-- 1 ---01
1530-- 0 ---00
1531-- 5 ---05
1532--CLR---20
1533-- 1 ---01
1534-- 3 ---03
1535-- UP---27
1536-- 0 ---00
1537-- 0 ---00
1538-- E ---60
1539--SFL---54
1540--GTO---44
1541--S/R---77
1542--LBL---51
1543-- π ---56
1544--CNT---47
1545--CLX---37
1546-- 0 ---00
1547-- UP---27
1548-- 1 ---01
1549-- E ---60
1550-- C ---61
1551--X=Y---50
1552-- 1 ---01
1553-- 5 ---05
1554-- 7 ---07
1555-- 2 ---02
1556-- C ---61
1557--GTO---44
1558--S/R---77
1559--LBL---51
1560-- 2 ---02
1561--CNT---47
1562--GTO---44
1563--S/R---77
1564--LBL---51
1565-- π ---56
1566--CNT---47
1567--GTO---44
1568-- 1 ---01
1569-- 5 ---05
1570-- 4 ---04
1571-- 5 ---05
1572--XFR---67
1573-- 3 ---03
1574-- 1 ---01
1575-- UP---27
1576--XFR---67
1577-- 1 ---01
1578-- 0 ---00
1579-- 1 ---01
1580-- + ---33
1581--X=Y---50
1582-- 1 ---01
1583-- 5 ---05
1584-- 9 ---11
1585-- 1 ---01
1586--GTO---44
1587-- 1 ---01
1588-- 6 ---06
1589-- 1 ---01
1590-- 0 ---00
1591--XFR---67
1592-- 1 ---01
1593-- 0 ---00
1594-- 5 ---05
1595--XTO---23
1596-- 3 ---03
1597-- 1 ---01
1598--CLR---20
1599-- 1 ---01
1600-- 3 ---03
1601-- UP---27
1602-- 0 ---00
1603-- 0 ---00
1604-- E ---60
1605--GTO---44
1606-- 1 ---01
1607-- 5 ---05
1608-- 4 ---04
1609-- 0 ---00
1610--CLR---20
1611-- 1 ---01
1612-- 2 ---02
1613-- UP---27
```

```
1614-- 0 ---00
1615-- E ---60
1616-- C ---61
1617--CLX---37
1618-- 0 ---00
1619-- UP---27
1620-- 1 ---01
1621-- E ---60
1622-- C ---61
1623--X=Y---50
1624-- 1 ---01
1625-- 6 ---06
1626-- 8 ---10
1627-- 7 ---07
1628--SFL---54
1629--GTO---44
1630--S/R---77
1631--LBL---51
1632-- 2 ---02
1633--CNT---47
1634--GTO---44
1635--S/R---77
1636--LBL---51
1637-- π ---56
1638--CNT---47
1639--CLX---37
1640--XTO---23
1641-- 3 ---03
1642-- 1 ---01
1643--GTO---44
1644--S/R---77
1645--LBL---51
1646-- π ---56
1647--CNT---47
1648--CLX---37
1649-- 0 ---00
1650-- UP---27
1651-- 1 ---01
1652-- E ---60
1653-- C ---61
1654--X=Y---50
1655-- 1 ---01
1656-- 6 ---06
1657-- 8 ---10
1658-- 7 ---07
1659--SFL---54
1660--GTO---44
1661--S/R---77
1662--LBL---51
1663-- 2 ---02
1664--CNT---47
1665--GTO---44
1666--S/R---77
1667--LBL---51
1668-- π ---56
1669--CNT---47
1670--XFR---67
1671-- 1 ---01
1672-- 0 ---00
1673-- 5 ---05
1674--XTO---23
1675-- 3 ---03
1676-- 1 ---01
1677--GTO---44
1678--S/R---77
1679--LBL---51
1680-- π ---56
1681--CNT---47
1682--GTO---44
1683-- 1 ---01
1684-- 6 ---06
1685-- 1 ---01
1686-- 7 ---07
1687--GTO---44
1688--S/R---77
1689--LBL---51
1690-- 1 ---01
1691--CNT---47
1692--GTO---44
1693-- 1 ---01
1694-- 8 ---10
1695-- 9 ---11
1696-- 7 ---07
1697--CNT---47
1698--CNT---47
1699--CLX---37
1700--XTO---23
1701-- 3 ---03
1702-- 1 ---01
1703--XTO---23
1704-- 3 ---03
1705-- 3 ---03
1706--STP---41
1707--XTO---23
1708-- 1 ---01
1709-- 0 ---00
1710-- 4 ---04
1711--XTO---23
1712-- 3 ---03
1713-- 2 ---02
1714--CLR---20
1715-- 1 ---01
1716-- 3 ---03
1717-- UP---27
1718-- 0 ---00
1719-- 0 ---00
1720-- E ---60
1721--SFL---54
1722--GTO---44
1723--S/R---77
1724--LBL---51
1725-- π ---56
1726--CNT---47
1727--CLX---37
1728-- 0 ---00
1729-- UP---27
1730-- 1 ---01
1731-- E ---60
1732-- C ---61
1733--X=Y---50
1734-- 1 ---01
1735-- 7 ---07
1736-- 4 ---04
1737-- 9 ---11
1738-- C ---61
1739--GTO---44
1740--S/R---77
1741--LBL---51
1742-- 2 ---02
1743--CNT---47
1744--GTO---44
1745-- 1 ---01
1746-- 7 ---07
1747-- 2 ---02
1748-- 2 ---02
1749--GTO---44
1750--S/R---77
1751--LBL---51
1752-- 1 ---01
1753--CNT---47
1754--GTO---44
1755-- 1 ---01
1756-- 8 ---10
1757-- 9 ---11
1758-- 7 ---07
1759--CNT---47
1760--CNT---47
1761--XFR---67
1762-- 2 ---02
1763-- 2 ---02
1764-- UP---27
1765--XFR---67
1766-- 1 ---01
1767-- 0 ---00
1768-- 1 ---01
1769-- X ---36
1770--YTO---40
1771-- a ---13
1772--XFR---67
1773-- 2 ---02
1774-- 3 ---03
1775-- UP---27
```

```
1776--XFR---67
1777-- 1 ---01
1778-- 0 ---00
1779-- 2 ---02
1780-- X ---36
1781-- α ---13
1782-- + ---33
1783--YTO---40
1784-- α ---13
1785--XFR---67
1786-- 2 ---02
1787-- 4 ---04
1788-- UP---27
1789--XFR---67
1790-- 1 ---01
1791-- 0 ---00
1792-- 3 ---03
1793-- X ---36
1794-- α ---13
1795-- ÷ ---33
1796--YTO---40
1797-- 6 ---06
1798-- 1 ---01
1799--XFR---67
1800-- 2 ---02
1801-- 5 ---05
1802-- UP---27
1803--XFR---67
1804-- 1 ---01
1805-- 0 ---00
1806-- 1 ---01
1807-- X ---36
1808--YTO---40
1809-- α ---13
1810--XFR---67
1811-- 2 ---02
1812-- 6 ---06
1813-- UP---27
1814--XFR---67
1815-- 1 ---01
1816-- 0 ---00
1817-- 2 ---02
1818-- X ---36
1819-- α ---13
1820-- + ---33
1821--YTO---40
1822-- α ---13
1823--XFR---67
1824-- 2 ---02
1825-- 7 ---07
1826-- UP---27
1827--XFR---67
1828-- 1 ---01
1829-- 0 ---00
1830-- 3 ---03
1831-- X ---36
1832-- α ---13
1833-- + ---33
1834--YTO---40
1835-- 6 ---06
1836-- 2 ---02
1837--XFR---67
1838-- 2 ---02
1839-- 8 ---10
1840-- UP---27
1841--XFR---67
1842-- 1 ---01
1843-- 0 ---00
1844-- 1 ---01
1845-- X ---36
1846--YTO---40
1847-- α ---13
1848--XFR---67
1849-- 2 ---02
1850-- 9 ---11
1851-- UP---27
1852--XFR---67
1853-- 1 ---01
1854-- 0 ---00
1855-- 2 ---02
1856-- X ---36
1857-- α ---13
1858-- ÷ ---33
1859--YTO---40
1860-- α ---13
1861--XFR---67
1862-- 3 ---03
1863-- 0 ---00
1864-- UP---27
1865--XFR---67
1866-- 1 ---01
1867-- 0 ---00
1868-- 3 ---03
1869-- X ---36
1870-- α ---13
1871-- + ---33
1872--YTO---40
1873-- 6 ---06
1874-- 3 ---03
1875--XFR---67
1876-- 6 ---06
1877-- 2 ---02
1878--STP---41
1879--XTO---23
1880-- 1 ---01
1881-- 0 ---00
1882-- 3 ---03
1883--YTO---40
1884-- 1 ---01
1885-- 0 ---00
1886-- 2 ---02
1887-- DN---25
1888--YTO---40
1889-- 1 ---01
1890-- 0 ---00
1891-- 1 ---01
1892--GTO---44
1893-- 1 ---01
1894-- 7 ---07
1895-- 6 ---06
1896-- 1 ---01
1897--END---46
```

APPENDIX C

Figures of the Major Views of the OV-10 and A-10 Models and the Views of the Combination of Shapes

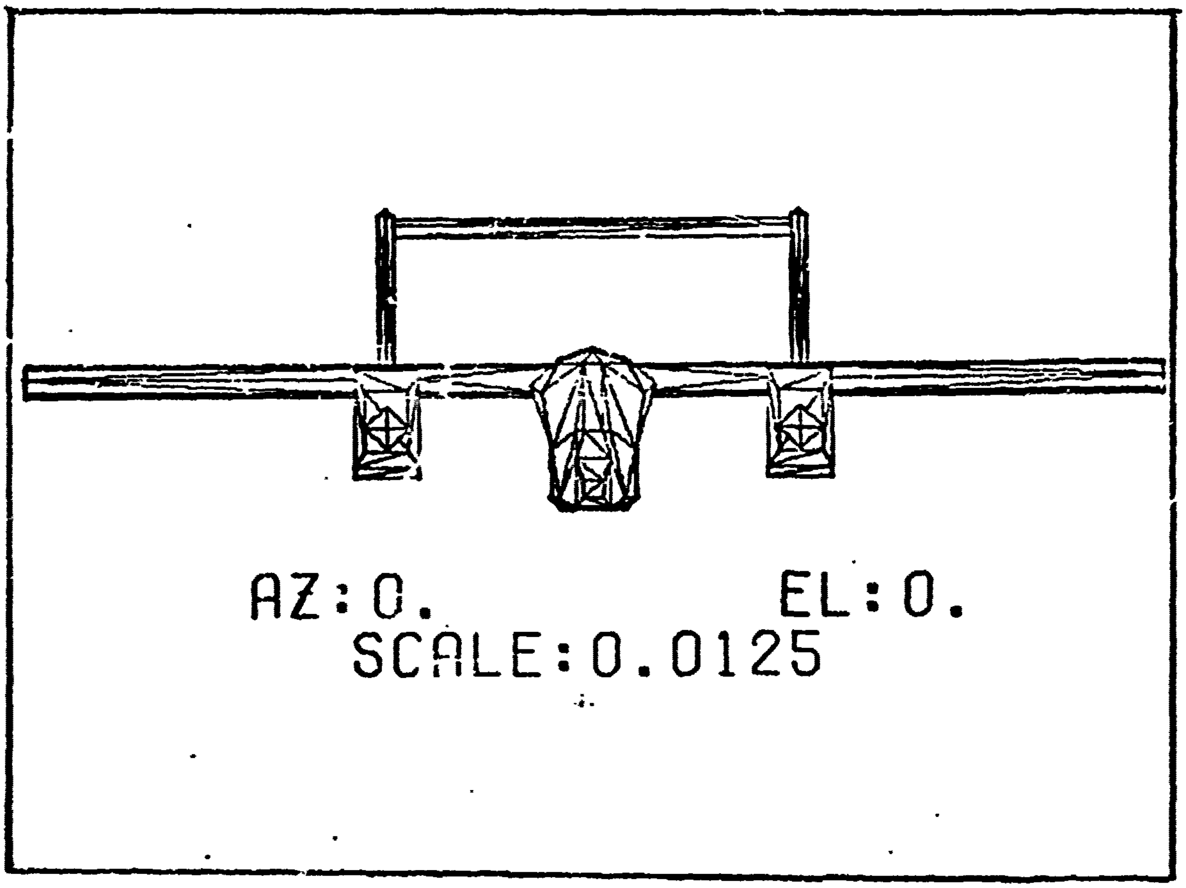

Figure 20. The OV-10 Computer Model Aircraft: View 14.

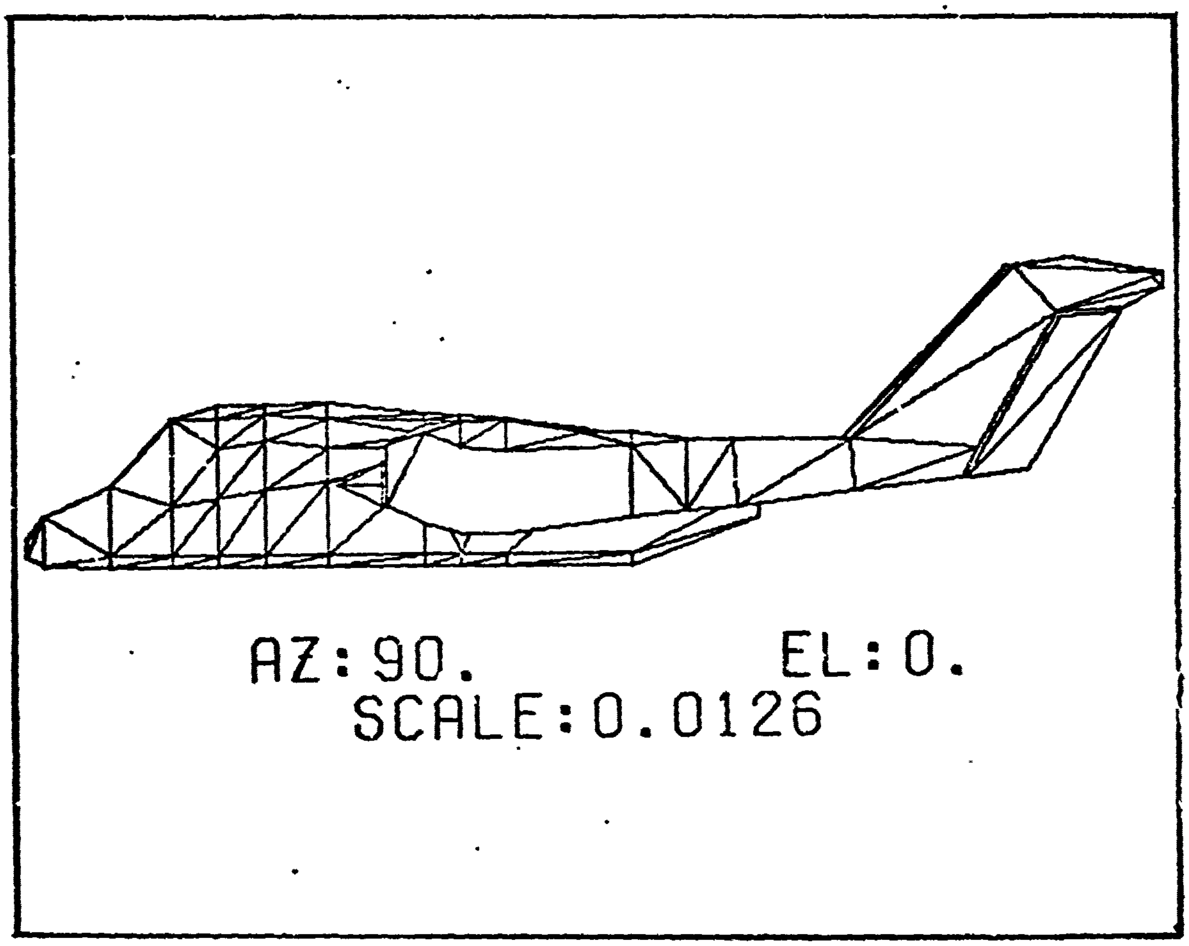

Figure 21. The OV-10 Computer Model Aircraft: View 16.

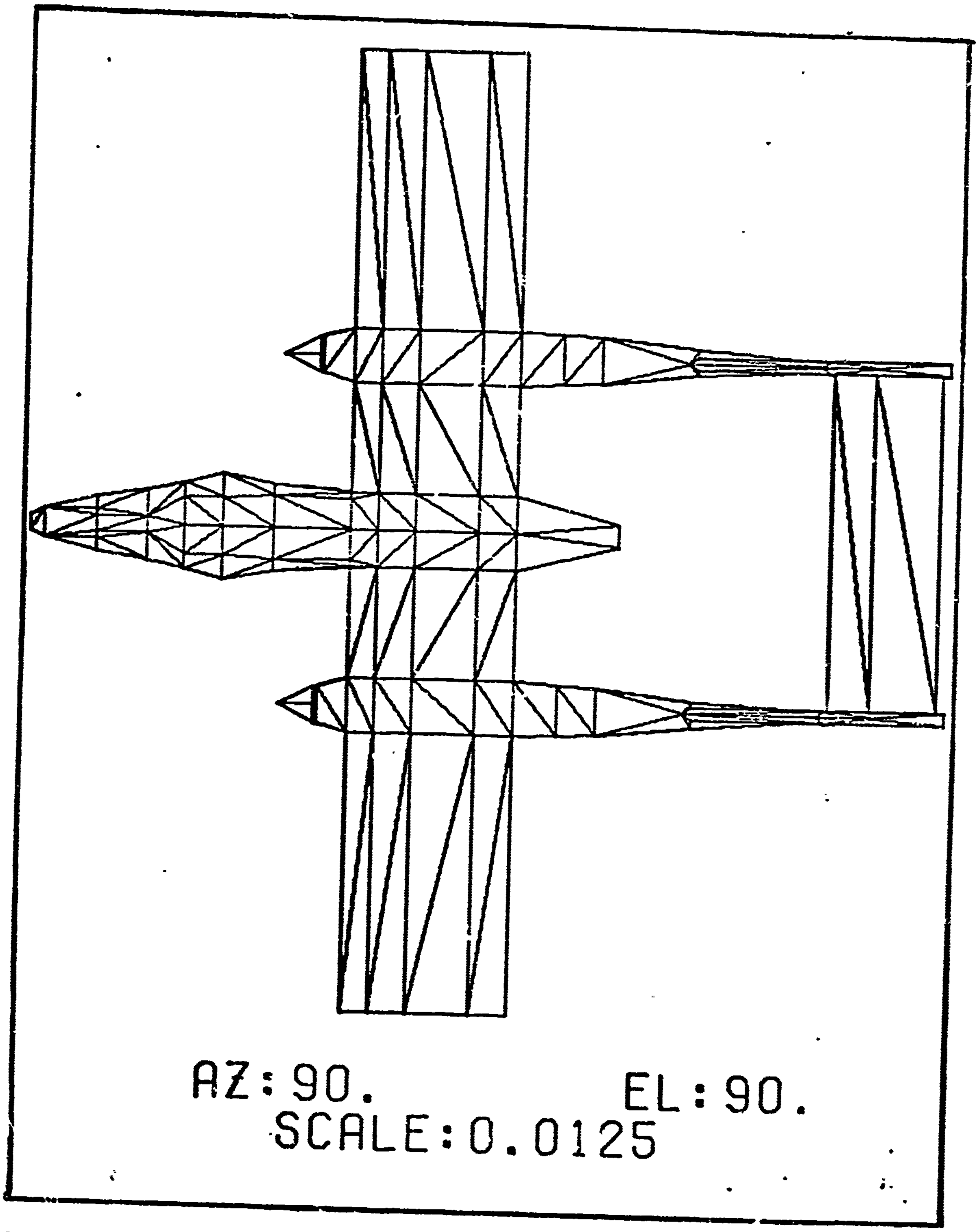

Figure 22. The OV-10 Computer Model Aircraft: View 26.

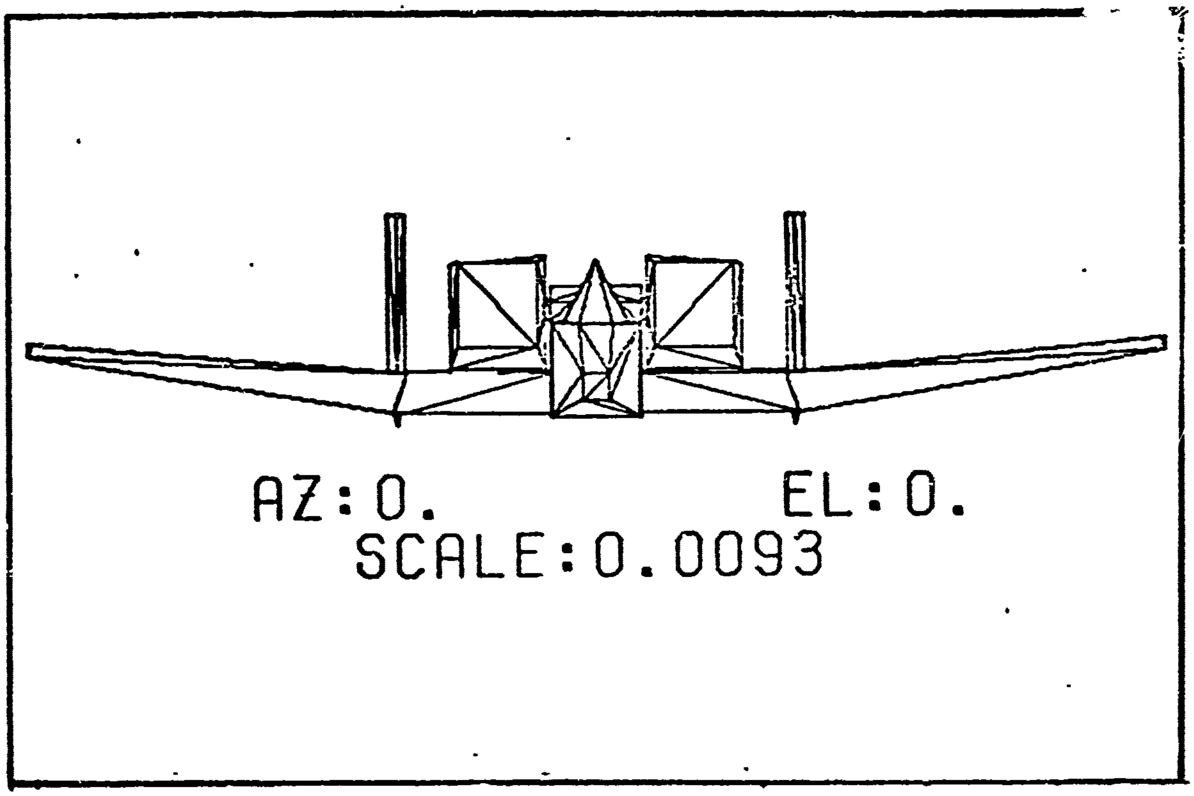

Figure 23. The A-10 Computer Model Aircraft: View 14.

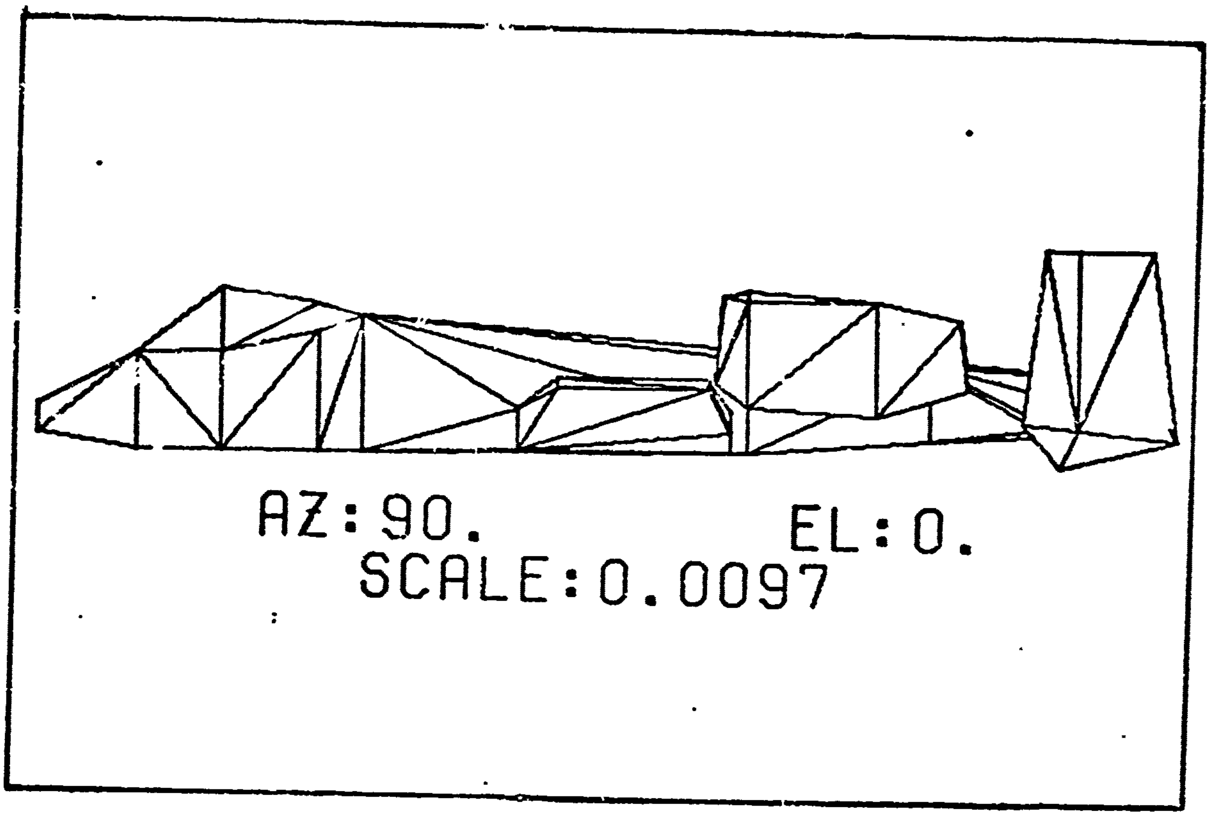

Figure 24. The A-10 Computer Model Aircraft: View 16.

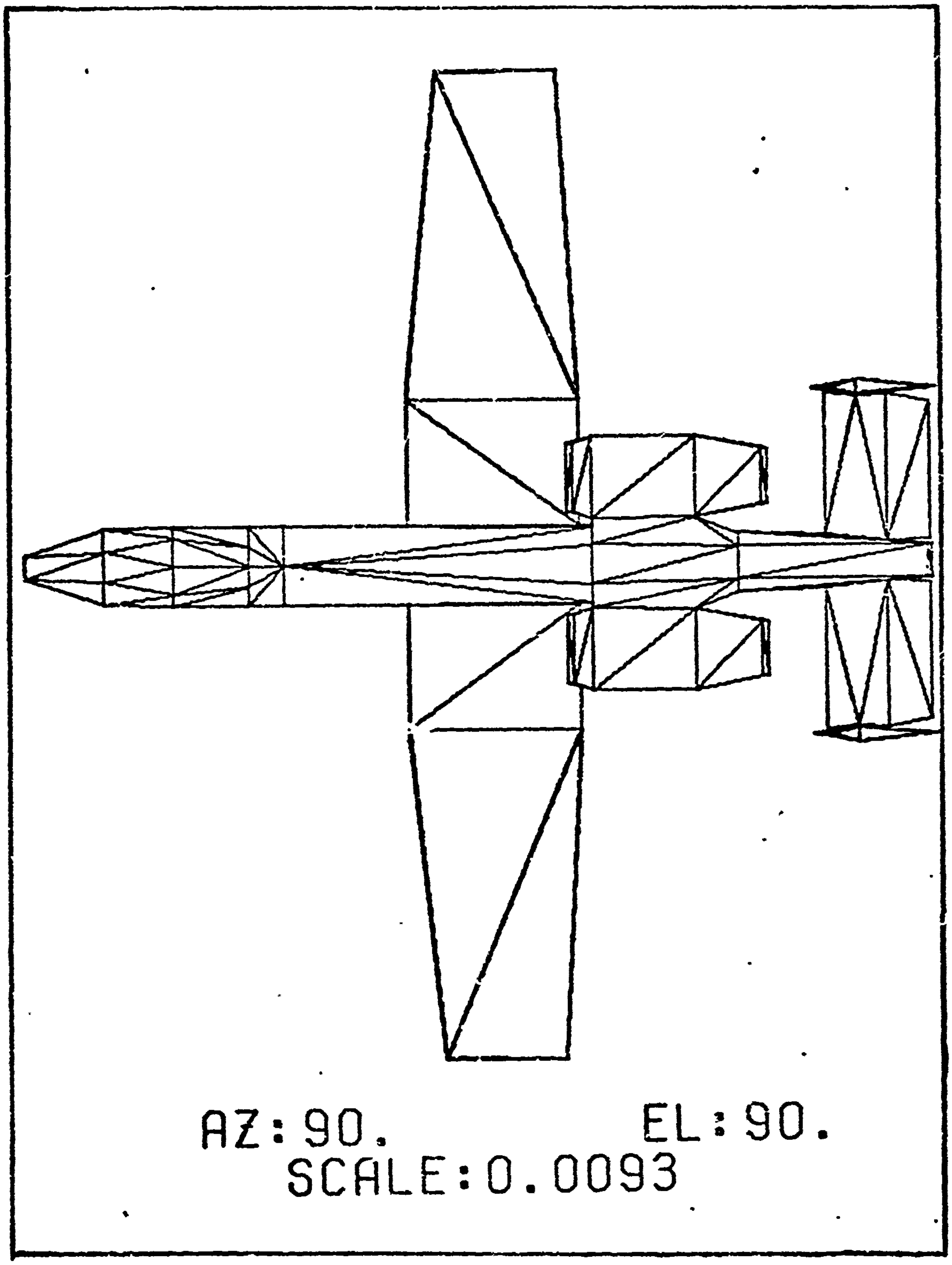

Figure 25. The A-10 Computer Model Aircraft: View 26.

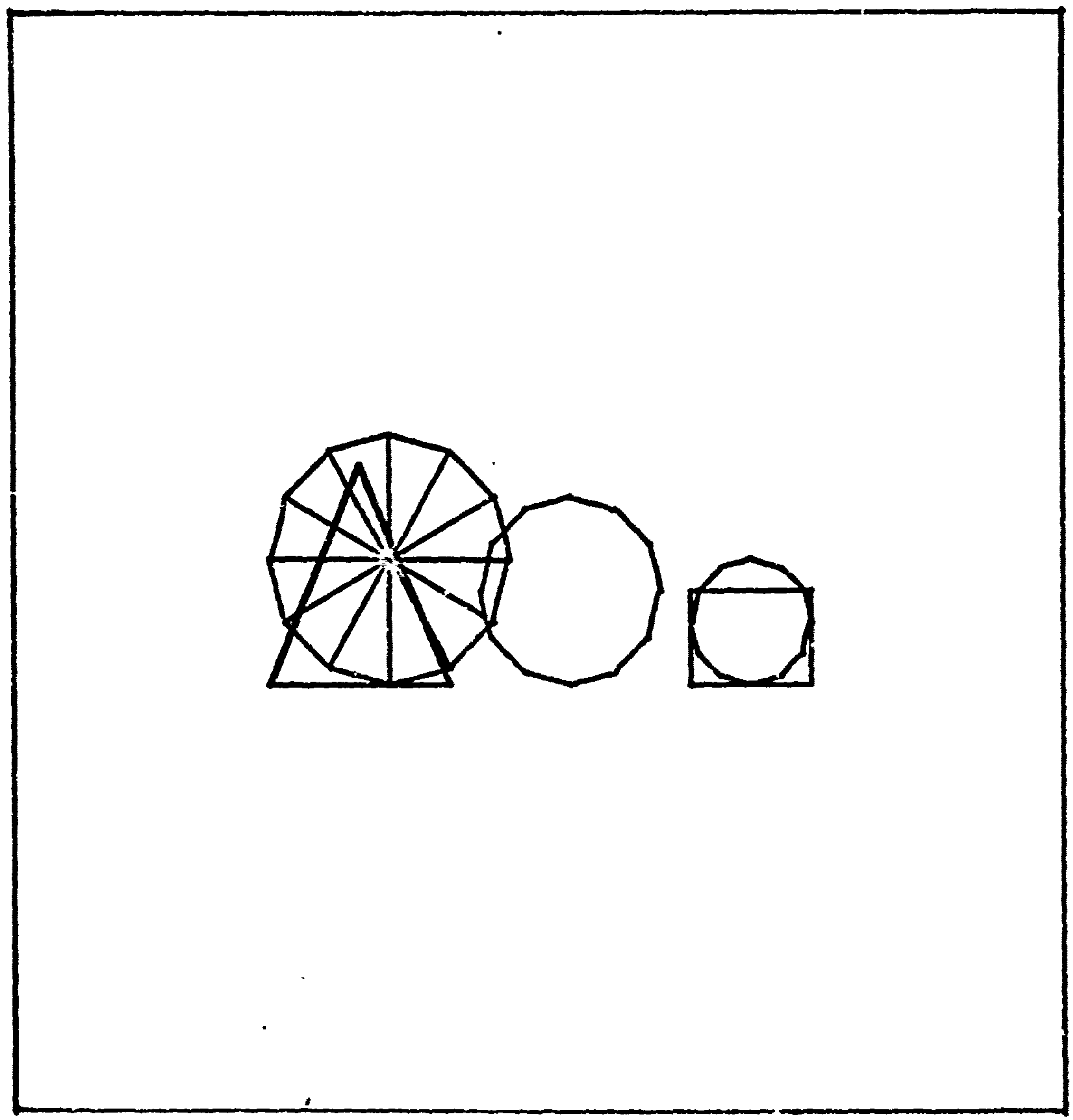

Figure 26. Combination of Shapes: View 14.

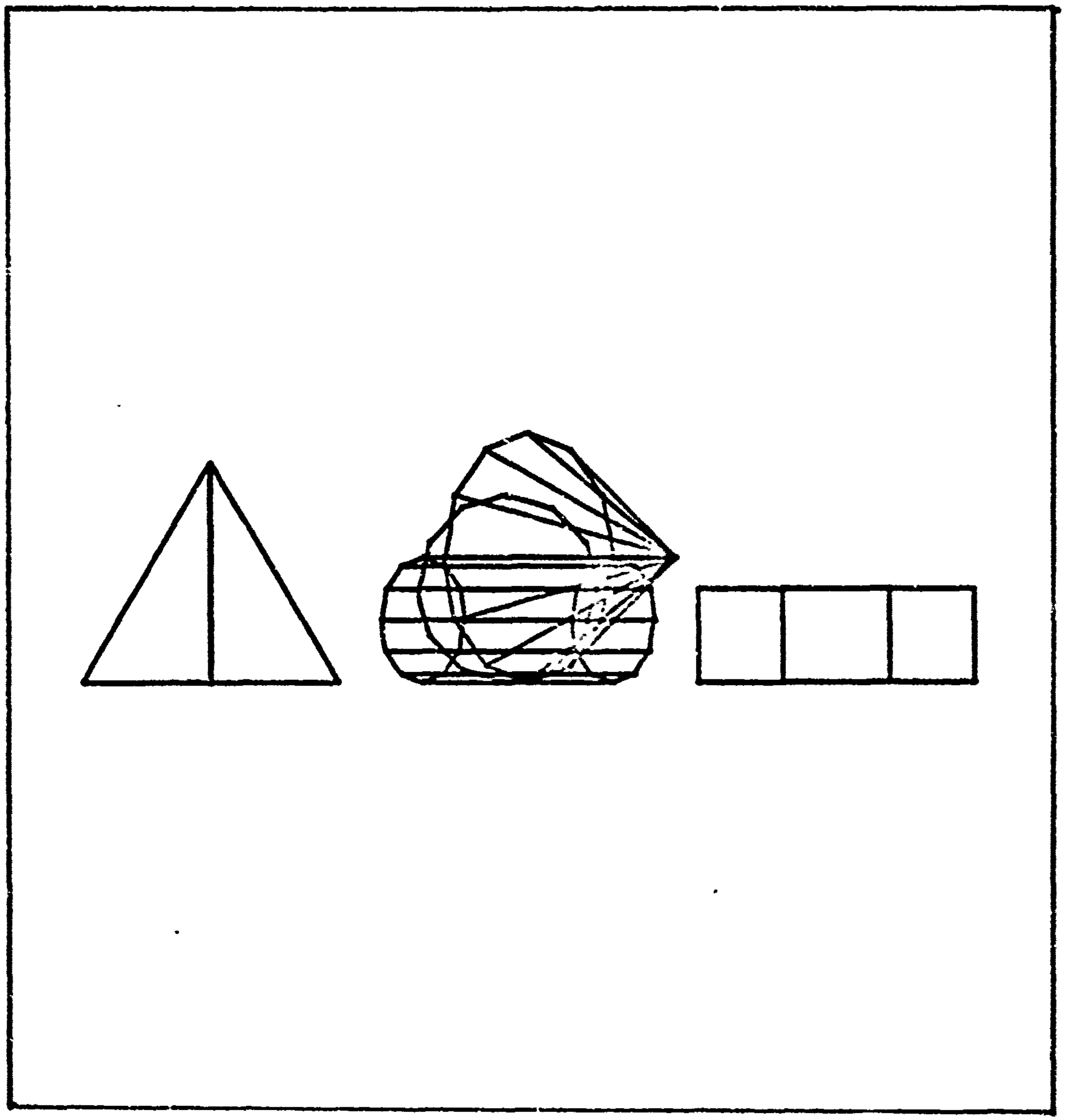

Figure 27. Combination of Shapes: View 15.

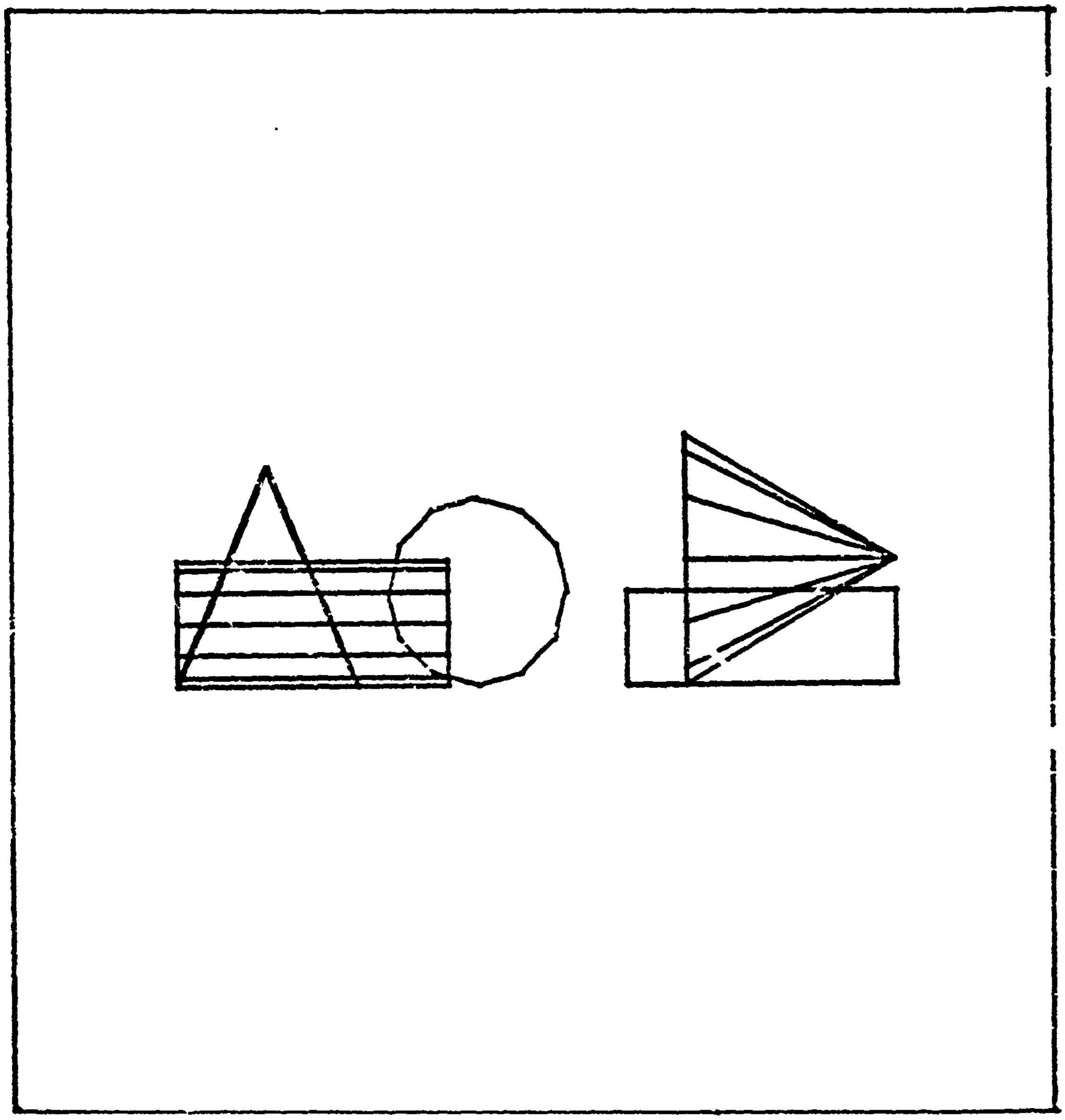

Figure 28. Combination of Shapes: View 16.

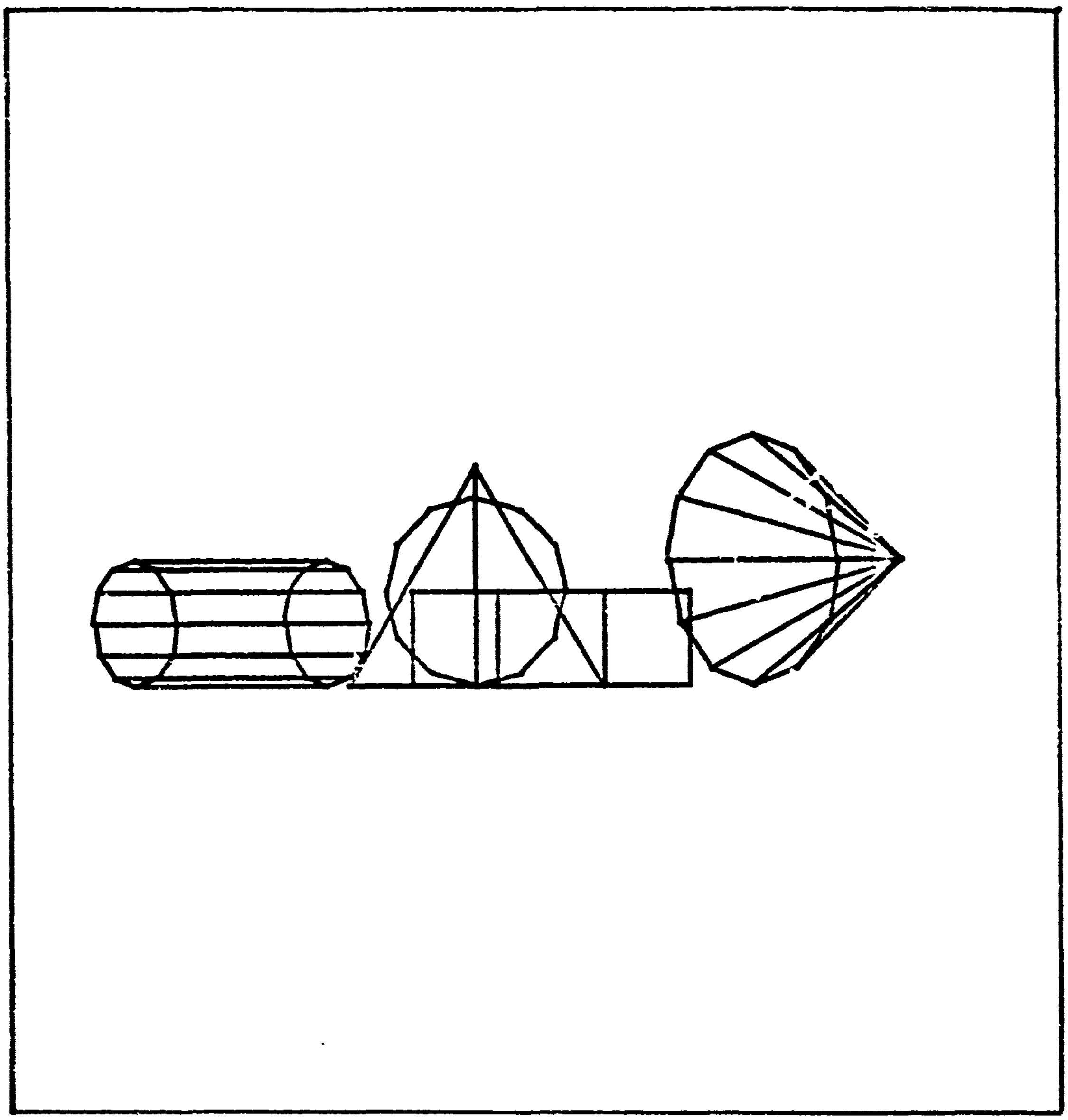

Figure 29. Combination of Shapes: View 17.

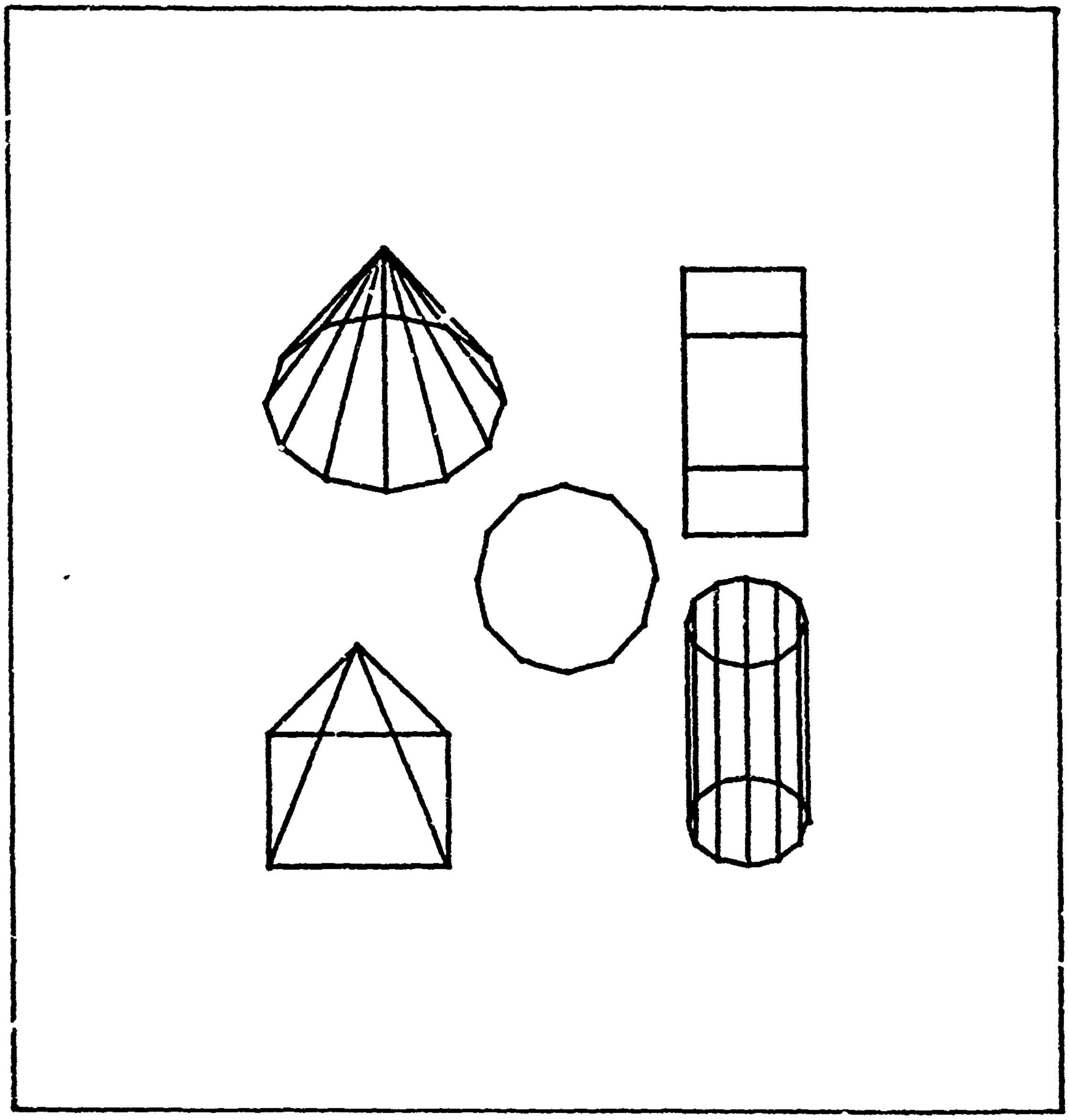

Figure 30. Combination of Shapes: View 22.

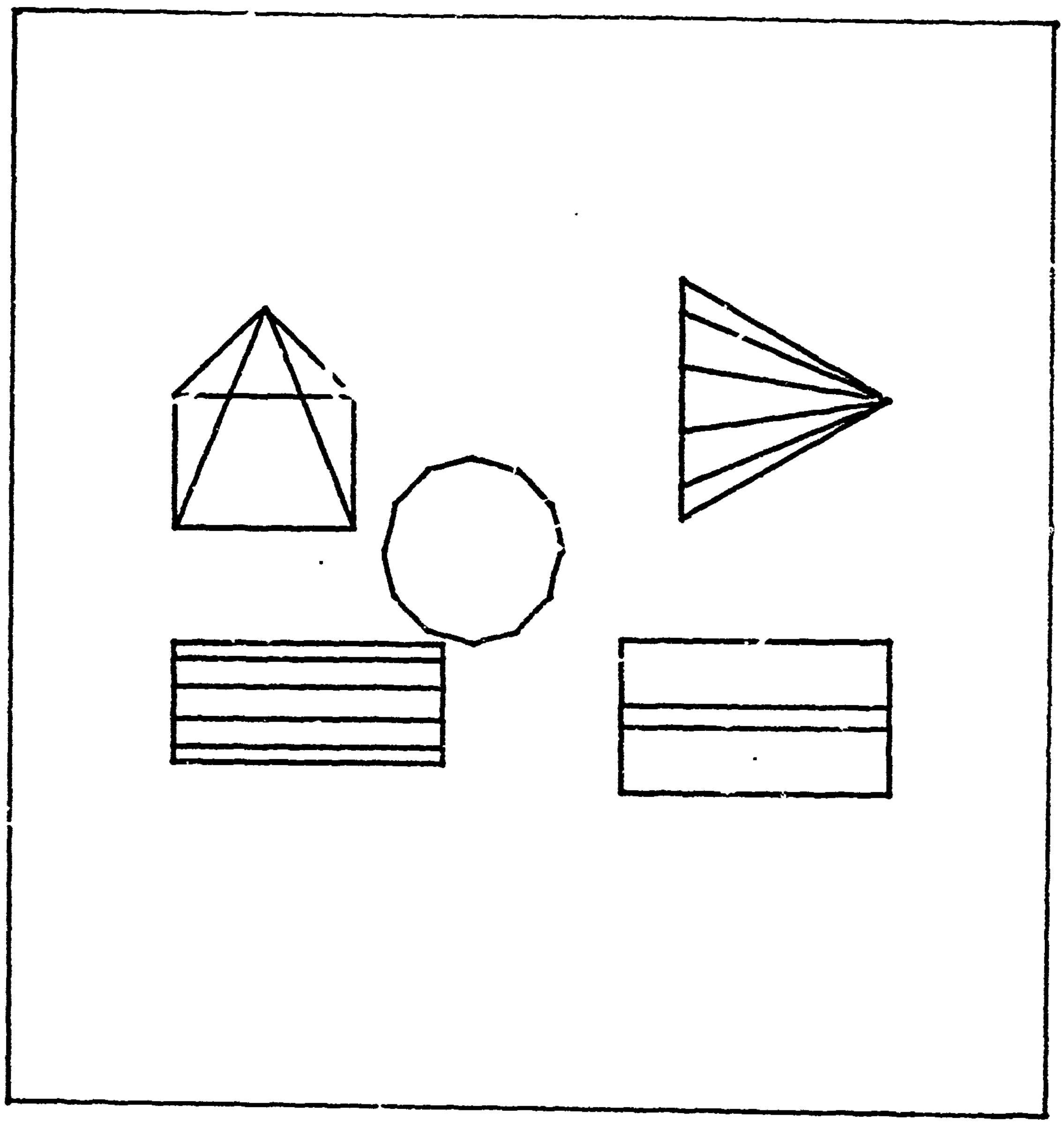

Figure 31. Combination of Shapes: View 24.

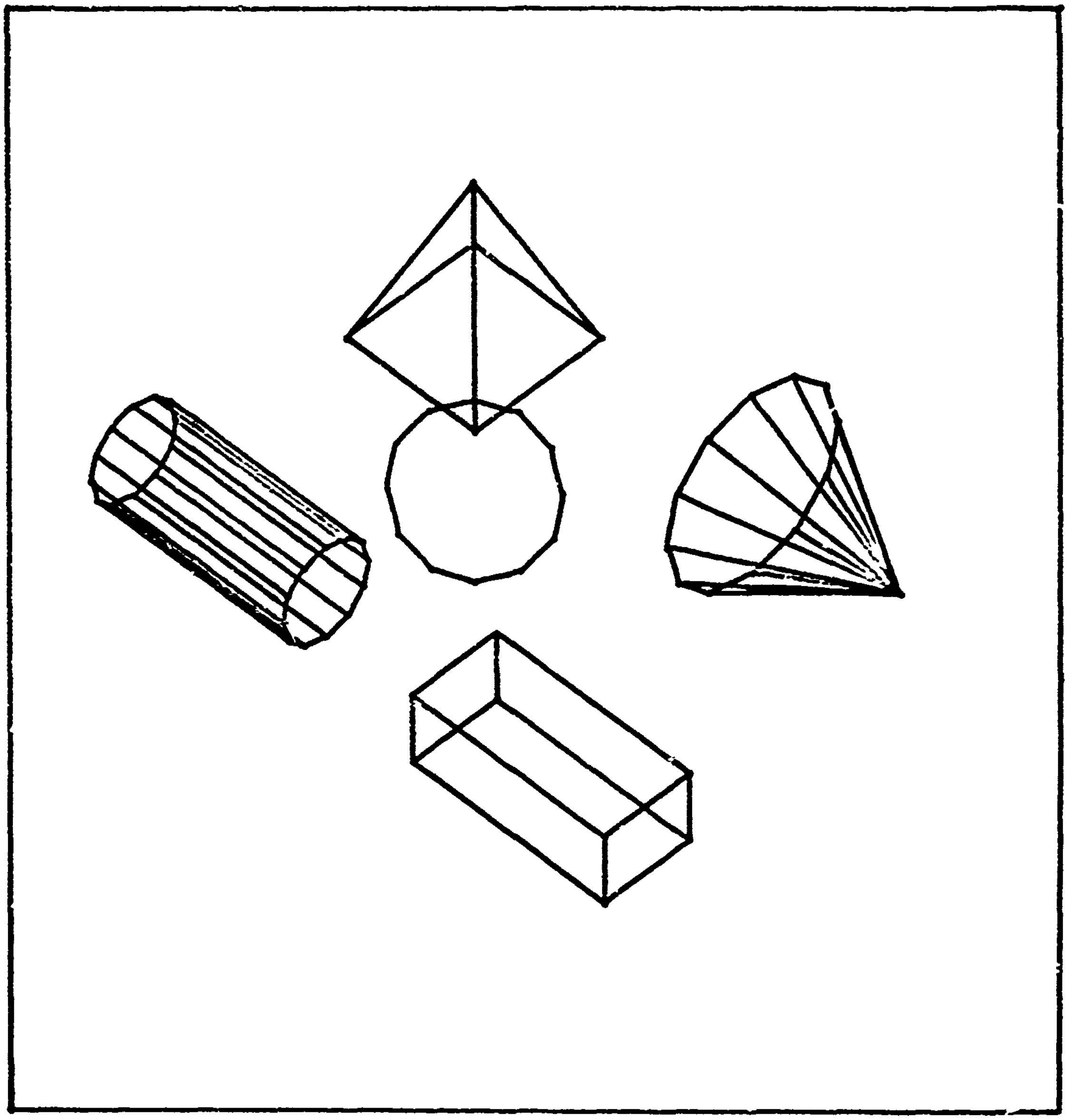

Figure 32. Combination of Shapes: View 25.

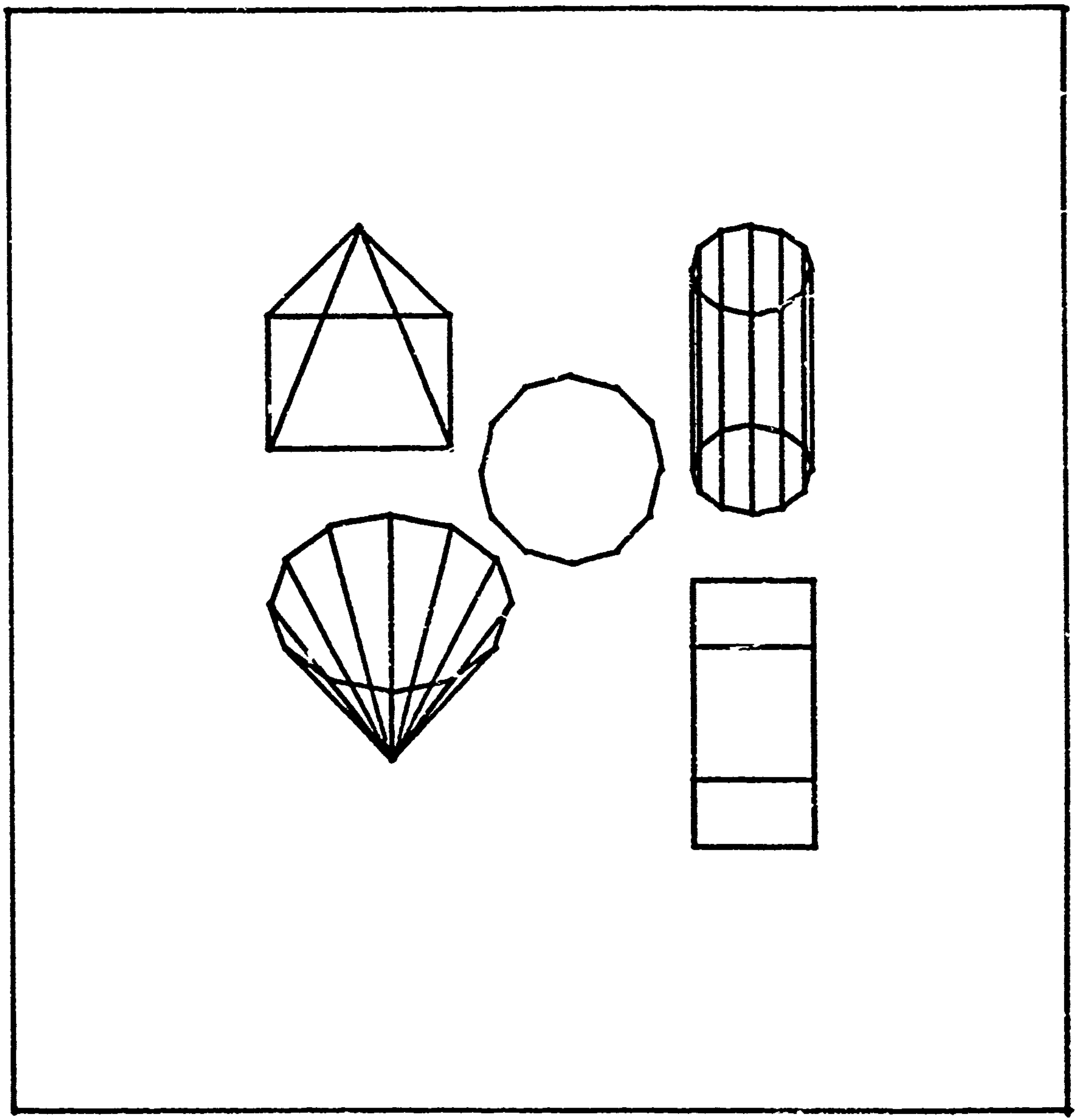

Figure 33. Combination of Shapes: View 6.

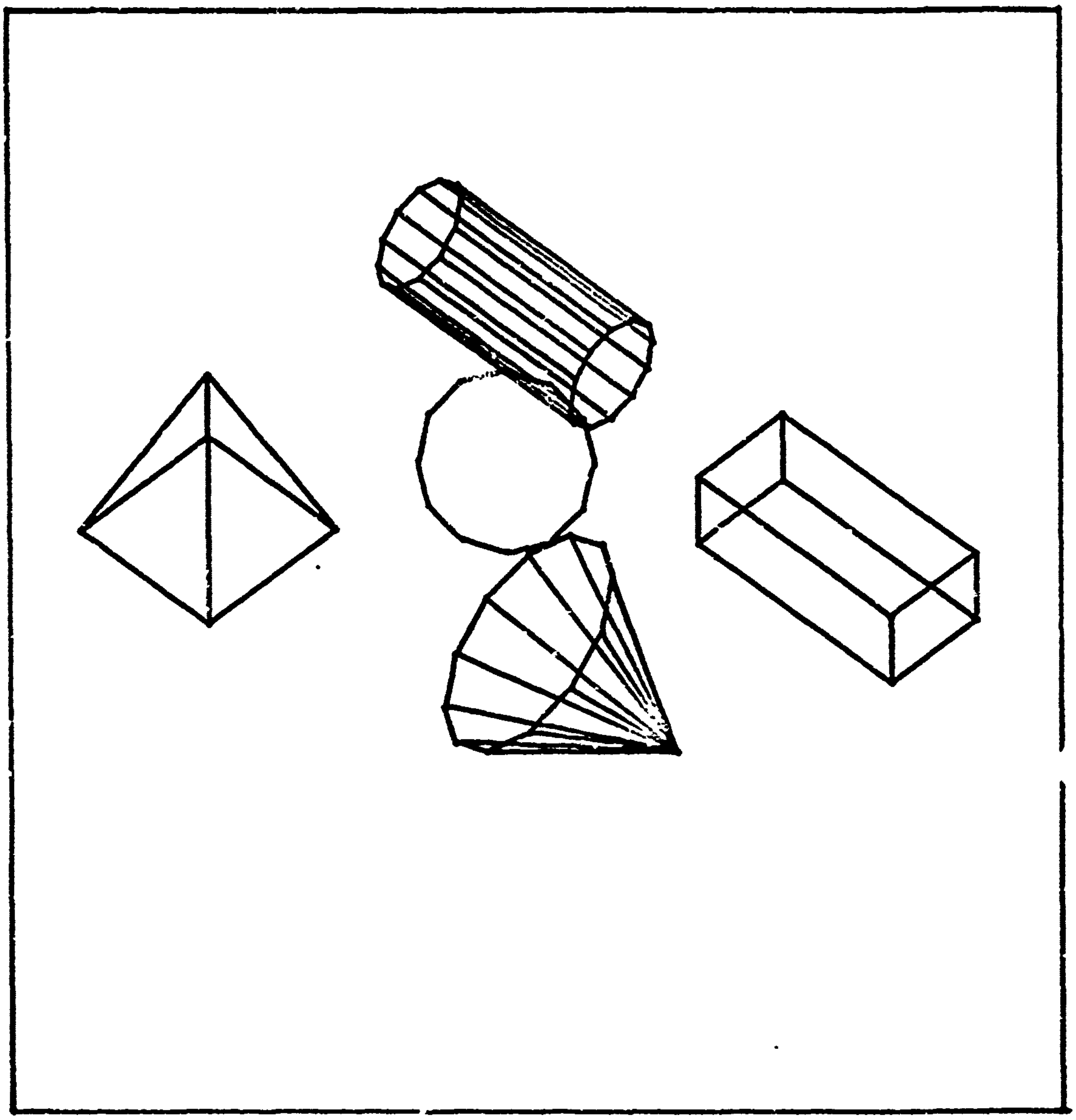

Figure 34. Combination of Shapes: View 7.

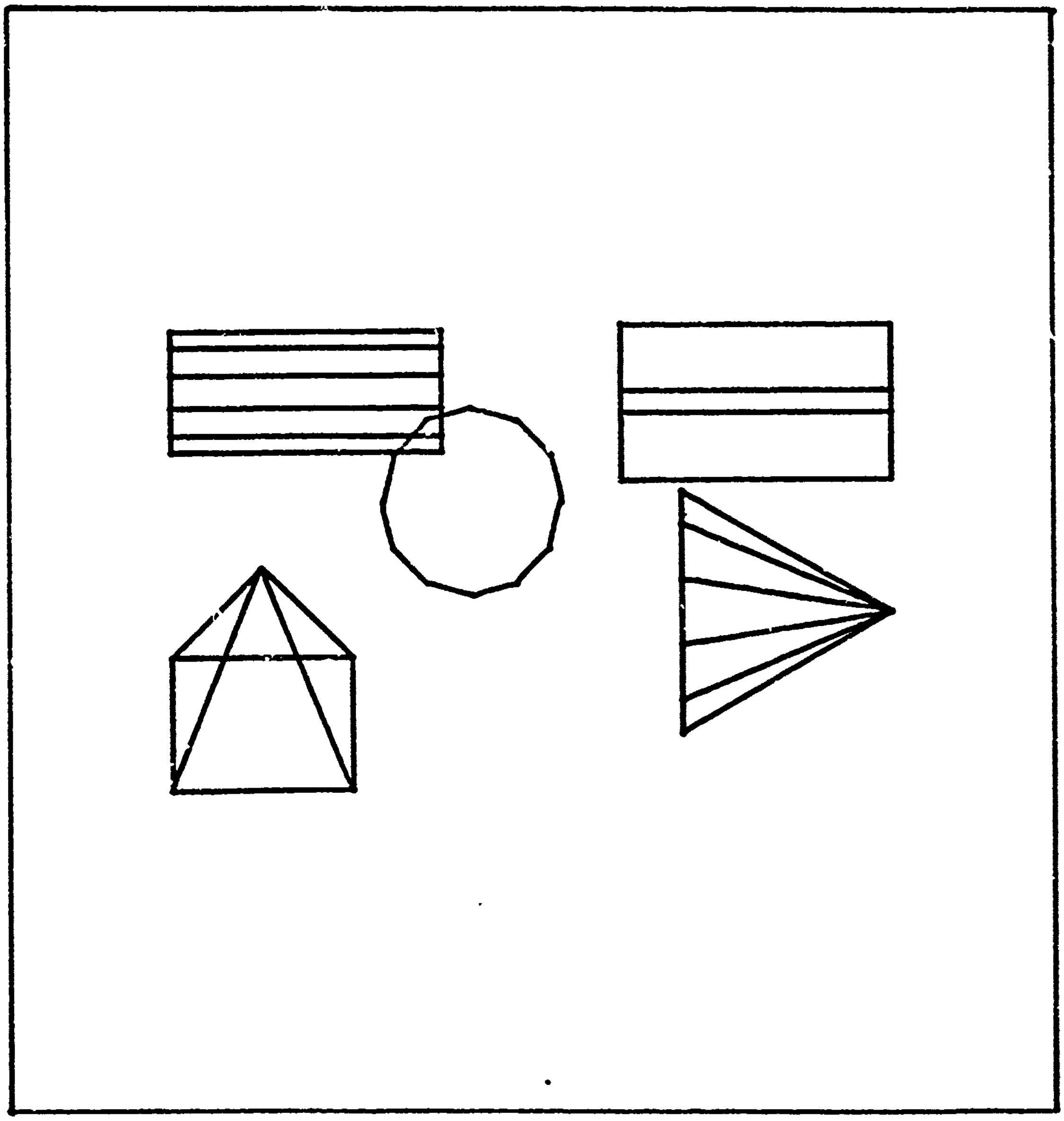

Figure 35. Combination of Shapes: View 8.

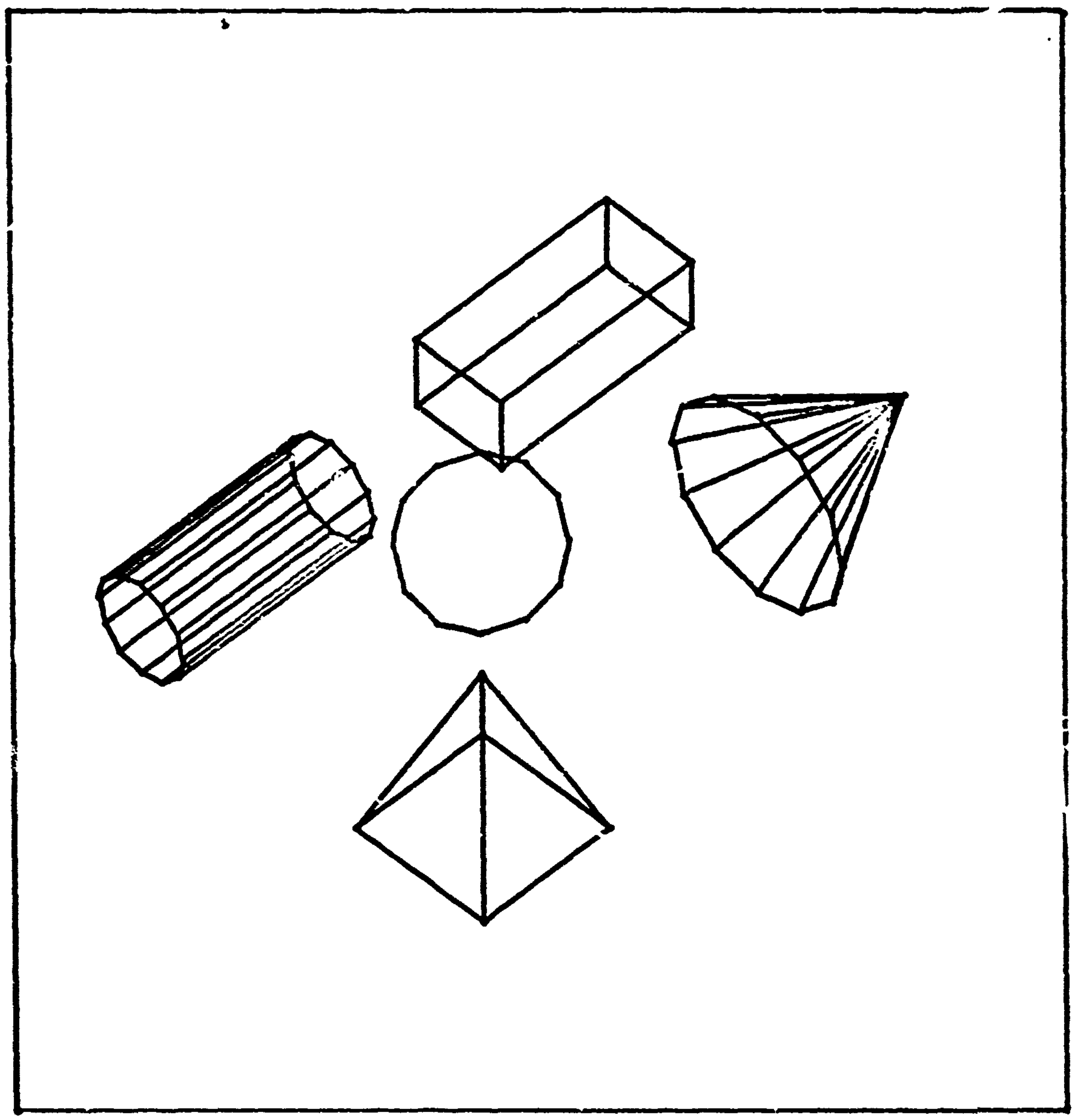

Figure 36. Combination of Shapes: View 9.

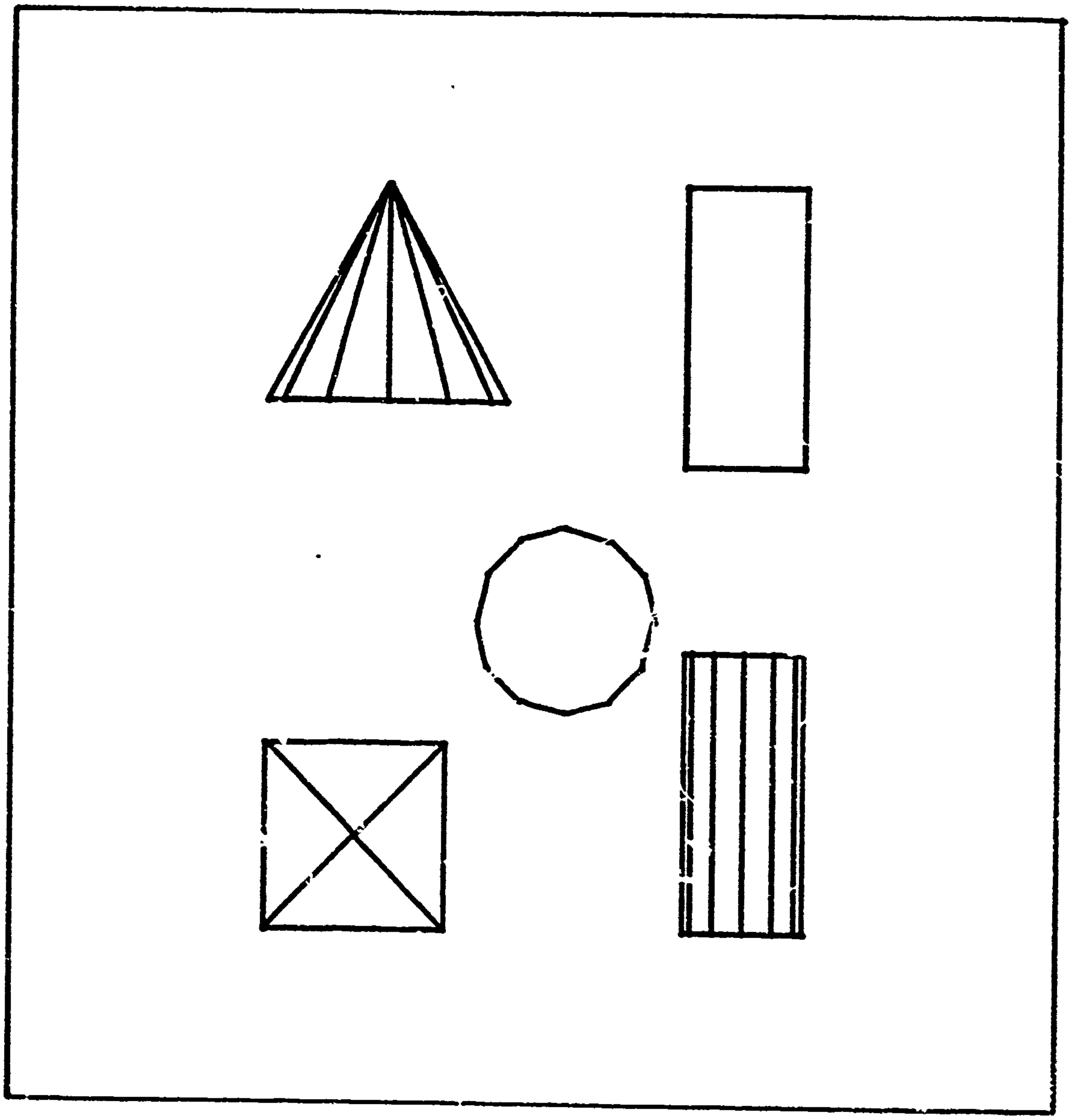

Figure 37. Combination of Shapes: View 26.

Vita

James P. VerStreate was born on 4 January 1942 in Bath, New York. He graduated from high school in Clifton Springs, New York in 1959, attended Rensselaer Polytechnic Institute and then the United States Air Force Academy from which he received the Bachelor of Engineering Sciences degree and a commission as a Second Lieutenant in the Regular Air Force in 1964. He completed undergraduate pilot training at Vance Air Force Base, Oklahoma in 1965 and served as an instructor pilot at Reese Air Force Base, Texas until 1970. He was an F-105 pilot in the 563rd Tactical Fighter Squadron, McConnell Air Force Base, Kansas and the 17th Wild Weasel Squadron, Korat Royal Thai Air Force Base until March 1972. He entered the Graduate Air Weapons program at the Air Force Institute of Technology in June, 1972.

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