A LOW-COST SIMULATOR FOR AIR-TO-GROUND WEAPONS DELIVERY TRAINING

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SUMMARY

A feasibility model of a low-cost air-to-ground weapons delivery trainer using an area of interest presentation was assembled and tested at the Naval Training Equipment Center. The primary factor evaluated was the pilot acceptability of the visual cue presentation while performing the final phase of the ground attack mission. The preliminary pilot evaluation showed feasibility of the area of interest concept for providing visual cues during the final phase of the attack using rockets. Other attack modes should also be feasible. Compared to other approaches developed, the system cost of the NAVTRAEQUIPCEN system is less, and the risk is less to provide a deliverable trainer to the fleet.

INTRODUCTION

While the NAVTRAEQUIPCEN and the AF Aeronautical Systems Division have defined and studied designs of air-to-ground weapons delivery trainers since about 1950, the potential users of the proposed trainers did not actually state their requirements until recently, nor did the upper echelons of the DoD look at these trainers as a necessary item. Then the AF Tactical Air Command raised the question of an adequate visual display for the A-10 flight simulator to cover a number of missions including A/G attack. In December 1976, the Commander in Chief, US Pacific Fleet, in a letter to the Chief of Naval Operations and a letter by the CNO Deputy Director, Naval Education and Training, described the problem and requested solutions be developed as follows:[1] In recent years encroachment and ecological considerations have imposed evermore demanding constraints on target use (land area target complexes essential to the objective of achieving realistic combat training), impacting adversely on Navy and Marine Corps high-explosive ordnance delivery practice. Examples were given where complaints by the local citizenry of alleged property damage and excessive noise impact from bombing operations portend continued pressure to reduce or desist in the use of high-explosive ordnance on land-based target ranges. Yet, the requirement for conventional air-to-ground ordnance delivery training and ship-to-shore bombardment practice will continue for many years, until either electronic scoring techniques preclude the requirement or new weapons make current systems obsolete. He states a requirement for an inexpensive air-to-surface, unguided practice bomb that will be ecologically nondestructive and noise suppressed. CNO (DNET) added that other solutions should also be looked at.

The Director, Planning and Evaluation in the Office of the Assistant Secretary of Defense in early 1976 requested an independent assessment of the status of simulators and the role they should play in military tactical flight training. The assessment provided by Calspan was based on information obtained from a literature survey and survey interviews with individuals in industry and government who are knowledgeable about flight simulators, military tactical flight training and related matters.[2] One of the areas covered was ground attack.

The general purpose of Air Force Project Number 2235 was to analyze and demonstrate various technical approaches to air-to-ground weapons delivery simulation in order to reduce the performance and cost risk of procuring aircrew simulators which require A/G capability.[3]

An early device which had A/G capability, the AF Device F-151 Gunnery Trainer, was evaluated in 1957. Reference 4 reported that ground target slant range and dive angles were difficult judgments to make due to the narrow field of view (15°) and inadequate resolution (600 TV lines). Reduced or lack of fidelity required pilots to approach within 4-5,000 ft of the target to make a decision. The terrain area presented by the target projection system was inadequate for presenting motion perspective cues in peripheral vision. The evaluation pilots' estimation of slant range and dive angle was inadequate and consequently they crashed into the ground. During the first air-to-ground missions in the training demonstration, experienced pilots hit the ground in 39 out of 40 passes.

Finally, one more example of the need for a new approach is low cost. The NAVTRAEQUIPCEN received a requirement for an air-to-ground attack visual attachment for the A6E Weapons Systems Trainer, Device 2F114, and the A7E Weapons Systems Trainer, Device 2F111. The A6E WST Project Master Plan specifically required training in air-to-ground weapon delivery (day mode only). The visual system requirement: FOV 270°H x 135° (90° up, 45° down), earth/sky projection in color, AOI 60° (diagonal). In both systems, the costs were greater than the user was willing to spend, without the knowledge of the exact FOV required. A typical cost example: for 100 miles of maneuvering, at 6500:1 scale, two 24' x 72' overlapping model boards would be required. The cost was estimated at $5M for the boards, $3M for the visual, and $2-3M for the R&D, or a total cost of $11 million.

DESCRIPTION OF THE FEASIBILITY MODEL

No new training or task analysis was conducted to establish the configuration of the simulator because the mission had been defined earlier.

Reference 5 defined the skills required for performance in the attack mission succinctly. Approach flight skills of navigation and/or observation while essential requirements for a complete mission should be well developed in separate, specialized, training tasks before beginning air-to-surface weapons delivery. Of course, general flying proficiency should be adequate. The training here must concentrate on the particular skills required for air-to-surface attacks. These skills include:

a. Attack preparation maneuvering to emerge on the weapons delivery flight path at a satisfactory range with good sight alignment

b. Tracking during the weapon delivery run

c. Timing of commence firing and cease firing or of bomb release

d. Use of sights and computer aides to attack accuracy

e. Integration of flying with weapons delivery.

Good judgment in the planning of attack preparation maneuvers and precision in their execution are essential to the successful air-to-surface attack. Premature emergence on the weapon delivery path exposes the aircraft to enemy fire during an unnecessarily long straight flight path. On the other hand, adequate time for sight alignment and tracking of target must be provided. The more precise the maneuvering, particularly the last roll-out onto the target track, the better the sight alignment and the less time required for aircraft control adjustment to come onto the firing track. Rapid and accurate adjustment of the aircraft to the target firing track and the development of fire control or bomb release timing are also essential. Firing at excessive ranges destroys accuracy and timing of bomb releases must be correct. Recovery initiation must be properly timed for continuation of firing after recovery initiation is wasteful of attack potential.

Since visual cues are an essential part of air-to-surface attack situations, visual displays, if they provide the necessary visual cues, should be useful in the development and training of skills to cope with such situations. Ideally, a training exercise should simulate for the trainee an actual combat situation with proper targets, full aircraft maneuverability and range, and enemy counteraction. He could then practice and develop his skills in all phases of the problem by flying air-to-surface attack missions in the world of the visual display. If this ideal situation could not be simulated, much useful training and practice could be obtained with a training device utilizing a visual display to reproduce standard training flight exercises used by Fleet Training Squadrons. By simulating these exercises, a visual display training device would provide training and practice with safety and economy and without delays occasioned by bad weather.

Reference 6 specifically states the visual simulation unsolved problems for the air-to-ground weapons delivery mission are: wide field of view as the minimum requirement and for full mission requirements, a wide field of view with medium resolution, in color.

Reference 2 provides a list of requirements for an A/G visual simulation system. Although general in nature, a visual display must provide:

a. Good fidelity of the mathematical models for the aircraft and scoring

b. Accurate aircraft data, force and motion cues

c. Improvements over present day systems in

Field of View
Resolution
Brightness
Gaming Area Size.

Using the above guidelines and existing resources in equipment, a minimum feasibility model as shown in Figure 1 was designed and assembled. A description and the performance of the subsystems follows:

Image. This is a transparent two-dimensional ground scene, prepared as described in reference 6, backlighted by a light box, scaled 2500:1, full color and an artist's rework of an actual photograph, size 6' x 6', representing a 2.5 x 2.5 mile area. The fluorescent light box provides an average illumination to the probe of 410 FTL, with a range of 280-710 FTL. The wide range is dependent on the type of terrain viewed on the transparency.

Television Camera. Has a 1-inch 8507A Vidicon; Scan Rate 1023 lines/frame, 60 Hz, Video Bandwidth 32 MHz, Automatic Light Range 0.1 - 5000 fc, and geometric distortion less than 2 percent. Resolves all ten shades of gray on EIA TV Resolution Chart, with 0.5 foot-candle highlight illumination on the face of the camera tube. Resolution is 1100 TV lines horizontally and 700 lines vertically.

Optical Probe. FOV 80°H x 60°V, (100° diagonal) depth of field 4" to infinity, f# 16, with motion in pitch +45 to -90 degrees, roll ± 90 degrees; yaw ± 90 degrees, and zoom 4.5:1. Transmission 48 percent, lens distortion 6 percent, resolution 40 LP/mm @5 percent MTF. The optical field of view was reduced to 60° diagonal by means of the zoom mechanism for the purpose of matching the projector's FOV.

Gantry. The X, Y, and Z travel at the scale factor used for this simulation, yields

x (range, without zoom) = 5.25 miles
with zoom (4x) = 23.6 miles (11.1 feet)

y (lateral travel) = 1.9 miles (4 feet)

z (altitude) = 2.1 miles (4.5 feet)

T-28 Cockpit. With inputs to the computer of throttle, rudder, elevator, aileron, flap and wheel signals, and computer output signals for airspeed, roll, pitch, R/C, altitude, rate of turn, slip indicator and heading. Matches aircraft in performance and flying qualities based on comparison of calculations and aircraft data. Servo performance, or lag characteristics were not measured, from cockpit response through computer input through instrument or visual response.

US Navy Mark VIII Gunsight. As in the T2C aircraft.

Computer. Analog computer, REAC 550, contains mathematical model for T-28 aircraft (reference 7) and the positioning model to slave entrance pupil of optical probe to weapons target. (Reference 8).

Horizon/Sky Projector. A point light source half dome, painted horizon for visual cues for pitch of ± 90 degrees of travel, roll ± 90 degrees of travel and yaw of ± 180 degrees of travel. Variable in brightness 0 to 0.5 FTL (SG = 1.8). Normal viewing = 0.135 FTL.

CRT Projector. Scan rate - 1023 lines/frame, 60 Hz, variable in aspect ratio, video bandwidth 30 MHz, with Thomas 6M75P45 CRT capable of a line width of 0.0035 inches center resolution at a brightness of 15,000 ft Lamberts.

Projection Optics. F.L. 4.4" - f/1.2 ± 30° FOV, transmission 75 percent minimum, distortion less than 1 percent at 1/2 FOV.

Screen. 10' radius, 360° dome. Gain = 1.8. Projected highlight brightness is 2.6 FTL while resolution is 800 TV lines horizontal with 10 shades of gray.

The subsystems described provide a 60° diagonal, high-resolution insetted display (area of interest) anywhere in the pilot's field of view, within the limitations of the hardware.

The eye position, and arrangement of the CRT projection and sky projector in the dome screen is illustrated in Figure 2.

The Servo Design Criteria is shown in Table I.

Why an area of interest display? It is assumed for this design that there exists a center of interest at any given instant of time to which the pilot's attention will be devoted. The center of interest for the weapons delivery runs would be the target area (point of interest) after crossing the initial (IP). By concentrating the TV system's resolution in this area (60° diagonal) about the pilot's line of sight to the target, current state-of-the-art closed circuit TV systems can be used. The peripheral cues of the horizon and sky orientation can then be presented separately. Figure 3 shows a typical "wander" of the pilot's line of sight during the 90° final turn segment for a 30° Dive Bomb pattern in a RF4C aircraft from reference 9. This reference estimates that a visual display field of view of 240° horizontally and 95° vertically would be needed. A continuous visual display of this size with the necessary resolution (800 x 5 = 4000 lines horizontally) is beyond the state-of-the-art.

The next question is why a two-dimensional model instead of a more expensive three-dimensional model? The various cues to depth can be classified in terms of their dependence on motion. Many of the most compelling cues such as interposition, relative size and aerial perspective can be considered essentially static, since they are present under both static and dynamic conditions. Others, such as motion parallax and change in vertical perspective can only occur as a result of relative movement between the observer and the object or scene being viewed. Although motion parallax is a relatively minor cue to depth, it provides the essential difference between imagery derived from two- or three-dimensional sources.

A study specifically designed to investigate the role of motion parallax in the perception of apparent depth on a dynamic TV display was conducted by King and Fowler (reference 10).

This study was primarily designed to investigate the perceptual process involved in viewing target imagery by means of a TV display. It was, however, considered desirable from the standpoint of potential application to use representative conditions in terms of flight trajectory, sensor viewing geometry, and ground imagery. Therefore, both constant dive angle and constant altitude approaches were employed at simulated velocities consistent with operational training problems.

The results of this study, to determine the relative effectiveness of two- and three-dimensional image storage media, indicated that movement parallax provides a cue to depth only at very close ranges. It was concluded that for the training problem, which requires simulation of television target imagery, there is little or no advantage in the more expensive three-dimensional storage devices for altitudes above 750 feet.

Since the present study does not require simulated operation below 1,500 ft, it is concluded that the two-dimensional transparency being used is adequate.

The evaluation mission in the simulator was the air-to-surface attack and exercised the skills described previously. Reference 11 provided actual flight parameters for a rocket delivery in a T-28B/D aircraft. It also provided the measures of accuracy needed to validate the pilot-aircraft-sight system performance.

Before each flight, the pilot was briefed on the initial conditions. After each flight, the pilot was given feedback as to his performance. The first three runs were for orientation purposes to familiarize the subject with the device and his expected performance. After completion of these preliminary trials, the subject was given a questionnaire to review. This was done at this time so that the subject was better prepared to observe particular aspects of the simulation. This questionnaire was completed by the subject when he completed all of his flights.

After the preliminary trials and review of the questionnaire, the subject made 10 consecutive flights.

Scoring was obtained by evaluating the course, airspeed, altitude, rate of dive and aircraft attitude time histories and a comparison of the reticle aim point location on the screen with the target location at the rocket release point visually and by computer readout. Details are covered in an unpublished NAVTRAEQUIPCEN in-house Technical Report.

CONCLUSIONS

On the basis of a preliminary evaluation, deficiencies in the simulation hardware can be ruled out as deterrents to the approach since they are engineering changes within the state-of-the-art and the consensus of the five pilots (one pilot flew two missions) was that the concept of using an area of interest display superimposed on a wide-angle projection of the horizon and sky on a spherical screen appeared as a feasible means to achieve air-to-ground training in rocket firing and could possibly be extended to include other types of A/G weapons delivery training.

To verify that this system is indeed low in cost, a comparison to another method is desirable. Perhaps a comparison to the method recommended for the USAF A-10 flight simulator program for A/G in reference 3 would be useful. This is shown in Table 2.

The cost advantage of the NAVTRAEQUIPCEN system is in the 2D model, camera, probe versus, the dedicated computer for CIG in the image generator. For the display, the cost advantage comes from one CRT projector versus many infinity optics windows in the CIG/MOSAIC approach.

From a performance standpoint, the servo, optical and photometric performance of this system exceeds that of other similar projection systems such as the LAMARS at the USAF Flight Dynamics Laboratory and the DMS at NASA, Langley Research Center.

It is recommended that a further evaluation of the concept should be attempted with a larger pilot sample and with a larger field of view area of interest prior to acquisition of units for the fleet. This question of a larger AOI field of view was very recently raised in a new study on the ASPT reported in reference 12.

TABLE 1. SERVO DESIGN CRITERIA

	RANGE TRAVEL	MAX VELOCITY	MAX ACCELER-ATION	POSITION RESOLUTION
Gantry				
Longitudinal	+3.6',-7.5'	20'/sec	3.0'/sec²	0.0025'
Lateral	±2.0'	20'/sec	3.0'/sec²	0.0025'
Vertical	+0.0,-4.5"	20'/sec	3.0'/sec²	0.0025'
CRT Projector				
Azimuth	±180°	10Rad/sec	50Rad/sec²	NA
Elevation	±90°	10Rad/sec	50Rad/sec²	NA
Horizon/Background Projection				
Roll	±90°	20°/sec	NA	0.01°
Pitch	±90°	20°/sec	NA	0.01°
Yaw	±180°	6°/sec	NA	0.01°

TABLE II.

COMPARISON OF NAVTRAEQUIPCEN A/G SOLUTION WITH CIG/MOSAIC

System	Method: NAVTRAEQUIPCEN	Method: CIG/MOSAIC
Image Generation	2D model Light Box Optical Probe/Gantry TV Camera Servo Control	CIG Computer
Image Display	CRT Projector Point Light Source Servo Control	Multi CRT's with infinity optics windows

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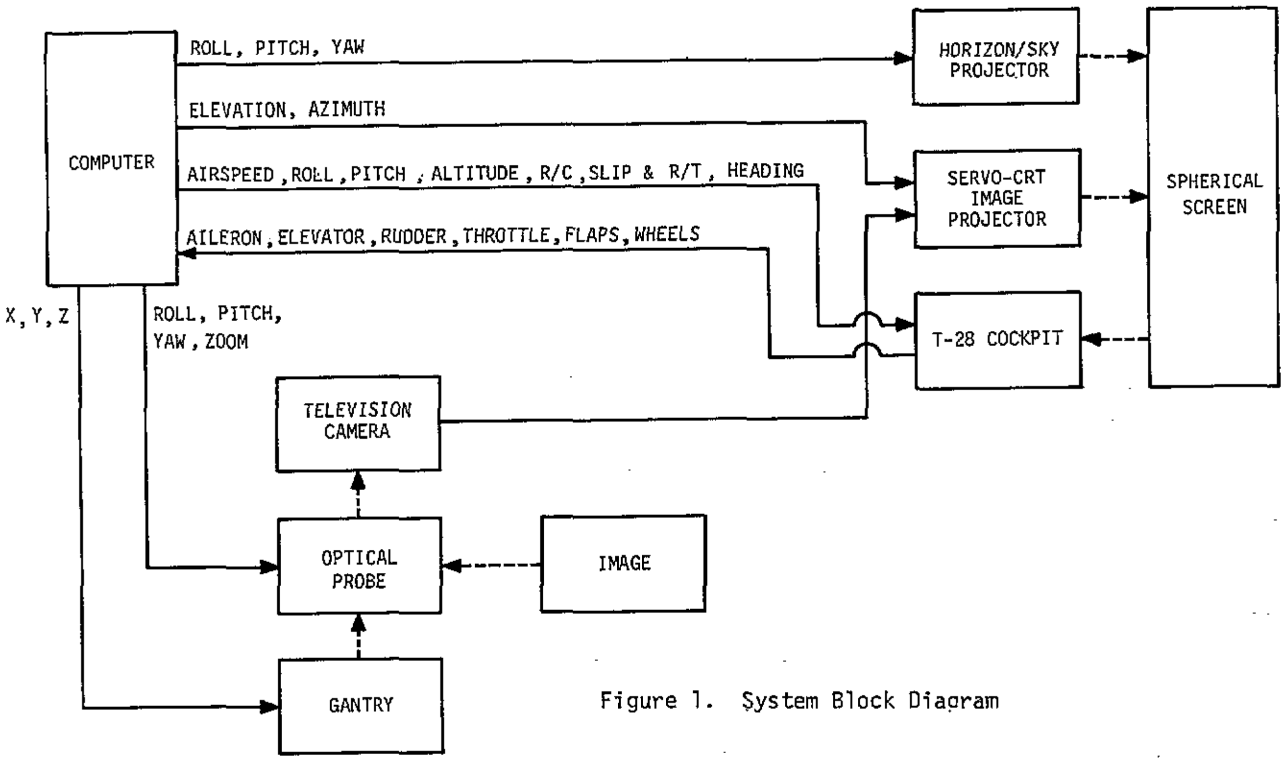

Figure 1. System Block Diagram

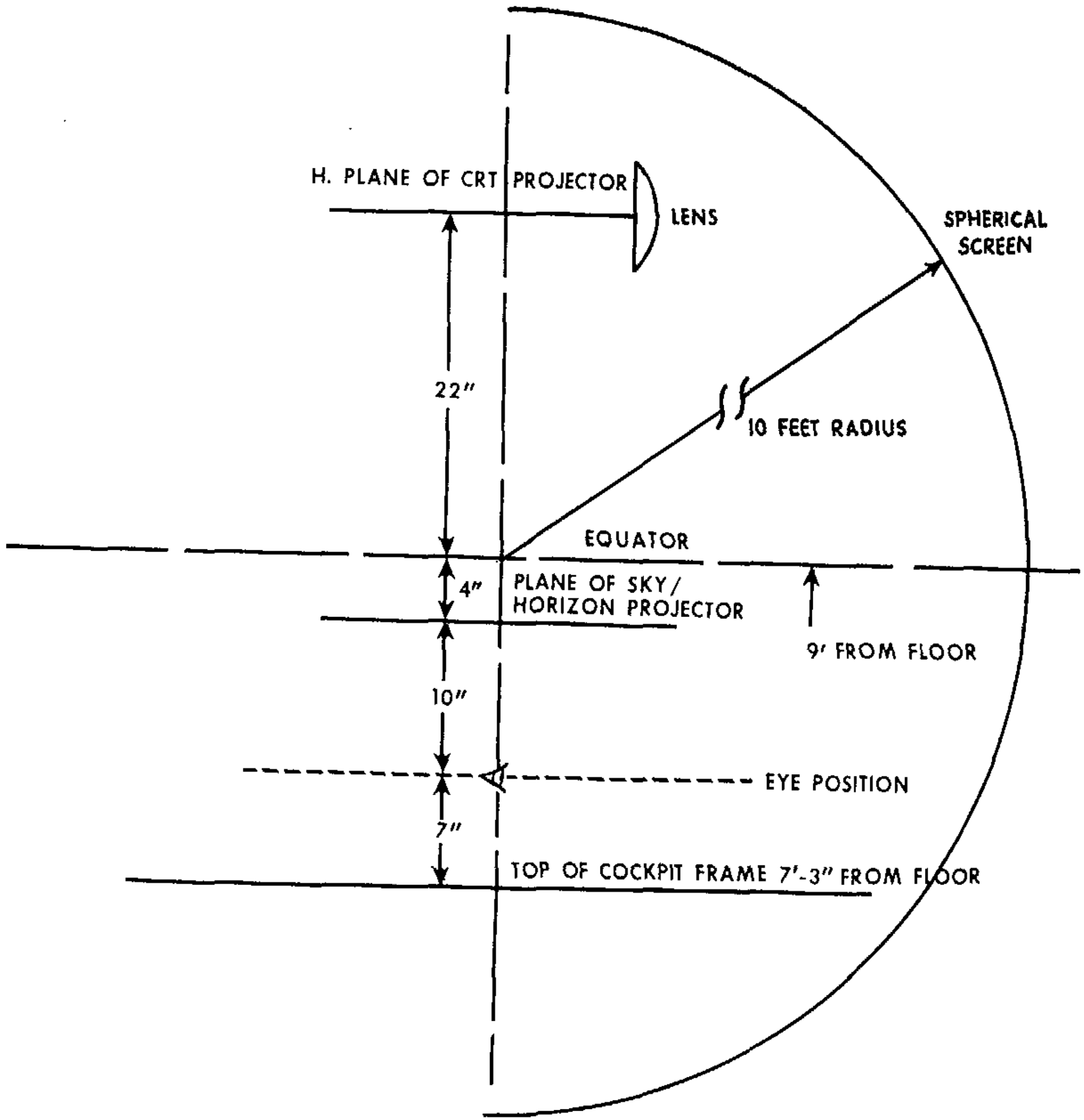

Figure 2. EYE POSITION AND ARRANGEMENT WITHIN SPHERICAL SCREEN

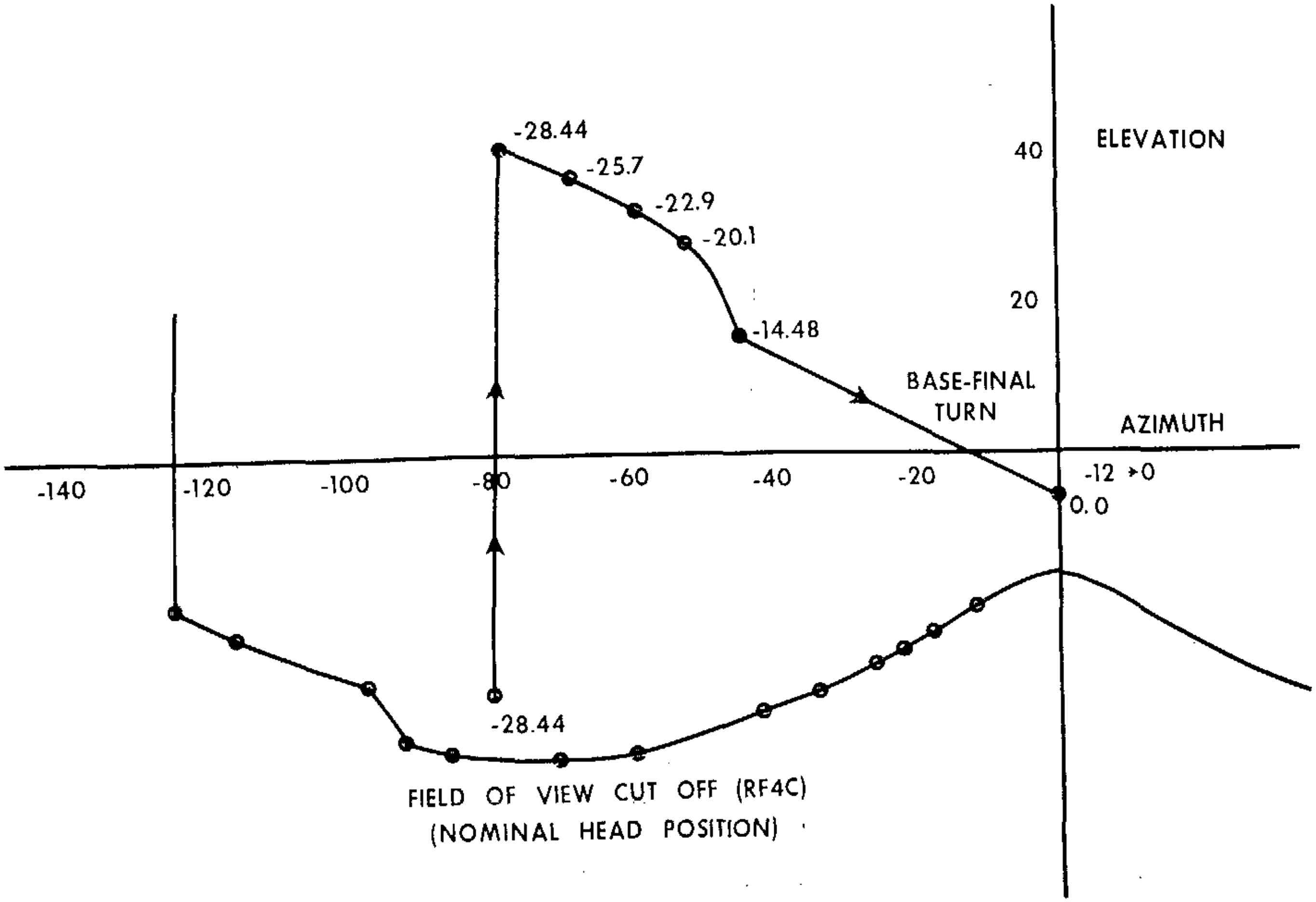

Figure 3. 30° DIVE BOMB - 90° FINAL TURN SEGMENT

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