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**FLIGHT TRAINING SIMULATORS:
EFFECTS OF TERRAIN ACCURACY
ON SIMULATED RADAR IMAGE QUALITY**

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September 1985

Interim Technical Paper for Period September 1984 - May 1985

Approved for public release; distribution unlimited.

HUMAN RESOURCES

AD-A160 905

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

AD-7160905

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFHRL-TP-85-28		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Operations Training Division	6b. OFFICE SYMBOL (If applicable) AFHRL/OT	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85240-6457		7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Human Resources Laboratory	8b. OFFICE SYMBOL (If applicable) HQ AFHRL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code) Brooks Air Force Base, Texas 78235-5601		10. SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO. 62205F	PROJECT NO. 6114
		TASK NO. 33	WORK UNIT ACCESSION NO. 01
11. TITLE (Include Security Classification) Flight Training Simulators: Effects of Terrain Accuracy on Simulated Radar Image Quality			
12. PERSONAL AUTHOR(S) Crane, Peter M. Bell, Herbert H.			
13a. TYPE OF REPORT Interim	13b. TIME COVERED FROM Sep 84 TO May 85	14. DATE OF REPORT (Year, Month, Day) September 1985	15. PAGE COUNT 18
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD 05	GROUP 08	digital, digital radar landmass simulation, image quality,	
05	09	radar simulation, terrain accuracy, training effectiveness	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)			
<p>This experiment evaluated the effect of terrain vertical accuracy on the quality and perceived training effectiveness of simulated radar images. Seven Air Force navigators judged the quality and training value of digital radar landmass imagery produced at six different levels of terrain vertical accuracy. Each image represented the simulated ground mapping radar image of a mountainous area viewed from an altitude of 10,000 feet. The results indicated that (a) increasing terrain vertical accuracy above the current production standard did not significantly increase either the judged quality of the imagery or its perceived training value; (b) decreasing terrain vertical accuracy below the current production standard significantly decreased both the judged quality and the perceived training value of the imagery. Although the results of this experiment do not provide any justification for more stringent accuracy requirements, it is recommended that this experiment be replicated using lower altitude imagery in which the effects of terrain evaluation are more pronounced.</p>			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION	
22a. NAME OF RESPONSIBLE INDIVIDUAL Nancy A. Perrigo, Chief, STINFO Office		22b. TELEPHONE (Include Area Code) (512) 536-3877	22c. OFFICE SYMBOL AFHRL/TSR

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This publication is primarily a working paper.
It is published solely to document work performed.

SUMMARY

This study was conducted to determine if more accurate transformations of digital terrain data would significantly increase the perceived image quality or training effectiveness of simulated radar imagery. While an increase in accuracy produces a more detailed image, it also requires more computer time to generate and therefore increases the cost of database development.

Seven KC-135 navigators evaluated simulated radar images, generated at six different levels of transformation accuracy, for usefulness in navigation and for training navigators. Analyses show that transformations which are more accurate than current standards do not produce perceptible increases in image quality or in rated training effectiveness. Before final conclusions are drawn, however, this study should be replicated using a larger sample of navigators with low altitude requirements and simulated images from lower altitudes.

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PREFACE

This project was conducted in support of the Air Force Human Resources Laboratory's Technical Planning Objective 3, Aircrew Training. The goal of this effort is to develop cost-effective strategies and equipment for aircrew training. This experiment was conducted under Work Unit 6114-33-01, Analysis of Imagery for Evaluation.

The goal of this experiment was to determine if increasing the digital terrain transformation accuracy would increase the apparent image quality and perceived training effectiveness of simulated radar images. Results show that increases in transformation accuracy over current standards did not produce noticeable changes in either the quality or the perceived training value of simulated ground mapping radar images. Simulated images produced with less accuracy, however, were judged to be of poor quality and not useful for training navigators. Therefore, the current standard for vertical transformation accuracy represents an appropriate compromise between cost and training effectiveness. However, operational navigators who served as subjects recommend that this study be replicated with lower altitude imagery before drawing final conclusions.

The authors wish to thank John Stengel of the Aeronautical Systems Division/Engineering for providing the stimuli and the navigators of the 161st Air Refueling Group, Arizona Air National Guard, who participated as subjects.

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FLIGHT TRAINING SIMULATORS: EFFECTS OF TERRAIN ACCURACY ON SIMULATED RADAR IMAGE QUALITY

I. INTRODUCTION

This preliminary experiment was conducted to determine if a more detailed transformation of digital terrain data would significantly increase the training effectiveness of simulated radar imagery. The results failed to show any significant increase in the perceived image quality or the perceived training value of the simulated radar imagery produced from the more detailed transformations.

One variable influencing the fidelity of simulated radar imagery is the number of polygons or faces used to model the earth's terrain. Current digital radar landmass simulators (DRLMSs) rely on digital data provided by the Defense Mapping Agency for terrain elevation information. These data typically consist of terrain elevations at intervals of 100 meters. A DRLMS transformation program fits polygons around these elevation values to depict the terrain. The transformed terrain data are then merged with surface feature information and stored for use in the real-time simulation.

One variable in the elevation data that influences the transformation program is terrain roughness. For perfectly flat ground, roughness equals zero, and for mountains, roughness can be greater than 10. In effect, roughness measures the rate of elevation change between data posts in a geographic region. The transformation program fits polygons about the elevation posts using an iterative process in which the simulated terrain is tested against a criterion measuring transformation accuracy. This accuracy criterion is inversely related to roughness. As roughness increases, terrain accuracy decreases; allowable differences between the elevations in the source data and the elevations of the transformed data increase. Simulated terrain elevations are, therefore, highly accurate for flat terrain and less accurate for rough or mountainous areas. This accuracy criterion influences the number of polygons and, therefore, the fidelity or realism of the simulated radar scene. Additional polygons are added, in an iterative manner, until the specified criterion is met. Because of the iterative nature of this transformation process, the accuracy criterion directly influences the number of polygons and the length of time required to transform the digital terrain data. Since the accuracy criterion influences the length of time required to complete the transformation process, it also affects the cost of developing the simulation. Therefore, radar simulations of the same area produced using different accuracy criteria can differ significantly in both fidelity and cost.

Because fidelity and cost are both directly related to the accuracy criterion, it is important to determine the relation between the fidelity of the simulated radar scene and its training effectiveness. As Roscoe (1980) points out, beyond a certain point, increases in simulation fidelity produce little or no increase in training effectiveness. The purpose of this experiment was to determine the relation between six levels of transformation accuracy and (a) the perceived similarity of the six simulated radar images and (b) the perceived training value of those images.

II. METHOD

Apparatus

A modified KC-135 DRLMS, normally used for engineering development, was used to transform and display an area 40 miles southeast of Knoxville, Tennessee. Six separate transformations of the

digital terrain elevation data for this area were produced using different accuracy criteria. With the apparatus available, it was not possible to directly manipulate transformation accuracy. It was possible, however, to change vertical accuracy by altering the terrain roughness criterion. Since the transformation accuracy requirement decreases with increasing roughness, multiplying terrain roughness by weights less than one has the effect of increasing transformation accuracy. Likewise, multiplying roughness by weights greater than one produces less accurate transformations. The weights used in this experiment were 6, 4, 2, 1, 0.6, and 0.6. These transformed terrain elevation data were used to produce simulated radar images at 15 and 30 NM ranges. The images were equivalent to ground mapping radar from a KC-135 flying at 10,000 feet above sea level. Glossy, black-and-white photographs were obtained for each of these 12 simulated radar images. Figures 1 through 6 are the different transformations of the 30 NM imagery. Figures 1 and 2 were produced with weights of 0.6 and 0.8, respectively; these images are more accurate than Figure 3 which is the current standard with weight of 1. Figures 4, 5, and 6 are less accurate transformations with weights of 2, 4, and 6, respectively.

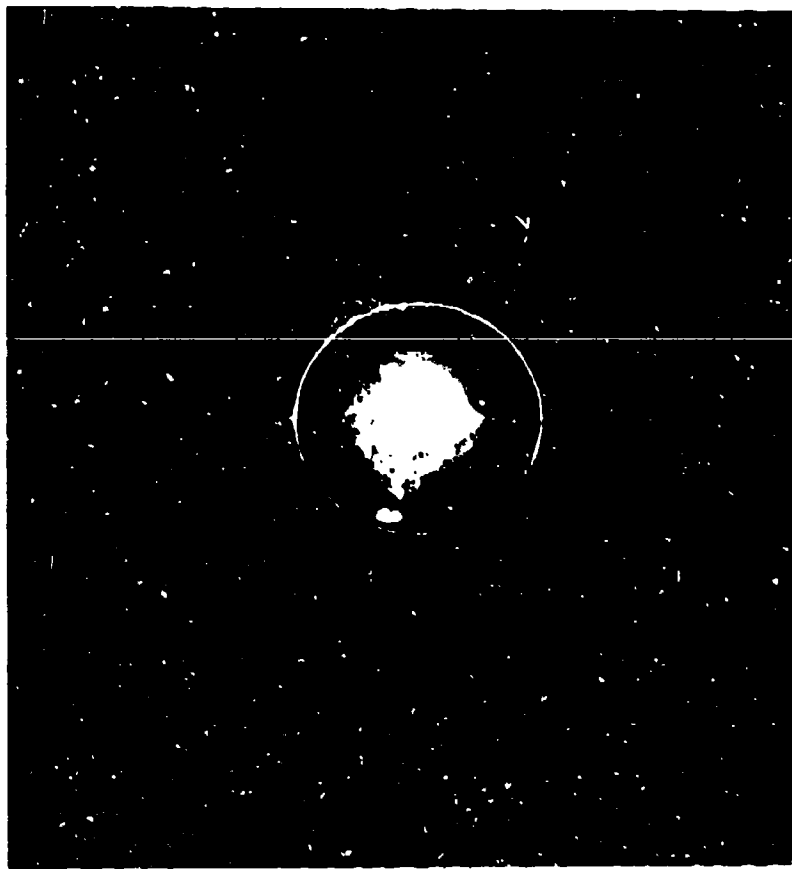


Figure 1. Simulated radar image produced with weight = 0.6; this is the most accurate transformation in the stimulus set. Altitude is 10,000 feet; range is 30 NM; north is at the top. This image was produced from terrain elevation data only and does not contain any surface features.

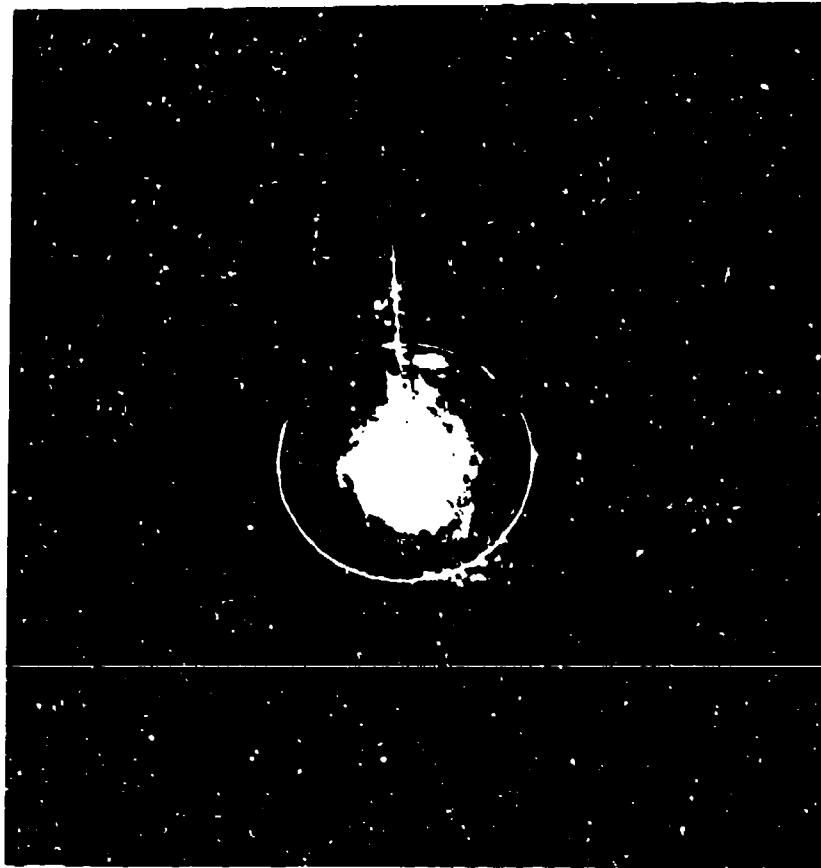


Figure 2. Simulated radar image produced with weight = 0.8.

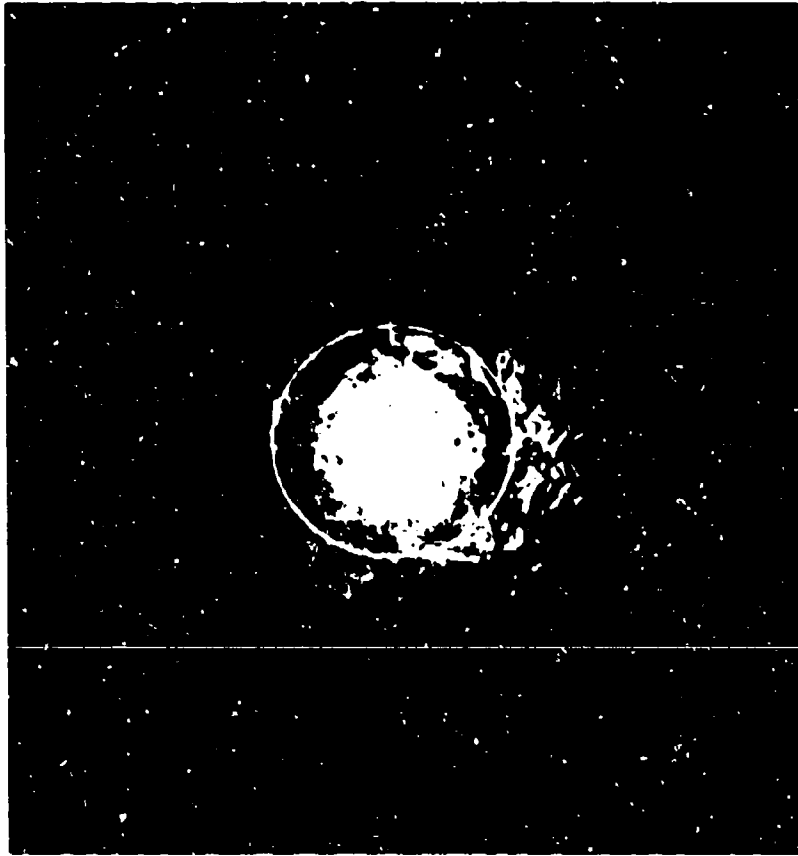


Figure 3. Simulated radar image produced with weight = 1. This is the current standard.



Figure 4. Simulated radar image produced with weight = 2.

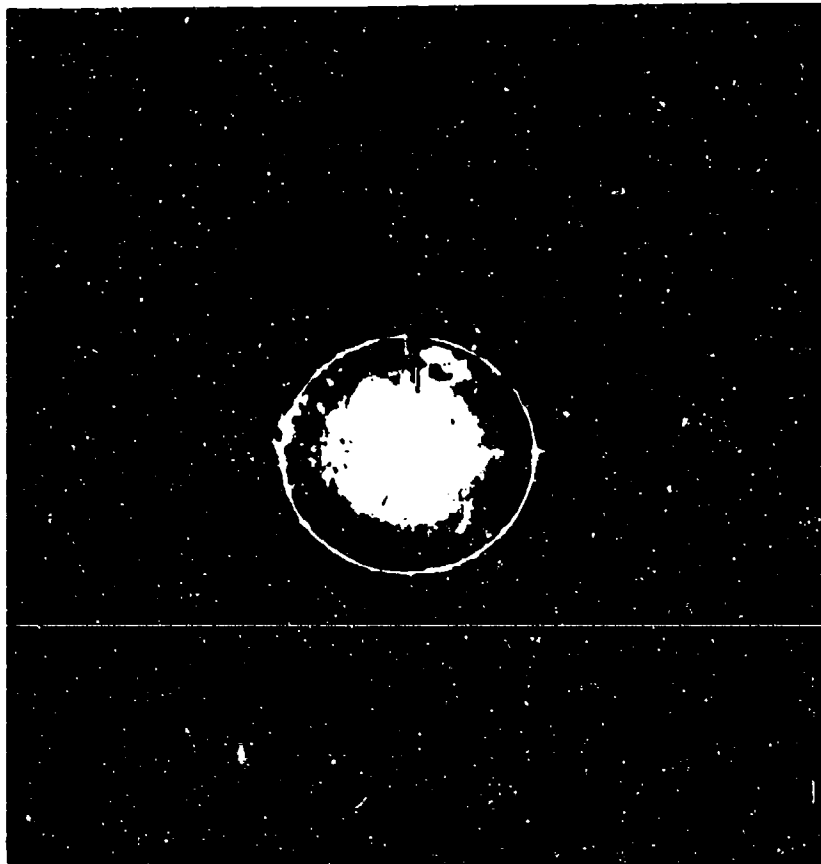


Figure 5. Simulated radar image produced with weight = 4.

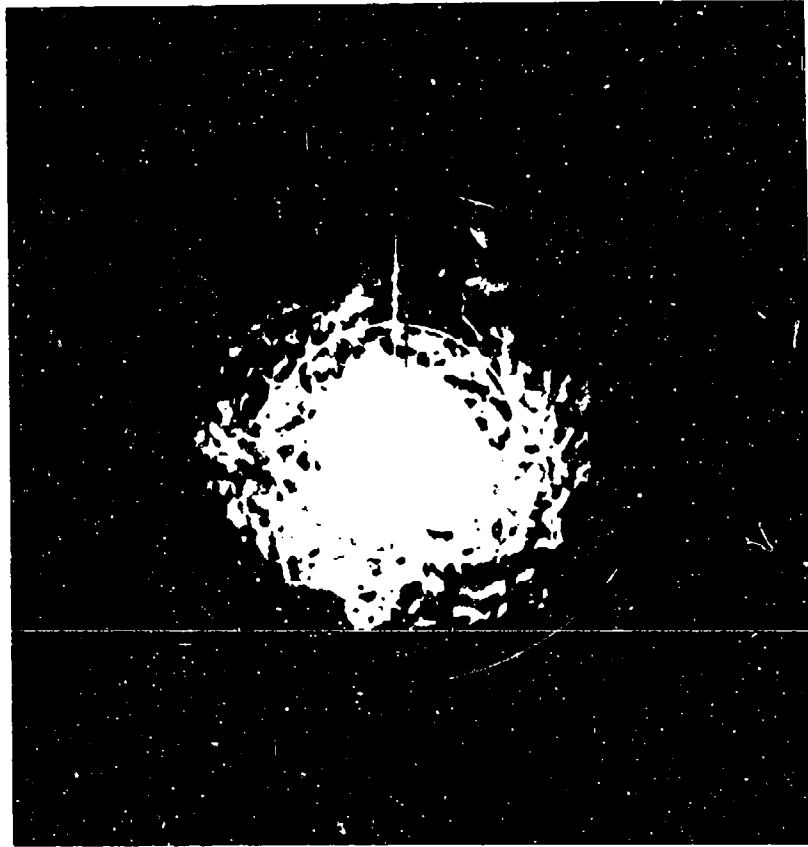


Figure 6. Simulated radar image produced with weight = 6. This is the least accurate transformation in the stimulus set.

Subjects

Seven KC-135 navigators from the 161st Air Refueling Group, Arizona Air National Guard, participated in this study. Each subject was operationally qualified and current.

Procedure

Subjects were tested individually and asked to judge the quality of the simulated radar imagery. At the beginning of the experiment, each navigator was briefed on the purpose of the experiment and was given a 1:50,000 navigation chart of the area. Each navigator was also given a pair of dividers and a 30 NM simulated radar image with an accuracy criterion of 1.0 (Figure 3). The navigators were then asked to orient themselves and to identify several prominent terrain features to ensure they were able to correctly interpret the image. All subjects were able to do this without difficulty.

Following this introduction procedure, each navigator evaluated the quality of the 30 NM simulated imagery by performing three tasks: preference, ranking, and rating. The three tasks were then repeated for the 16-mile range. All tasks were self-paced and took approximately 30 minutes to complete. After data collection, subjects were asked if they could offer any comments or suggestions about the experimental procedures or materials.

In the preference task, each image for a specific range was paired with each of the other images for that range. Each pairing was presented twice in random order for a total of 30 judgments; the position of the images was counterbalanced. The subjects were instructed to indicate which image in each pair they would rather use in navigation tasks and to indicate a preference even if differences between the images were very slight.

After completing the preference task, subjects ranked the six images from best to poorest quality. To perform this task, subjects were given all six images and instructed to arrange them on a table until they were satisfied with the order.

It is possible that even images judged to be poorer in quality than others may be considered adequate for training. Likewise, it is possible that simulated images ranked as better than all others may be judged inadequate for effective training. To test this, subjects were also asked to rate each image on a five-point scale of "Usefulness for Training Navigators." The scale anchors were "1. Excellent; undistinguishable from aircraft radar," and, "5. Unacceptable; not useful for training."

III. RESULTS

The preference data were analyzed using a Thurstone scaling approach that converted the data to an equal-interval scale of perceived quality (Baird & Noma, 1978, Chapter 7; Munnally, 1978, Chapter 2). The zero point of this scale is arbitrary, and the interval between images is based on standard deviations computed from the unit normal distribution. Figure 7 shows that for the 30 NM range, the three most accurate transformations, weight = 1, 0.8, and 0.6, form a tight cluster. This clustering indicates that these three images are not discriminably different from each other. The results for the 16 NM range are different. They show that the two most accurate transformations, weights of 0.8 and 0.6, are not discriminable from each other, and that the third most accurate weight of 1 is discriminably poorer than the two more accurate transformations.

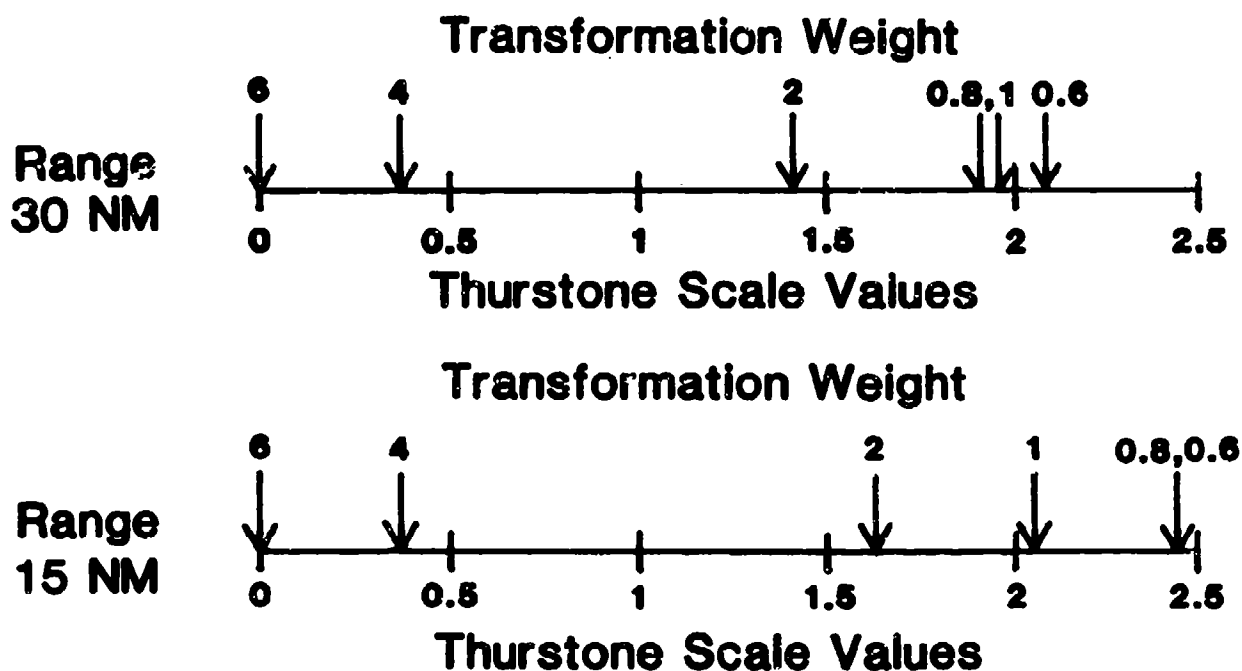


Figure 7. Thurstone scales of preference data. Higher scale values indicate greater preference. Lower transformation accuracy weights indicate greater fidelity.

The mean ranking data are summarized in Table 1. A Friedman Multi Sample Test (Bradley, 1968, Chapter 5) indicates no significant differences among the mean ranks for the three more accurate transformations ($\alpha = .05$) at either range. However, the differences between the mean ranks for these transformations and the next transformation level, 2, was significant ($p < .05$) for both ranges. These results indicate that the three most accurate transformations were not perceptibly different from each other and that the next level was consistently ranked as lower in quality.

Table 1. Mean Rankings of Image Quality

Range, NM	Weighting Factor					
	6	4	2	1	0.8	0.6
30	5.8	5.4	3.6	3.0	1.6	1.9
15	5.6	5.4	3.7	2.9	2.0	1.4

The mean rated training value of each image is shown in Table 2. These data were analyzed using a one-way analysis of variance (Miner, 1971, Chapter 4). These analyses show that the ratings assigned to the three most accurate transformations were not significantly different from each other for either range ($\alpha = .05$) and that the mean rating for these images was significantly higher than the next most accurate transformation level.

Table 2. Mean Ratings of Usefulness for Training Navigators

Range, NM	Weighting Factor					
	6	4	2	1	0.8	0.6
30	4.7	4.6	2.9	2.4	1.6	1.6
15	4.9	4.9	3.7	2.6	1.9	1.7

IV. DISCUSSION

The present project addressed two major questions. The first question dealt with the level of fidelity or realism that is necessary to produce an adequate simulation. In this study, increasing fidelity was achieved by increasing terrain vertical accuracy; i.e., changing the accuracy criterion. Increasing transformation accuracy significantly increases the processing time necessary for the DRMS to transform digital data base information into a simulated radar image. Compared with the standard transformation, weight = 1, the most accurate transformation with weight = 0.6 required 25% more processing time while the least accurate, weight = 6, required 39% less time. The data obtained from the preference and ranking tasks indicate that transformations with weights of 1, 0.8, and 0.6 are perceptually similar to one another. Therefore, it can be concluded that increasing the fidelity of the simulation by using a weighting factor less than 1.0 produces no significant gain in the perceived quality of the simulated image.

The second question addressed by the present study concerns training effectiveness. The preference and ranking tasks assess the discriminability of the stimuli but not their usefulness for training. The rating data, however, show that the three more accurate transformations are judged to have equal training value and to be significantly more useful than the less accurate images. According to Roscoe (1980), increasing realism beyond some point can increase cost without increasing training effectiveness. These results support Roscoe's assertion. For both ranges, radar simulations produced with normal accuracy, weight = 1, (a) are indistinguishable from more accurate simulations with weights of 0.8 and 0.6, (b) have the same training value as the more accurate transformations, and (c) can be produced at significantly lower cost. Although the training effectiveness of each level of simulation fidelity cannot be tested, a reasonable assumption is that if operational navigators cannot reliably distinguish between the various levels of transformation accuracy, then these simulations should have approximately the same training value.

The subjects were asked to comment on the experimental materials and procedures. The altitude of the stimulus images, 10,000 feet, was consistently mentioned as a problem. These subjects were navigators on KC-135 aircraft, which normally fly at altitudes above 30,000 feet. Other aircraft, such as B-52s or FB-111s, typically fly at less than 1,000 feet above the highest local terrain. The stimulus images produced at 10,000 feet are therefore not representative of nearly all Air Force navigation environments. Since the effect of transformation accuracy on image quality is more pronounced at low altitude than at high altitude, a level of transformation accuracy which produces acceptable images for low altitudes will also produce acceptable images for higher altitudes. Before a final decision is made, the present experiment should be repeated using lower altitude radar imagery and navigators familiar with low altitude missions.

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