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ABSTRACT

A review of the literature was made resulting in 41 references, 12 of which described research in applied experimental settings. Subjects in 10 of the 12 studies showed some improvement in performance as a result of using color in the displays. The decision as to whether a color or monochrome television system should be used appeared to be dependent on the specific application and cost factors. Given equivalent cost, there was evidence to suggest the performance with color television is as good, and for some applications, better than monochrome television. (HAB)

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A review of the literature was made as part of Task 6723-01, Wide-Angle High Resolution Color TV Techniques for Training Systems. Forty-one references were consulted, twelve of which described research in applied experimental settings. Subjects in ten of the twelve studies showed some improvement in performance as a result of using color in the displays. The decision as to whether a color or monochrome television system should be used appears to be dependent on the

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specific application and cost factors. If either type could be produced and maintained for equivalent costs, then there is evidence to suggest that performance with color TV would be as good, and for some applications, better than monochrome TV.

PREFACE

A review of the literature was made as part of Task 6723-01, Wide-Angle High Resolution Color TV Techniques for Training Systems. Forty-one references were consulted, twelve of which described research in applied experimental settings. Subjects in ten of the twelve studies showed some improvement in performance as a result of using color in the displays. The decision as to whether a color or monochrome television system should be used appears to be dependent on the specific application and cost factors. If either type could be produced and maintained for equivalent costs, then there is evidence to suggest that performance with color TV would be as good, and for some applications, better than monochrome TV.

I am indebted to Dr. Stanley C. Collyer for leading me to some of the references and for reviewing the manuscript. I would also like to extend my thanks to Ms. Jeannette Price for skillful preparation of the report.

REQUIREMENTS FOR COLOR IN TELEVISION DISPLAYS

INTRODUCTION

The importance of providing color cues is difficult to determine; however, it is known that color plays an important role in some operations. During night aircraft takeoffs and landings, color is employed to provide command information, e.g., green boundary lines and red obstruction lights. This is an example which uses color coding as a relevant stimulus of the training situation. This is an obvious example; however, other situations are more subtle and are difficult to analyze in terms of the requirement for color. For example, it is difficult to determine the importance of color to visual navigation at high altitude, as atmospheric attenuation reduces the saturation of colored objects until they are indistinguishable from achromatic objects.

As monochrome television systems display an image that varies only in luminance level, it would seem that a great deal of potentially useful information is being lost. In determining the identity of an object, color should be superior to an achromatic presentation as it is one of its distinguishing characteristics. As stated by Middleton (1963), "... green forests and red barns have sometimes to be used as 'visibility marks', and the conspicuity of a bright-colored aircraft crash-landed in a green wilderness may be a matter of life and death." Some researchers (e.g., Hillman, 1967) have suggested that acquisition performance should be improved substantially if this extra information were available to the observer, particularly when operating at simulated low altitudes in clear weather.

REVIEW OF THE LITERATURE

Only a few realistic studies have been designed to investigate the use of color TV systems in target acquisition. These studies have generally failed to demonstrate clear-cut differences in detection performance as a function of color contrast, although recognition and/or identification performance may be enhanced in certain instances. A review of the experimental literature on the effects of color on visual search, primarily for displays, was conducted by Christ (1975). He concluded that while color can be an effective aid to performance under some conditions, it can be detrimental in others. If the observer has been briefed concerning the colors of certain classes of targets, his performance might improve. Christ also concluded that, in general, color is superior to size, brightness, and shape as unidimensional target features, but inferior to alphanumeric symbols.

One study of the ability of subjects to acquire colored military targets was performed by Fowler and Jones (1972). They investigated whether the use of a color television display would enhance detection or recognition performance over that achieved with a black and white TV picture. Using video tapes prepared by "flying" over a terrain model, they found no advantage due to the color display, regardless of whether the target colors were similar to, or different from, their background colors. Later research in the same laboratory employed lower target/background brightness contrast values than used in the earlier study. The results again failed to demonstrate any advantage due to the use of color displays.

An earlier simulation study (Snyder et al., 1964) comparing color with black and white film, arrived at essentially the same conclusion. No significant differences were found in mean recognition ranges or percent correct recognitions, even when two of the five targets employed were yellow vehicles, which are seldom encountered in real life tactical environments. A similar conclusion was reached in a recent study by Davies (Parkes, 1972).

Because of the results of such studies and because of certain other considerations, it is doubtful whether presenting the observer with a realistic color picture of the scene is particularly advantageous in most air-to-ground operations. This is especially true considering the increases in cost and weight associated with color systems. One reason for the relative unimportance of color information is that the atmosphere reduces color contrast, imparting a bluish tinge to low-contrast objects (cf. Middleton, 1963). In general, as the distance between the object and the observer increases, colored objects become less saturated until they are virtually indistinguishable from achromatic objects. The range at which this occurs depends upon the amount of haze, the nature of any atmospheric contaminants, and the interest saturation of the object. In many instances, the target and its background may be essentially achromatic at the range at which an observer initially detects the target.

In addition, of course, most tactical targets are deliberately colored to match their probable surroundings as closely as possible, which further decreases the importance of color as an operationally significant variable. Furthermore, the dominant wavelengths of most natural objects appearing on the earth's surface lie within a fairly narrow range, which means that the range of color contrasts likely to be encountered in most missions is limited (Jones, Freitag, and Collyer, 1974).

Despite the negative results of the studies just cited, other studies provided experimental data in support of using color. These are briefly described in the annotated references (Table 1). Other references which provide pertinent information, but do not describe experiments directly applicable to the problem, are listed separately.

DISCUSSION

The studies reviewed indicate that color television may offer a small but significant improvement in target detection over conventional black and white television. The presence of color, in the visual field, tends to increase contrast, thereby, increasing the range of detection and recognition. Color contrast can overcome, to a great extent, loss of luminance contrast. Although luminance contrast is by far the more effective of the two, color contrast will contribute a small but sometimes important addition to the visual scene.

Color and its associated luminances have an effect on the perception of distance (Taylor and Sumner, 1945). It is possible, therefore, to influence the apparent depth of a displayed scene by the use of color. The effect may be more the result of luminance changes than the colors per se but in any case, an apparent depth change may be noted between an achromatic and color presentation. This effect may be negligible in most cases, nevertheless, for the simulated situation in which depth perception is considered critical, it may be a fact worthy of consideration.

Chase (1976) while conducting an experiment with his Computer Generated, Calligraphic, Full Spectrum Color System, found that the display produced better performance and confidence among his subjects. It was reported that this improvement resulted from the perceived three-dimensional characteristics of the color night landing scene. The subjects also reported that the red colors appeared to be in front of and above the blue colors. This effect has been commonly referred to as "color stereoscopy". The study by McCain (1971) in which he used a modified Bausch and Lomb Orthorater to demonstrate the apparent depth of colors, supported these results.

Chase's (1976) study was also of interest in that it demonstrated the differences in pilot performance produced by changing the positions of colors within a visual display. The following display configurations were used: (1) two landing approach scenes, one with red approach lights and blue taxiway lights and the other with the colors reversed, and (2) three perspective arrays of either red, blue, or red and blue lights. The results supported the study hypothesis that specific colors in displays can influence the pilot's control characteristics during the final approach.

In addition to providing an illusion of depth, color can compensate for insufficient resolution. In most cases, the response to a question as to the visual acuity of the human eye will be "one minute of arc", without any qualification of the statement. This response is accurate for the minimum separable acuity and only under certain circumstances. Nevertheless, this is a good value to use as a basis for discussion. Vision through an aircraft windscreen will reduce visual discrimination to about three minutes of arc. Based on this value, a visual presentation using a television format with a vertical field of view of 40 degrees would require 1600 TV lines (60 min./deg./3 min. x 40° x 2 TV lines/optical line pair). Since the television systems in general use have about one-third of this resolution, color may be helpful in compensating for low resolution by increasing the <u>apparent</u> resolution of the display. As to the question, "What visual cues are required for simulation in flight training?," the Air Transport Association visual simulation subcommittee has written a specification (1970) for guidance in establishing minimum requirements. A preliminary copy of these guidelines is included in Appendix A. Note in particular, Items 4. <u>Resolution</u> and 7. <u>Color Presentation</u> under Design Criteria.

Color can also add to the interpretation of visual motion patterns by improving the identification of objects seen, thereby improving estimates of their relative size and distance (Squires, 1931). Pattern discrimination is a function of the ability to detect gradients of brightness, color, and saturation (Fitts, 1951). In Wagner's (1975) two studies, color helped the detection task in one study, while in the acquisition study, color was of no benefit.

There is no question as to pilot preferences with respect to the dimension of color; pilots almost unanimously prefer color to black and white presentations in simulations of the visual world. Quantitative tests of advantages afforded by color have shown small but positive results (Chase, 1970). When color provides a significant dimension of information, as in the case of signal lights, it is obviously important. Extensive efforts to replicate the exact color conditions that exist in the visual world would probably be misplaced, however. These color relations are subject to constant change from one time of the day to the next, with changes in weather and with changes in season. Observers are quite tolerant of rather large deviations in actual color, and subjective standards of acceptability are probably quite adequate. The range of colors available on a color television monitor is probably sufficient for a simulation display, even though the range is somewhat limited relative to the full range of natural colors. Color would appear to be important first, in those circumstances where important information is encoded in color variations and, second, for its value in added realism which influences pilot acceptance of a simulation device (Brown, 1973).

CONCLUSION

In conclusion, results of research in applied experimental settings generally favor the use of color television in training simulation. The consensus from the studies reviewed is that color did not decrease performance but, in most situations, helped performance. The results of ten of the twelve studies reviewed indicated some improvement in observer performance as a function of using color in the display. The decision as to whether a color or monochrome television system should be used, therefore, seems to be dependent on the particular application and cost factors. If either type could be produced and maintained for equivalent costs, then there is evidence to suggest that performance with color TV would be at least as good, and for some applications, better than black and white TV.

TABLE 1. ANNOTATED REFERENCES

Source

Chase, W. D. Evaluation of several TV display system configurations for visual simulation of the landing approach. IEEE Transactions on Man-Machine Systems, Vol. MMS-11, No. 3, Sept. 1970.

Description

A study was conducted to determine the effects of several variations of two types of visual display systems on subjective pilot evaluations and objective measures of performance in the landing approach. Two types of flight approaches were made with either a projector or collimated monitor visual display: (1)* the instrument approach, and (2)* the visual approach without the normal cockpit instrumentation assistance. The variables examined were color, differences between displays due to collimation, and reduced resolution.

Resolution	Display System	Chroma	*
304.8 TV lines (7.08')	projector	color	(1)
		color	(2)
		black/white	(2)
356 TV lines (5.12')	monitor	color	(1)
		color	(2)
		black/white	(2)
228.6 TV lines (7.97')	monitor	color	(2)
		black/white	(2)

Results

The pilots were more critical of the black and white variation for either display, and favored more use of a color system.

Advantages cited for a color system included greater pilot relaxation, decreased fatigue, better picture quality, and more realistic depth perception.

The objective performance measures of the study were reasonably consistent with the pilot's subjective evaluations and comments. For the flights made without color, the landings were predominantly to the right of the runway centerline with twice the standard deviation.

TABLE 1. ANNOTATED REFERENCES (CONT)

Source	Description	Results
Chase, W. D. Effect of color on pilot performance and transfer functions using a full-spectrum, calligraphic, color display system. Presented at the AIAA Vision Simulation and Motion Conference, Dayton, OH, April 26-28, 1976.	A study was conducted with the full-spectrum, calligraphic, computer-generated display system to determine the effect of chromatic content of the visual display upon pilot performance during the landing approach maneuver. This study utilized a new digital chromatic display system, which was previously shown to improve the perceived fidelity of out-the-window display scenes, and presented the results of an experiment designed to determine the effects of display color content by the measurement of both vertical approach performance and pilot describing functions. This method was selected to more fully explore the effects of visual color cues used by the pilot. Two types of landing approaches were made; dynamic and frozen range with either a landing approach scene or a perspective array display. The landing approach scene was presented with either red runway lights and blue taxiway lights or with the colors reversed, and the perspective array with red lights, blue lights, or red and blue lights combined.	The vertical performance measures obtained in this experiment indicated that the pilots performed best with the blue and red/blue displays, and worse with the red displays. The crossover frequencies were lowest with the red displays and highest with the combined red/blue displays which provided the best overall tracking performance. Describing function performance measures, vertical performance measures, and pilot opinion support the hypothesis that specific colors in displays can influence the pilots' control characteristics during the final approach.

TABLE 1. ANNOTATED REFERENCES (CONT)

Source

Chase, W. D. Computer-generated, calligraphic, full-spectrum color system for visual simulation landing approach maneuvers. Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 59, Anaheim, CA, March 17-18, 1975.

Description

To obtain information on how color in terminal-approach visual displays affects pilot performance and opinion, a high brightness chromatic projector was developed for use in research. A brief experimental study, using four airline pilots was conducted in a fixed-base simulator to determine the effect, on pilot performance and opinion, of a color landing display as compared to that of a monochromatic display. The color display was presented in two modes: as a rear-screen projector image, and as an aerial image. Touchdown performance data from this simulator experiment were compared to similar performance data from previous flight experiments.

Results

1. No significant differences were found between longitudinal touchdown performance with the monochromatic and chromatic displays, nor between the simulator performance data and some actual flight data.

2. Rate-of-descent at touchdown was lower for the more realistic chromatic aerial-image display than for the monochromatic display, but still not as low as in actual flight.

3. Pilot opinion indicated that both performance and confidence were enhanced by the chromatic display, particularly when presented as an aerial image. This effect was reportedly due to an enhancement of perceived three-dimensional characteristics.

TABLE 1. ANNOTATED REFERENCES (CONT)

Source

Dust, D. C. Color closed-circuit television as a means of providing visual cues in simulation Paper 70-347 presented at AIAA Visual and Motion Simulation Technology Conference, Cape Canaveral, FL, March 16-18, 1970.

Description

Describes the equipment and techniques used at NASA Ames to provide visual cues and discusses the necessity for their use during certain parts of the flight profile, such as during flare and touchdown. Using Ames equipment, an attempt was made to relate objective measurements of television picture quality to the descriptive picture requirements of the Air Transport Association guidelines. A discussion of why color television was used and the tradeoffs that were made to provide the best overall visual system capability, were included.

Results

Six, four, and two foot objects could be detected much sooner during an approach using the color monitor than with the black and white monitor.

A vertical six foot object was recognized on runway from a simulated distance of 1/2 mile with color TV but not with monochrome TV. This is equivalent to a visual angle of eight minutes of arc. (Stated at the Simulation Technology Conference by Mr. Dust.)

Source

Fowler, F. D. and Jones, D. B. Target Acquisition Studies: (2) Target acquisition performance: color vs. monochrome TV displays. Martin Marietta Corp., Orlando, FL, OR 11,768. January 1972 (AD736244).

Description

This experiment evaluated the differences in acquisition performance elicited by color and monochrome TV display presentations of ground targets. Two-D building type target silhouettes were used which provided a range of contrasts relative to their backgrounds, in terms of brightness and color differences. The Martin Marietta Guidance Development Center simulation facility, including the 40 ft. x 40 ft., 600:1 scale terrain model, was used for basic stimulus generation.

Results

Results showed that color contrast did not affect displayed target acquisition performance for this type of mission over the range of target/background conditions used. Brightness contrast appeared to determine acquisition distance more than any other factor. It was concluded, therefore, that color contrast normally plays a secondary role in airborne target acquisition.

Source

McCain, C. N., Jr., and Karr, A. C. Color and subjective distance. U. S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, MD. Human Engineering Laboratories Technical Memorandum 20-70, August 1970.

Description

Sixteen observers adjusted the position of a white or colored rod until it seemed to be alongside a reference white or colored rod. The colors used were blue and red of matched luminances. (Illumination of 0.20 foot-candles at the observer's position and 0.25 foot-candles at the target machine.)

Results

Observers tended to see the red rods as nearer and the blue rods as further away. It was concluded that red and blue are used as cues for depth perception.

Source

McCain, C. N., Jr., and Karr, A. C. Color, differential luminance and subjective distance. U. S. Army Aberdeen Research and Development Center, Aberdeen Proving Ground, MD, Human Engineering Laboratories Technical Memorandum 4-71, April 1971.

Description

A modified Howard-Dohlman type apparatus was used to quantify the ability of 12 observers to adjust the relative distance of gray, red and blue rods under six relative luminance combinations (left or right rod having equal, one-half, or one-quarter the luminance of its comparison rod). (Illumination of 0.20 foot-candles at the observer's position and 0.25 foot-candles at the target machine.)

Results

The observers perceived the red rod as nearer than the blue under all conditions, with no significant effect of luminance under any condition. It was concluded that color per se is a cue for depth.

TABLE 1. ANNOTATED REFERENCES (CONT).

Source

Wagner, D. W. Target detection with color versus black and white television. China Lake, CA, Naval Weapons Center, Report NWC TP 5731, April 1975, 36 pp.

Description

Investigated target detection performance on color and black-and-white television. Green, brown, and gray model tanks were viewed under 25, 35, and 300 TV lines resolution against a green and a brown background on a terrain model. Target-to-background luminance contrasts studied were positive (targets lighter than surround), negative (targets darker than surround), and zero.

Results

Color provided a slightly higher percentage of target detection than did black and white TV (74 vs. 69%). Background color did not affect performance, although it figured prominently in several interaction effects. Gray targets were more detectable than either brown or green targets. Higher resolution improved performance about equally for both color and black and white TV, and targets lighter than the background were detected more easily than either negative or zero contrast targets.

Source

Wagner, D. W. Target acquisition with color versus black and white television. China Lake, CA, Naval Weapons Center, Report NWC TP 5800, October 1975, 26 pp.

Description

Two simulator experiments, differing only in field of view (FOV) investigated air-to-ground target acquisition with color and black and white television. A television camera obliquely viewed a terrain model from a simulated altitude of 4,000 feet with two FOV's: 4.5 and 3.25 degrees. Subjects searched for green, olive, brown, and earth-colored tanks and trucks as the camera "flew" over the terrain.

Results

(1) Color TV was not generally superior to black and white TV; (2) the earth-colored targets provided more correct detections at faster response times than the other colors; (3) tanks were detected, but not identified, slightly faster than trucks; (4) target detection and identification was affected by the background; and (5) the smaller FOV more than doubled correct target detections (41 versus 86%).

TABLE 1. ANNOTATED REFERENCES (CONT)

Source

Whitehurst, H. O. The effects of pattern and color on the visual detection of camouflaged vehicles. Naval Weapons Center, China Lake, CA. Report NWC TP 5746, April 1975, 28 pp.

Description

Two camouflage experiments were conducted in which subjects searched for model armored personnel carriers placed singly on a terrain model. The effects of pattern contours, the number of colors used to paint the patterns, and the particular colors used on search times and detection probabilities were measured.

Results

Analyses of variance revealed no significant effects due to pattern contours or number of colors, whereas, color per se was found to have a significant effect in reducing search times.

Source

Williams, L. G. Visual search: eye fixations as determined by instructed target characteristics. Honeywell, Inc., St. Paul, MN, Rept. TRANS-125 AD-620 336, August 1965.

Description

Observers were briefed concerning the colors of single and multiple targets in crowded fields. Visual search was monitored using eye movement recordings.

Results

With prior instruction about single target characteristics, searcher's eye fixations tended strongly to fall on objects of instructed color, and less on objects of instructed size or shape.

In general, when instructed about multiple target characteristics, fixations were related to a single characteristic, color if provided, otherwise size.

TABLE 1. ANNOTATED REFERENCES (CONT)

Source

Wong, K. W. and Yacoumelos, N. G. Identification of cartographic symbols from TV displays. Human Factors, 1973, 15(1), pp. 21-31.

Description

Investigation of the resolution capability of TV displays in distinguishing details from line-maps and picto-maps, and to establish the relative merits of color and black and white TV display systems. The experimental variables included two display types, three map types, four symbol types, and three image-resolution levels.

Results

The results showed that a color display offered some advantage over a black and white display of equivalent effective resolution. However, a black and white system could provide the same performance at the expense of a slightly higher effective resolution. At an image-resolution level of nine TV-lines/mm, alphanumeric symbols were identified almost 100% correctly for all map types and display types. Area and line symbols achieved their maximum level of performance at five and seven TV-lines/mm, respectively.

APPENDIX A

ATA VISUAL SIMULATION SUBCOMMITTEE

GUIDANCE FOR ESTABLISHING MINIMUM VISUAL SPECIFICATIONS FOR TOTAL SIMULATION -- FLIGHT TRAINING

The stated goal for visual simulation is to permit the total training of flight crew members in a flight simulator for such future airplanes as the SST aircraft. Therefore, if visual cues are required to execute a maneuver or any part of a flight regime, visual simulation will be considered necessary. The specifications should call for an ability to accomplish training in the following:

TRAINING NEED

1. Taxiing. In addition to normal taxiing to takeoff position involving maneuvering the aircraft on taxiways and on to the runway for taxi and pre-takeoff check list and taxi procedures, consideration should be given to practice in aircraft docking. A special area or separate display may be considered for this purpose with transition to the general visual simulation display either at a transition point on a given taxiway or as a discreet break from taxi practice to preparation for takeoff and landing.

   Note: General topography for taxiing appears within the state-of-the-art, however new techniques and/or scaling may be necessary to provide realistic taxiing and docking capability.

2. Rejected Takeoff. Realistic practice in acceleration to any given speed prior to V_1 and stopping utilizing available deceleration devices both operating normally and abnormally is required. In addition, simulation of various runway and takeoff conditions such as ice, wind, and wet runway surfaces must be realistically simulated.

3. Takeoff and Climb. Accomplish normal takeoffs, day, dusk and night, with ability to climb as directed by visual reference to horizon. Airlines desire the capability to takeoff and maneuver to approximately 3,000' and 15 miles from takeoff.

   Visual simulation should provide practice in crosswind takeoffs with realistic side slip and/or yaw on dry, wet or slippery runway surfaces.

   Note: Because the requirement for greater distance in maneuvering for landing will seriously stretch the capabilities of many visual systems, it may be necessary to limit the altitude and distance somewhat on the takeoff end.

4. Loss of Engine after V_1 on Takeoff. The visual scene must be capable of following any airplane and/or operator inputs involved in this regime. This includes yaw capability without loss of visual scene equivalent to the combined yaw due to engine failure and momentary error in rudder input.

5. Air Work. Typical horizon reference (desirably ground reference) both day and night, should provide for the ability to practice climbing turns, level turns, demonstration of roll rates, minimum speed maneuvering under VFR conditions, recovery from approach to stalls, dutch roll recovery and entry to and level out from emergency descent. Performance rates should be compatible with aircraft limitations. Performance may be with reference to generalized cloud deck horizon.

   Note: The use of a general cloud deck for horizon reference may be considerably less costly and more readily available than the simulation of continuous terrain at the higher elevations required for these maneuvers.

6. VFR Approach and Landing. The visual presentation should permit practice in visual approach and landing with normal power available and with one or more engines inoperative; approach and landing with jammed stabilizer; day and night landings; crosswind landing; landing simulating no reverse or reverse malfunctions; landing simulating no anti-skid or malfunctioning anti-skid operation; landing with vertical off-set; landing with lateral off-set; approach and landing with zero flaps; and pull out or rejected landing from any of the aforementioned approaches. To accomplish these VFR approaches and landings in jets such as the SST, it is conceivable that a maneuvering area of 15 miles from landing at an altitude of up to 3,000' may be necessary.

   Note: Obvious technical improvements in the state-of-the-art of visual simulation will be necessary to provide this VFR capability. Consideration should be given multiple media mapping and presentation.

7. Break Out from Instrument Approach. The visual simulation should provide realistic presentation of reduced ceiling and visibility simulating conditions, i.e., this may be to a point approaching zero-zero conditions under Category III operations. Lighting and runway guidance information should be realistic enough to provide practice in approach continuance decision making under all low minima conditions.

8. Missed Approach. Practice in accomplishing missed approaches from any instrument approach either as a result of lateral offset, unacceptable visibility or other conditions warranting abandoning an approach should be realistically available.

9. Landing Roll Out. Practice in landing, touchdown and roll out with decision capability to turn off on any available taxiway or high speed turn off is desirable. Realistic effect of wind, ice, snow and wet runway conditions should be available.

   Note: Present systems indicate problems in obtaining all desired conditions of high resolution, focus and/or flexibility.

10. Circling Approach. Ability to circle, approach and land under altitude and visibility restrictions applicable to the airlines operating specifications.

   Note: If this requirement remains applicable to future type aircraft, the capability to meet VFR and IFR requirements for training as above specified will satisfy the requirements of this maneuver.

DESIGN CRITERIA

1. Field of View. Training requirements call for full view from all front and side cockpit windows.

2. Freedom of Head Movement. The pilots should have full normal freedom of head movement without cropping or distortions that would interrupt the "real world" acceptance of the scene.

3. View Availability. The field of view must be correct to both pilots simultaneously and provide correct reference to an observer/instructor.

4. Resolution.

   a. The following resolution is required for daylight scenes. (The point reference is defined as distance out on a 2-1/2 to 3^0 glide slope unless otherwise noted):

Point	What You Must See	How Well	With Ability to Accomplish
(1) 15 mi. 3000'	Airport area	To recognize the airport	Plan approach path
(2) 10 mi.	Airport area with buildings visible and partial runway definition	General plan of the airport	Runway alignment
(3) 6 mi.	Airport and runway	Recognize the runway	Runway alignment
(4) 4 mi.	Runway and taxiways	Recognize taxiways	Runway alignment and establish glide slope slot
(5) 2 mi.	Runway striping	Number of stripes	Runway alignment, glide slope slot and touchdown point
(6) 1/2 mi.	Complete runway detail	To recognize a 6' vertical object on end of runway	Alignment, touchdown point and establish closing rate
(7) 1000'	Complete runway detail	To recognize a 4' vertical object and perceive texture	Runway alignment, aiming point, final descent rate
(8) Over end of runway	Complete runway detail	To recognize a 2' vertical object and texture	Runway alignment, touchdown point and flare

b. The following criteria may be used to establish resolution requirements for dusk or night lighting scenes (distances are assumed to be at extended glide slope altitude):

(1) Strobe lights (6 mi.) or within confines of map
(2) Approach lights (6 mi.) or within confines of map
(3) White runway edge lights (6 mi.) or within confines of map
(4) Centerline lights (3 mi.)
(5) Threshold green lights (2.5 mi.)
(6) Threshold red lights (2 mi.)
(7) Touchdown lights (2 mi.)
(8) Taxi lights (2 mi.)
(9) Amber runway runout lights (1 mi.)
(10) High speed taxi turnoff (1 mi.)
(11) VASI (if installed) (5 mi.)

5. Performance Limitations. Airport maneuvering -

Ceiling Height and Breakout	0 - 3000 ft.
Vertical Velocity	0 - 6000 fpm.
Transverse Velocity	0 - 160 fps.
Forward Travel	16 mi. min. on approach and 10 mi. departure
Forward Velocity	0 - 350 Kts
Roll Angle	± 50 degrees
Pitch Angle	± 30 degrees
Yaw Angle	± 30 degrees
Heading Angle	0 to 360 degrees
Visibility Control	0 to 15 miles
Scud	Variable
Wind through 360 degrees	0 - 60 Kts
Gusts (air and ground)	0 - 40 Kts
Landing Lights (Airplane)	Realistic and operable from simulator
Taxi Lights (Airplane)	May be turned on or off by flight crew
Roll, pitch and yaw velocity	To match airplane performance

6. Response. The visual scene shall respond at the same rate and acceleration as the flight simulator such that no delays, lags, hysteresis, smear or coasting is perceptible to the pilot. For takeoff and landing, the visual response to airplane yaw will be translated in terms of the pilot's position, i.e., include both lateral and angular displacement in correct relationship to the airplane. Yaw in the air, including the approach will account for the infinite radius of the arc.

7. Color Presentation. Color for runway lighting is an absolute minimum requirement. The importance of full or true color for other cues should be considered for depth perception, simulation acceptance and the psychological effect of realism.

8. Side Slip. Realistic simulation of all runway conditions will be required including complete freedom of airplane movement on the runway under wet and slippery runway conditions.

9. Lighting. All night and day runway and airport lighting must be simulated such that light presentations will be recognizably realistic from any direction viewable by the pilot in the air or on the ground. Night and day runway and airport lighting to include:

   a. Approach lights
   b. Sequence flashing strobe lights
   c. Centerline lights
   d. Taxi lights and high speed turn off light to taxiways intercepting the runway used
   e. Runway edge lights
   f. Touchdown lights
   g. Full category II lighting
   h. Category III lighting and guidance
   i. VASI
   j. Random airport lighting -- desirable

10. Brightness. Brightness balance will provide for as realistic a daylight cockpit condition as possible for daylight scenes to permit reasonable simulation of daylight lighting in the cockpit.

11. Visibility Variability. In addition to complete instantaneous variability of ceiling and visibility by instructor and/or operator, a condition of ragged ceiling and scud should be available.

    Improved special effects are required.

12. Gradual Breakout. The visual system shall provide for linear and non-linear reduction of obscuration during breakout to visual contact.

13. Heads Up Display Compatibility is required.

14. Maintainability and Reliability must be compatible with the basic simulator on which used.

15. Display Device and Distance must be compatible with the flight simulator, its motion system and the viewing requirements of each crew member. Consideration should be given to virtual image presentation for realistic depth perception for VFR maneuvering.

16. Motion Compatibility. The visual system should be compatible with the motion system and capable of withstanding the buffeting and accelerations of the motion system.

17. To accomplish all training requirements, consideration should be given to multiple media visual presentation with the media best suited to the specific portion of the maneuver being phased in where necessary and the media providing flexibility phased in when flexibility becomes paramount. This concept could also apply in the taxiing and docking concept to provide the larger scaling detail necessary for this presentation.

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