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DEVELOPMENT OF VISUAL AIDS TO ALLEVIATE SPATIAL
DISORIENTATION DURING TAKEOFF AND LANDING

TECHNOLOGY, INC.

PREPARED FOR
FEDERAL AVIATION ADMINISTRATION

JUNE 1973

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-73-26	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DEVELOPMENT OF VISUAL AIDS TO ALLEVIATE SPATIAL DISORIENTATION DURING TAKEOFF AND LANDING	5. Report Date June 1973	6. Performing Organization Code
7. Author(s) W. H. Bowie, S. C. Collyer, D. S. Stolarski	8. Performing Organization Report No.	10. Work Unit No. TRAIS 25090
9. Performing Organization Name and Address Technology Incorporated Life Sciences Division 8531 N. New Braunfels San Antonio, Texas 78217	11. Contract or Grant No. Contract FA72WA-2760	13. Type of Report and Period Covered Final
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591	14. Sponsoring Agency Code LG-350	15. Supplementary Notes
16. Abstract <p>The concept for a ground based visual aid to help alleviate spatial disorientation during takeoff and landing approaches has been developed. The proposed device consists of a 2/3 mile diameter circle of 12 lights mounted at least 2 miles from the end of the runway. This array has the appearance of a flat ellipse during most of the departure phase of flight. However, the array's usefulness deteriorates as the pilot approaches a distance of 1/2 mile from the array.</p> <p>The relative degree of spatial disorientation hazard associated with a particular runway has been researched. A device has been designed and built with which to assess such hazards. The device is designated a Visibility Meter. In addition, a tentative design for visibility markers to aid in determining horizontal visibility was proposed.</p>		
<p>NATIONAL TECHNICAL INFORMATION SERVICE</p>		
17. Key Words VFR Spatial Disorientation Visibility Marking Approach and Landing	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 47
		22. Price \$ 2.00

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TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Purpose	1
Background	1
DISCUSSION	12
Development of Visual Aid System	12
Airport Hazard Evaluation	20
Visibility Markers	23
TEST RESULTS	25
Visual Aid System	25
Airport Hazard Evaluation	29
Visibility Markers	32
CONCLUSIONS	38
Visual Aid System	38
Airport Hazard Evaluation	38
Visibility Markers	39
REFERENCES	40

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PREFACE

The work described in the following report was performed under Department of Transportation Contract No. DOT-FA72-WA-2760 for the Federal Aviation Administration.

The Contractual objectives were:

- 1) to develop visual aids to alleviate spatial disorientation during takeoff and landing approach and
- 2) to develop criteria for determining whether any given runway may present a hazard from spatial disorientation either in the approach or during takeoff under authorized VFR condition.

Technology Incorporated particularly wishes to thank the personnel of the General Aviation District Office No. 10 for their support, cooperation and advice.

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INTRODUCTION

Purpose

This report presents the results of a research effort designed to define a visual aid system to assist the general aviation pilot in avoiding spatial disorientation during certain takeoff and landing situations. The system is designed primarily for the pilot who is flying under visual flight rules (VFR) and who may have insufficient instrument experience or instrument awareness to be able to avoid the onset of disorientation when conditions are right for its occurrence.

Background

A survey and analysis of those factors contributing to disorientation is presented herein, with particular emphasis on those factors that could be alleviated by a visual aid system in the vicinity of the airport. Various aspects of the approach to the problem and the proposed solution will be discussed. In particular, the rationale behind the chosen approach will be presented along with the consequences of this course of action. In addition, a simple technique has been devised to help determine the potential degree of disorientation hazard present during takeoffs and approaches at certain airports.

Once a pilot leaves the confines of the earth's surface he is faced with unique problems of orientation due to the occurrence of conflicting, misleading and inadequate cues concerning his true attitude and position. Consequently spatial disorientation may be defined simply as an erroneous perception concerning one's true position and attitude in three-dimensional space.

The hazards of spatial disorientation have long been recognized by workers in the field of aviation safety. Studies of aircraft accidents have implicated spatial disorientation as a primary or contributing factor responsible for a significant number of these accidents.

For example, Nuttal and Sanford (1) studied spatial disorientation in the USAF European command and found that disorientation was responsible for 4% of major accidents and 14% of all fatal accidents.

(1) Nuttal, J. B. and Sanford, W. G. Spatial disorientation in operational flight. In Evrard, E., Bergeret, P. and Van Wulfften Palthe, P. M. Medical aspects of flight safety. Pergamon, New York, 1959.

In a more recent study, Moser (2) presented figures of 9% and 26%, respectively. A questionnaire study by Clark and Nicholson in 1953 (3) was one of the earliest to show how prevalent spatial disorientation experiences were in aviation personnel. Other recent studies referring to the role of disorientation as a causative factor in accidents are those of Hixon, et al. (4), and Barnum and Bonner (5), among others. Although studies have shown disorientation to be more common among jet pilots than among pilots of propeller aircraft, the seriousness of the problem for the general aviation pilot is nevertheless recognized. Dougherty (6), for example, has implicated spatial disorientation in a number of fatalities at Lakefront Airport in New Orleans.

The following sections will focus on the disorientation factors of particular relevance to the general aviation pilot with emphasis on those likely to exist during takeoff and landing operations. A complete discussion of those runway factors that may produce depth illusions affecting the pilot shortly before he reaches the runway threshold will not be presented. Solutions to problems of this nature are considered to be outside the scope of this research effort. A discussion of such runway factors is presented by Pitts (7),

(2)

Moser, R. Spatial disorientation as a factor in accidents in an operational command. *Aerospace Medicine*. 1969. 40:174-176.

(3)

Clark, B. and Nicholson, M. A. Vertigo: A cause of pilot error in naval aviation students. *U. S. Naval School of Aviation Medicine; NM 001 059*. 01. 37: August 1953.

(4)

Hixon, W. C., et al. Major orientation-error accidents in regular army UH-1 aircraft during fiscal year 1967: Accident factors. October 1970. *U. S. Army Aeromedical Research Lab.; Naval Aerospace Medical Research Lab. 2100/NAMRL-1109*.

(5)

Barnum, F. and Bonner, R. H. Epidemiology of USAF spatial disorientation aircraft accidents. 1 January 1958-December 1968. *Aerospace Medicine*. 1971. 42:896-898.

(6)

Dougherty, J. D. Lakefront Airport: An epidemiologic approach. *Aerospace Medicine*. 1965. 36:558-561.

(7)

Pitts, D. G. Visual illusions and aircraft accidents. SAM TR-67-28, Final Report, April 1967.

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Robson (8) and others.

Vestibular Factors - Probably the most important single category of illusions encountered by pilots are those resulting from false or ambiguous information from the vestibular system. Due to the range of accelerative forces attainable in today's high-performance aircraft, many of these illusions are far more compelling and severe for jet pilots than they are for pilots of single- or dual-engine propeller driven aircraft. On the other hand, since jet pilots generally possess a greater awareness of the hazards of these illusions, and have extensive experience in instrument flight, the danger may often be greater for the relatively inexperienced general aviation pilot caught without adequate visual reference to the outside world. The most significant of these illusions will be briefly summarized in this section, with emphasis on those presenting the greatest hazards to the private pilot.

It is important to note that the in-flight illusions involving the labyrinthine system do not represent an abnormal functioning of this orientation mechanism; rather, they result from a normal response to an "abnormal" situation, namely flight. It is for this reason that these illusions are so common; since the false vestibular input cannot be prevented, it is necessary to devise the most effective means by which it may be overcome.

A number of references in the area of flight safety and related fields discuss in detail the in-flight illusions of vestibular origin, as well as the anatomical and physiological bases for these illusions, for example, Gillingham, (9); Clark and Graybiel (10); Clark (11);

(8)

Robson, R. C. Trapped in the approach bog. Aviation Week, 1956. 64:154.

(9)

Gillingham, K. K. A primer of vestibular function, spatial disorientation, and motion sickness. Review 4-66, USAF School of Aerospace Medicine; Brooks AFB, Texas. June 1966.

(10)

Clark, B. and Graybiel, A. Disorientation: A cause of pilot error. U. S. Naval School of Aviation Medicine; Research Report No. NM 001 110 100. 39: March 1955.

(11)

Clark, B. Visual space perception as influenced by unusual vestibular simulation. In Baker, C. A. (ed). Visual capabilities in the space environment. Pergamon, New York. 1965.

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Howard and Templeton, (12). The following paragraphs present a general overview of these illusions.

The main structures of the inner ear are the semicircular canals, which act as sensors for angular acceleration in any of three orthogonal planes of rotation; and the otolith organs, which are transducers for linear accelerations. While both of these mechanisms are highly sensitive to accelerative forces, both are capable of transmitting grossly erroneous information under certain circumstances, such as during particular flight maneuvers commonly encountered in high and low performance aircraft. Whereas earth-bound man is normally subjected to rather brief accelerations and decelerations, in flight accelerations are often prolonged and not immediately followed by an equal deceleration, with the result that the vestibular mechanisms behave in unusual fashions, producing sensory information which the human being is not equipped to interpret accurately.

Coriolis Effects - Probably the most potent of the disorienting effects produced by the vestibular system occurs in flight during a rotary maneuver, when the pilot moves his head so as to change the position of his semicircular canals with respect to the axis of rotation. The resulting movement of fluid in the canals, and the concomitant cupular displacement, are referred to as Coriolis effects, although, as Howard and Templeton (12) point out, a distinction should properly be made between cross-coupling effects and true coriolis effects. The results, regardless of terminology, can be particularly devastating, and can be produced, for example, when the aircraft is in a roll and the pilot looks down and to one side. Depending on the direction of roll and the direction of head movement, the pilot receives a compelling sensation of change in attitude in one or more directions. This may be accompanied by extreme dizziness (sometimes termed vertigo) and by such physiological responses as sweating and nausea.

These Coriolis effects have been blamed for a number of fatalities, most notably in aircraft in which the placement of the radios or other instruments required the pilot to bend down and look to one side in order to change frequencies or observe the dials. (13)

(12)

Howard, I. P. and Templeton, W. B., Human Spatial Orientation. Wiley, New York. 1966.

(13)

Nuttall, J. F., The problem of spatial disorientation. JAMA. 1958. 166: 431-438.

Oculogravic and Oculogyral Illusions - The oculogravic and oculogyral illusions are briefly mentioned here because they are frequently discussed in the literature. They are more likely to be experienced by the pilot of a high-performance aircraft than by the general aviation pilot. These illusions are essentially sensations of a visual displacement of a target, brought on by linear or angular acceleration.

In the case of the oculogravic illusion, a linear acceleration can cause target displacement in a direction consistent with the resultant gravito-inertial force vector. If a pilot accelerates during straight and level flight, the resultant G-vector is mistakenly interpreted as a cue to verticality, causing the pilot to feel that he is tilting backward. In an otherwise darkened environment, a target in a fixed location relative to the observer would then appear to rise as the pilot senses he is tilting.

The oculogyral illusion refers to the apparent motion of a target as a result of angular acceleration. If a subject is seated in a rotating chair, viewing a target that rotates as he does, an acceleration to the left will cause an apparent leftward motion of the target. The illusion may also occur when viewing a moving target in darkness, so that the effects of real and apparent motion may either summate or cancel each other (11).

These illusions have been demonstrated in flight, and are considered by many to constitute serious hazards under the proper conditions (10). The general aviation pilot, however, is probably in little danger from these particular illusions, because the accelerations he is likely to experience are not as great, and because the circumstances necessary for their occurrence (e. g. night formation flying) are seldom, if ever, encountered.

For more information concerning the nature of these illusions and their etiology, see, for example, Whiteside, et al. (14), Graybiel (15), and Pitts (7).

(14)

Whiteside, T. C. D., Graybiel, A. and Niven, J. I. Visual illusions of Movement. U. S. Naval School of Aviation Medicine, NSAM-877: October 1963.

(15)

Graybiel, A. Oculogravic illusion. Archives of Ophthalmology. 1952. 48: 605-615.

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Illusions of Attitude - There are a number of ways in which the pilot of a relatively low-powered aircraft can be seriously misled as to his true orientation in three-dimensional space, due to misinformation provided by the vestibular system as a result of a variety of normal flight maneuvers. These may be generally termed illusions of attitude, and will occur when there is little or no visual information to contradict the information provided by the vestibular system. If a pilot is flying in clear daytime weather, with good ground and horizon references, the visual information will take precedence, and he will have little or no difficulty maintaining an accurate perception of his orientation.

With minimal visual cues, however, illusions of attitude can be overwhelming, and may persist even when a pilot flies by reference only to his instruments. That is, the "cognitive" information provided by visual reference to his instruments is not as effective as "perceptual" information provided by a good look at the outside world. With sufficient training, the cognitive information can be adequate for the pilot to maintain his aircraft in the proper orientation, but the illusions can persist.

One commonly encountered illusion is the sensation of climbing when the aircraft is actually in a coordinated turn. In such a turn, the increase in the magnitude of the G-vector from head to seat is easily perceived as an accelerated straight-ahead climb, which would produce an identical G-loading.

A typical situation in which this illusion could be extremely dangerous would be on takeoff over an area having few lights, or none at all (e. g., a large body of water). If the pilot inadvertently entered into a bank, he could believe himself to be climbing when in fact he was losing altitude, and could crash without ever having realized his error.

Conversely, in recovering from a turn the reduction in G-loading can be perceived as the entry into a dive.

One category of illusions commonly experienced are those that are due to a change in attitude occurring at a subthreshold rate. It is possible for an aircraft to enter into a turn or pitch so gradually as to be imperceptible, and the pilot may become disoriented accordingly. Similarly, if a turn is initiated gradually, but recovery from the turn is sufficiently rapid to be detected by the vestibular apparatus, the sensation produced may be one of being in a bank in a direction opposite to that of the initial bank. The pilot may then attempt to "correct" this situation and roll the plane in the direction of the initial turn. An interesting corollary to this illusion is that a condition commonly referred

to as the "leans" (16) may result if the pilot uses his instruments to regain straight and level flight. The illusion of a turn may persist for some time, and the pilot may feel a compulsion to lean over in his seat in order to align himself with the perceived vertical. This nicely illustrates the inability of cognitive information to suppress sensory information.

Other false perceptions resulting from aircraft maneuvers have been discussed in the literature and may be observed in flight. For example, if a skid is produced during a turn to the left, the centrifugal force will act in such a way as to produce the sensation of tilting to the right. Other illusions of a similar nature, including some primarily of interest to the jet pilot, are described in a variety of sources (e. g. Armstrong (16); Bonner, (17); Nuttal, (13).

In summary, it has been shown that vestibular illusions are often the consequence of normal flight maneuvers and of normal body movements during these maneuvers. For this reason, the problem of minimizing the likelihood of serious spatial disorientation caused by these illusory sensations is especially difficult. In most cases it is not possible to prevent the occurrence of the illusion, therefore, it is important that the pilot be thoroughly indoctrinated as to: (a) the total unreliability of his vestibular system in flight, and (b) the particular kinds of maneuvers and movements during which disorientation is most likely to occur. Such indoctrination, of course, already takes place for both military and civilian pilots; in the case of the latter, however, the effort should probably be stepped up. In addition to instructional efforts, it is highly desirable to investigate thoroughly any and all possibilities of external visual aid systems to assist those pilots who do not have recourse to, or sufficient experience in the use of extensive onboard flight instrumentation.

The second major category of factors important to a consideration of spatial disorientation pertains to the visual cues available to the pilot in a given situation. The visual conditions that may either contribute to or produce disorientation will be discussed in the following section.

(16)

Armstrong, H. G. Aerospace Medicine. Williams and Wilkins, Baltimore. 1961.

(17)

Bonner, H. Spatial disorientation current concepts and aeromedical implications. Review 7-63, USAF School of Aerospace Medicine: Brooks Air Force Base, Texas. August 1963.

Insufficient "Slant Range" Visibility - Probably the single most important visual factor likely to result in spatial disorientation in a pilot flying VFR can be referred to as insufficient "slant range" visibility. This means that, due to weather conditions and/or darkness, the pilot's forward visibility and visibility to either side is restricted, such that judgment of the true horizontal is neither as rapid nor as accurate as would otherwise be possible. The optimal situation exists, of course, when the true horizon is actually visible. As more and more objects and features close to the horizon become obscured, the judgment of proper orientation can become increasingly difficult, especially when the surface features within the range of visibility are themselves inadequate or misleading.

This inability to see the horizon or objects close to it is of paramount importance in a consideration of spatial disorientation. The principal environmental conditions producing such a visibility restriction for the VFR pilot include darkness, haze, fog, and precipitation. If none of these conditions is present, it is unlikely that disorientation will occur. As Moser (2) has pointed out in a study of disorientation accidents over a four-year period in the Aerospace Defense Command, all such accidents were found to have occurred during either weather operations, nighttime operations, or both. Thus, reduced visibility during darkness or adverse weather can be considered as necessary conditions for the onset of spatial disorientation during VFR flight. Normally, however, these conditions are not sufficient in themselves to produce disorientation. The other factors discussed in this report can be regarded as secondary factors, inasmuch as: (a) conditions of reduced visibility must be present in order for them to occur; or (b) they must occur in conjunction with reduced visibility in order for disorientation to be possible. This has been shown to be true for the vestibular factors already discussed, and will be true for the remaining factors to be discussed in this section.

Insufficient Number and Placement of Ground Lights - Under conditions of nighttime flying without benefit of moonlight the pilot must, of course, rely on the patterning of ground lights as his principal source of outside information concerning his true orientation. In the vicinity of cities or reasonably populated areas, difficulties would be seldom expected, as a more or less continuous array of lights would be provided. The sight of a distant city on the horizon provides an excellent source of information to the pilot, and a city beyond the horizon may even give sufficient horizontal information, due to atmospheric scatter, or to lights reflected from the bottom of a cloud layer. Even a small city can easily give good attitude information in one axis; since cities are usually roughly circular, their elongation when seen from a distance provides a good horizontal reference.

Mistaken Orientation or Identity of Lights - In addition to the insufficiency of lights discussed above, disorientation can result from a misjudgment of the orientation of an array of lights. For example, if a string of lights from a row of towers was viewed straight ahead and was assumed to be running perpendicular to the direction of travel, the pilot could align his aircraft with respect to this perceived horizontal cue. If the lights were actually running at other than a 90° angle to the line of flight, this misperception could result in the pilot's inadvertently placing his aircraft in a bank.

An infrequent situation when flying over a very sparsely populated area with few ground lights in that some of the distant lights can be mistaken for stars, or vice versa. If ground lights seen straight ahead are thought to be stars, the pilot may perceive himself to be in a nose-high attitude, and compensate by entering a shallow dive. For a discussion of other similar illusions resulting from misperception of lights see, for example, Vinacke. (18)

Autokinesis - The autokinetic illusion refers to the apparent movement of a fixed object in the visual field when other visual references are absent. The best stimulus for its occurrence is a single small, dim light seen against a dark background. It has been observed often in flight, particularly by military pilots--for example, when one is flying in a night formation by reference to a single light on the lead aircraft. It is unlikely to be of serious consequence in general aviation, although it could occur if a pilot flew directly toward a distant light on the horizon and maintained a steady fixation on that light for a short time.

Illusions of Height Based on Misperceived Altitude - Cocquyt (19) has described an interesting phenomenon by which a misjudgment of altitude can result in an incorrect estimate of height above the ground. The basic idea is that if, for example, a pilot is unwittingly in a slight bank to the left, and looks to the right at a distant landmark such as a beacon, his judgment of his height above the ground may be based on the following information: (a) the distance to the landmark; and (b) the angle between his line of regard to the perceived horizon and his line of regard to the beacon. In the example given, this angle would, of course, be overestimated

(18)

Vinacke, W. E. Illusions experienced by aircraft pilots while flying. . Aviation Medicine. 1947. 308-325.

(19)

Cocquyt, Propser P. Sensory illusions. Reprinted from Shell Aviation News. 1953; by the Flight Safety Foundation, New York.

assuming a reasonably accurate estimate of the distance to the beacon, the result would be an overestimation of his altitude. If this illusion occurred at low altitude, such as during takeoff, a hazardous condition would exist.

Misjudgment of Terrain Slant and Distance, due to Misleading Depth Cues - False perceptions concerning height above the terrain and slope of the terrain can occur during landing operations during both daytime and nighttime flight, if inadequate or insufficient cues to depth are present. For example, during the day smooth surface features (e. g. snow, calm water) provide no texture information with which to judge height, and the pilot will have a tendency to fly low. In fact, flying over any surface having different texture characteristics from what the pilot is accustomed to seeing can result in misjudgment of height. Surface slant can go unperceived in the absence of nearby objects known to be vertical (trees, buildings) or horizontal (bodies of water). Misjudgment of distance between objects can result in a misjudgment of the observer's distance from them. For example, if the pilot sees two lights on the ground which he thinks are 100 feet apart, when their actual distance is 50 feet, he will be closer to them than he thinks he is. It is for this reason that in any configuration of lights that may occur at a variety of airports, the distance between the elements should remain fixed.

Perspective Reversal - Another illusory perception that has been suggested as a cause of some aircraft accidents is perspective reversal (20). If only the outlines of a figure are visible against a dark background, it is possible for the figure to be perceived in more than one way. For example, the lighted edges of a runway viewed at an angle in darkness or fog can give rise to the illusion that the runway has reversed in depth, with the far end of the runway appearing closer than the near end. The illusion might become evident to the pilot only if he were to fly perpendicular to the runway, in which case the relative motion perspective between the near and far positions of the runway would cause the runway to appear to rotate in the direction of the aircraft's movement.

Inadequate Visibility during VFR Conditions - Meteorological conditions can exist in which the prevailing visibility may be reported as greater than VFR minimums but the actual visibility in a certain direction may be very low or below these minimums. A condition such as this was the apparent cause of an accident at Jacksonville, Florida in 1971 (21).

(20)

Howe, J. A. M. and Gregory, R. L. Visual perception in simulated space conditions. Journal of the British Interplanetary Society. 1968. 21:209-221.

(21)

Hedstrom, D.M. Recommendation for accident prevention. Jacksonville District Office, Florida. Department of Transportation, Federal Aviation Administration. 6 March 1972.

In this case sea fog was the responsible agent.

To determine visibility, various "markers" have been designated around reporting stations. Personnel at these stations observe the markers at specified times and report the visibility as a function of the contrast, clarity and detail of the target. Targets in use today are comprised of any number of arbitrary man-made objects such as apartment buildings, water towers, radio towers, outdoor movie screens, etc. These objects are typical examples of visibility targets and as such it seems obvious that this variety can do nothing but introduce an element of uncertainty into the reported visibility values. For example, an outdoor movie screen will certainly be more visible during daylight than radio towers at approximately the same distance.

Numerous airports are located in areas with no visibility markers in certain directions; Jacksonville, Florida is an example. East of Jacksonville is the Atlantic Ocean with the airport located very near the water. It is from this direction that the most critical weather approaches the airport. This is also the direction in which no visibility markers are located (21).

There appear to be at least two major problem areas associated with the use of visibility markers as currently defined. One is the wide variety of objects in use and the other is the lack of markers in all quadrants around airports which have an official weather observation service. These problems will be further addressed in later sections of this report.

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DISCUSSION

Development of Visual Aid System

Current Visual Aids - A number of visual aid systems are currently in use to aid the pilot in making landing approaches during periods of low visibility. Among these are the various VASI (Visual Approach Slope Indicator) systems and a multitude of approach light configurations. Currently the VASI systems seems to fulfill the requirements of most pilots; both instrument and non-instrument. These systems are simple in design and use and are very effective in aiding even the non-instrument pilot in making a properly executed landing approach during daylight and darkness. However, the VASI systems and approach lights are useful only during the landing approach. As a consequence, the pilot making a take-off at night or during periods of low visibility has no external visual aid or reference. His only recourse is to refer to his flight instruments; for a non-instrument rated pilot this is virtually impossible.

An attempt to alleviate the problem of no take-off reference has been approached at Lakefront Airport in New Orleans. Two search lights were positioned along side the departure runway and were directed up at what was determined to be a proper climb angle for most general aviation aircraft. During takeoff and departure the pilot could see the two search light beams; one on either side of his aircraft. His task during this phase of flight was merely to fly between the two beams of light. A visual aid system such as this depends entirely upon the presence of sufficient atmospheric moisture or dust to reflect light from the searchlight beam. It is also conceivable that a visual hazard might be introduced into an already critical situation. If a pilot were to inadvertently orient his aircraft such that he were able to look directly into the search lights, the results might well be flashblindness during a time when acute central vision would be most essential.

At night there is usually no "horizontal reference" or "ground plane" visible unless the expanse of a city is within visual range. When a city is thus utilized, the effect is to present the pilot with an essentially horizontal row of lights. During night flight, the non-instrument rated pilot is forced to rely upon these city lights and the lights visible over the country side for his horizontal reference. In both cases, the pilot must maintain a wing level attitude by reference to these lights.

Simulation Apparatus - An analysis of disorientation accidents indicates that entry into an "unusual attitude" probably precedes an actual crash resulting from spatial disorientation. An "unusual attitude" is defined as any aircraft attitude not required for normal flight operations. During training, the prospective pilot is usually introduced to recovery from unusual attitudes. Since these attitudes usually incorporated a rather steep bank, the pilot's instructions, depending on the actual

attitude of the aircraft, are first to stop the turn (22). To do this, the wings must be leveled. Final recovery is then made from this wing level attitude by reference to either the natural horizon or the aircraft instrumentation. This "level the wings" approach was chosen as the basis for the simulation experiments conducted by Technology Incorporated.

The device for the simulation tests was constructed with a slide projector mounted so as to rotate about its optical axis. During experimental sessions, the subject was presented slide projected views of the particular light array being tested. The slides were taken as if the camera were mounted on the cowling of the aircraft with the aircraft pointed directly at the light array and were presented randomly with regard to degree of tilt, altitude, approach angle and distance from the array. Each array condition was presented to the subject for a 3.5 sec. time interval with another slide immediately following. The subject's task was to move a joystick side-to-side in order to orient the array as nearly horizontal as possible on the screen within this time interval.

All array patterns were constructed of miniature incandescent lamps and photographed on color transparency or direct positive film for projection. Artist conceptions of the five geometrical patterns are shown in Figures 1 through 8.

A total of eight arrays and a large number of conditions were studied due to the fact that various altitudes, tilts (roll angle), distances from the array and approach angles were possible. In addition, tests of one of the circle arrays were conducted with three different array sizes. This large number of possible array conditions precluded any live flight tests at this time. In addition, a simulation allowed more control of the experimental parameters than would have been possible with live flight tests. It was felt that live flight tests would have also introduced the possibility of a serious accident into a flight condition which is known to have resulted in a number of fatalities. Consequently, it was felt to be unnecessary and dangerous to risk inflight interpretation of the light patterns until a more thorough knowledge of the cues obtainable from such patterns was available.

(22)

Federal Aviation Agency. Flight Training Handbook No. AC 61-21.
Washington, D. C. 143p. 1965.

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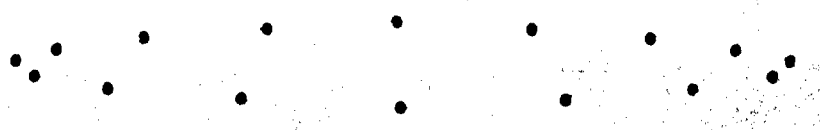


Figure 1. Sixteen light circle array: 1/2 mile diameter circle.
Seen from 2 miles at 900 ft. altitude.

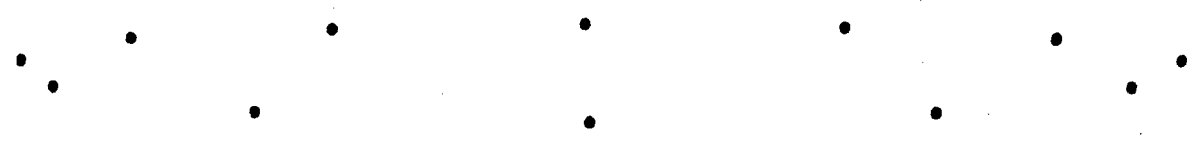


Figure 2. Twelve light circle array: 2/3 mile diameter circle.
Seen from 2 miles at 900 ft. altitude.

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Figure 3. Forty light grid: Approximately 2800 ft. long. Seen from 2 miles at 900 ft. altitude.



Figure 4. Four light square: Approximately 1970 ft. per side. Seen from 2 miles at 900 ft. altitude.

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Figure 5. Eight light circle array: Approximately 100 ft. per side. Seen from 2 miles at 900 ft. altitude.




Figure 6. Three light triangle: Approximately 1/2 mile per leg. Seen from 2 miles at 900 ft. altitude.

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Figure 7. Ten light single straight line. Approximately 1800 ft. long. Seen from 2 miles at 900 ft. altitude.

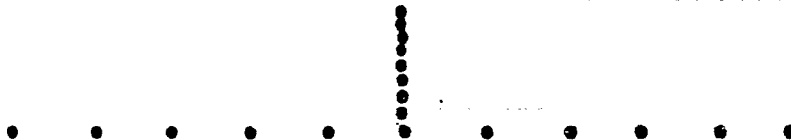


Figure 8. Eleven light "T". Approximately 2000 ft. per leg. Seen from 2 miles at 900 ft. altitude.

Experimental Approach - The approach taken by Technology Incorporated to develop a ground based visual aid system was centered on simplicity and safety. It was determined that the system must present completely unambiguous orientation information and be readily interpretable by even a novice pilot. In addition, the device had to be visible from take-off to at least pattern altitude. The principle of lights against a dark or featureless background was employed by Technology Incorporated to develop the proposed visual aid system.

Any number of ground-based light configurations were possible, therefore, five basic geometrical designs were utilized. These were a straight line, triangle, square, rectangle and circle. Two configurations of straight lines were used; these were a single line and a "T". The triangle, square and circle all may be considered circles with different numbers of light elements. One each equilateral triangle, square, octagon, twelve light circle and sixteen light circle were constructed and tested. Two rectangular configurations were investigated; one with lights around the perimeter only and one with a number of lights within the rectangle. Experimental parameters tested for the appropriate arrays are indicated in Table I.

A total of four subjects were utilized for the initial array selection tests. Each datum for the triangle and single straight line was composed of nine trials per array condition. Each datum for the square, octagon, sixteen light circle and "T" was composed of ten trials for each of these array conditions.

Subject scores consisted of the angle of the projected array as measured from horizontal. The difference between this angle and the true horizontal was measured and standard deviations of the absolute error in degrees were calculated and are presented in Table II. This procedure was consistent for all arrays tested by the subject panel. Data were initially obtained in this manner for six geometrical light patterns. These patterns consisted of a circle, octagon, square, "T", straight line and triangle.

An examination of these data shown in Table II revealed that of all the arrays tested, the 16 light circle showed the least overall variability among various conditions as judged by the standard deviations and mean absolute tilt error.

This information provided the basis for the continuing array tests which utilized a twelve light circle. These tests were later expanded to include a 40 light, filled rectangle. Nine subjects were utilized for the twelve light circle evaluation with a total of 25 trials for each array condition. The grid tests employed three subjects and six trials each for each array condition.

Table 1 .
Experimental Parameters for Simulated Arrays

	Circle (12 Light)		Circle (16 Light)	Octagon	Square	"T"	Line	Triangle	Grid
	2/3 mi. dia.	1/3 mi. dia.	1/2 mi. dia	1/2 mi.dia.	1970'/side	2000'/leg	1800'	1/2 mi./side	2800'x1600
Tilt (+ indicates counter-clockwise, - indicates clockwise)			X	X	X	X	X	X	X
	+25°		X	X	X	X	X	X	X
	+15°	X	X	X	X	X	X	X	X
	+5°	X							
	0°	X	X	X	X	X	X	X	X
	-10°	X	X	X	X	X	X	X	X
Distance	-15°								X
	-20°	X							
	-25°		X	X	X	X	X		X
	4 mi	X							
	2 mi	X	X	X	X	X	X	X	X
	1/2mi	X							X
Altitude	300'	X	X	X	X	X	X	X	X
	350'								
	200'	X							
	90°	X	X	X	X	X	X	X	X
	80°			X	X	X	X	X	X
	78-3/4°	X	X	X	X	X	X	X	X
Approach Angle	75°								
	67-1/2°								
	57-1/2°				X				X
	45°				X	X	X	X	X
	20°				X	X	X	X	X
	0°								X

Airport Hazard Evaluation

A number of airports are located in areas such that approach or departure routes are over large expanses of featureless, unlighted terrain or water. Takeoffs over such areas at night present little or no problem for the instrument rated pilot or for most VFR pilots as long as they are aware of the conditions. However, the transient pilot in particular may not be aware that such a disorientation potential exists, consequently his takeoff may be attempted entirely by outside visual references. If so, at some point in his climb-out, he will suddenly discover that he no longer has any outside references; he will then be forced to quickly transition to his instruments. For the inexperienced, unaware, or poorly trained pilot this may be impossible in time to prevent an accident. Flight operations in such areas during daylight hours do not present problems of the same magnitude as during night flight. If the weather conditions are such that VFR flight is possible, the chances of spatial disorientation are slight. However, disorientation during daylight hours is a genuine hazard when the VFR pilot flies into instrument flight weather conditions. This occurrence was not considered in the present contract effort.

At night over sparsely populated areas the pilot can, during periods of transient disorientation, mistake the occasional ground lights for stars. This condition is usually found enroute but may occur during departure maneuvers. The statements did not require any enroute or area evaluation. It is possible with the procedure developed by Technology Incorporated.

The approach to disorientation hazard evaluation chosen by Technology Incorporated was based on the idea that a pilot must have ground detail or a natural horizon in his field of view in order to maintain his aircraft in a wing-level attitude. Detection of these features basically depends upon the contrast of the scene during daylight hours. During periods of overcast, haze, smoke, etc., this contrast is reduced with the possible result of totally obscuring the natural horizon. However, as long as the obscuring medium does not reduce visibility below VFR minimum, the chances of disorientation are slight.

Departures in different directions from the same airport can and usually do present different landscape views to the pilot. At night on these different departures the pilot may have an infinite variety of orientation references ranging from the lights of a nearby large city to no lights at all. These departures will then present different potentials for spatial disorientation depending on the number and spatial arrangements of the lights in the pilots field of view. The most pertinent parameter for night flight, then, is some minimum number of ground

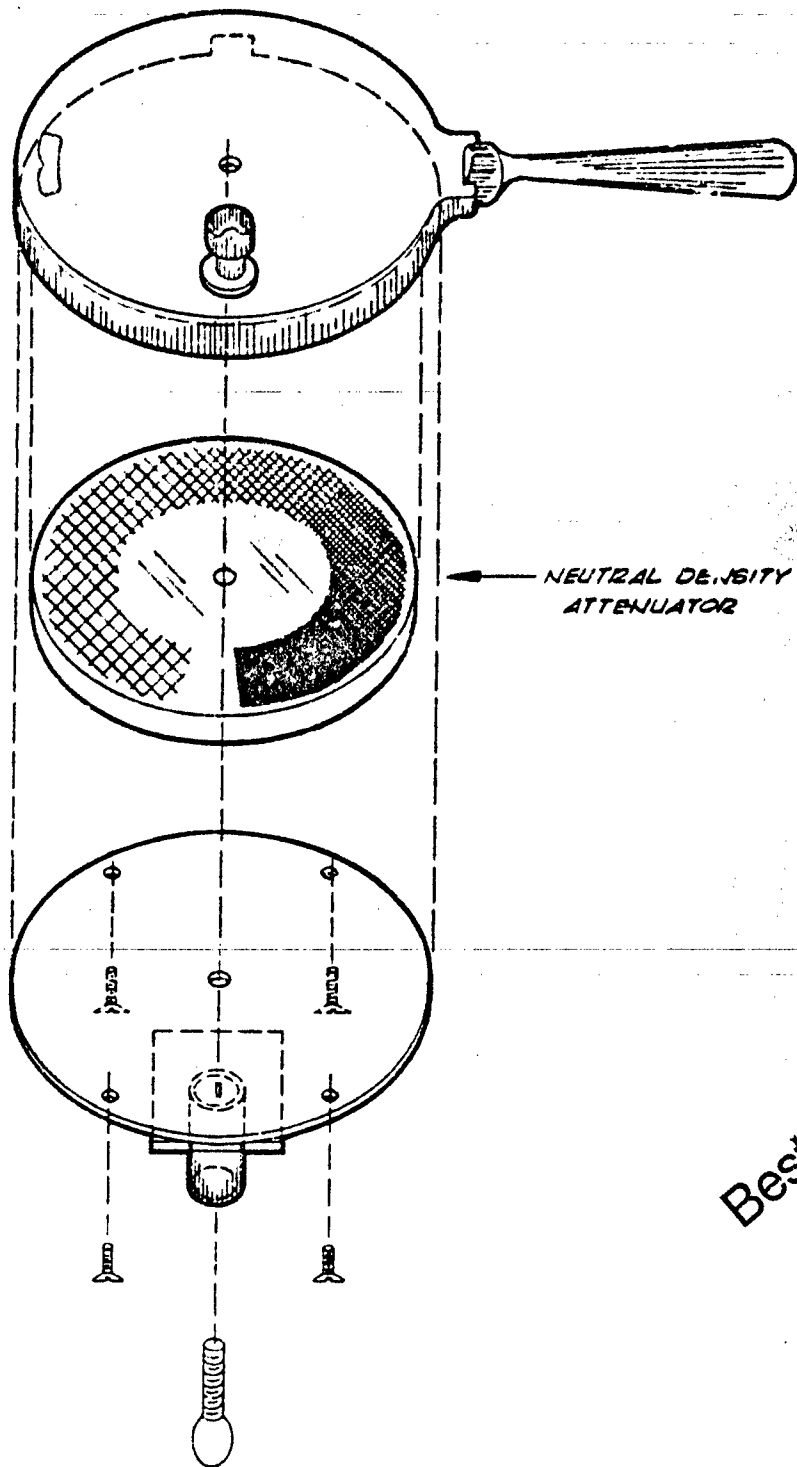
lights that will provide adequate horizontal reference cues. Consequently, Technology Incorporated has constructed a device which allows a person to make an assessment of the possible dis-orientation hazard associated with night flight and night take-offs and landings.

The device utilized by Technology Incorporated and designated a "Visibility Meter", operates on the principle of luminance reduction and thereby raises the contrast threshold when the luminance is low. The net effect is an apparent reduction of contrast along with the decreased luminance. The visibility meter is basically a continuously graded neutral density wedge. The wedge was produced by the Eastman Kodak Company and is mounted between two optically flat glass discs. Mounted on one side of the glass discs is a 360° protractor scale; zero on the scale corresponds to the most transparent portion of the wedge. The scale is rotated 90° to the wedge such that the sighting is made through the left side of the instrument but the value from the scale is read at the top of the device. The wedge is contained within a flat metal case with a wing-nut protruding from the front. An opening is milled into the right side of the case through which the edge of the wedge disc protrudes. The entire device is mounted on a handle by which it is held close to the operator's face. To eliminate stray light interference, a dark cloth can be draped over the operator's head and instrument. An exploded view of the device is shown in Figure 9.

Field use of the Visibility Meter must be preceded by a period of practice; this is necessary to assure reasonably consistent results under field conditions. Instructions for use of the device during practice and in the field are identical and are listed below:

1. Adjust meter to "0".
2. Sight scene to be evaluated through viewing slit. As soon as the scene is located, have a companion start timing an interval of 10 sec. (See Note)
3. During the 10 seconds progressively darken the scene by rotating the glass disk protruding from the right edge of the device. When the scene can no longer be distinguished, rotate the disc in the opposite direction. Stop this movement when the scene is barely visible. With practice this darken-lighten process can be repeated

NOTE: chosen to limit the observer's dark adaptation and to give sufficient time to adjust meter.



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Figure 3. Exploded view of the Visibility Meter

several times within the 10 sec. interval. Each darken-lighten repetition should consist of progressively smaller movements of the wedge disk.

4. At the end of the 10 sec. interval, complete the disk adjustment in progress (if any) and read the value in the window at the top of the device.

A number of field trials were conducted with the Visibility Meter in order to determine the operational capabilities of the device. Data were taken at San Antonio International Airport; Mustang Beach, north-east of Corpus Christi on Mustang Island; and Cotulla, Texas. These data were plotted on polar coordinate graph paper about the runway heading. Eight observations were made about each airport from a pattern altitude of 800 feet above the ground. The data thus collected are shown graphically in Figures 10, 11 and 12.

The numbers plotted do not represent any linear measure of visibility; rather they represent an arbitrary assessment of the ease or difficulty of being able to distinguish a natural earth-sky horizon or a ground light horizon. The visibility meter values are directly proportional to the apparent horizon visibility. In other words, the higher the visibility meter values the better the visibility of the horizon. A value of "0" would indicate absolutely no horizon contrast and would indicate the presence of a condition conducive to a very high probability of disorientation.

Visibility Markers

The National Weather Service is currently responsible for determining and reporting horizontal visibility to the aviation community. To accomplish this, a person must make a judgment as to the clarity of certain specified objects as seen through the prevailing atmosphere. These objects are termed Visibility Markers and are identified as dark or nearly dark objects when viewed against the horizon sky during the day. At night unfocused lights of moderate intensity (about 25 cd) are used (23).

When visibility around the horizon circle is greater than the distance to the farthest markers, the greatest distance that can be seen in each direction is estimated. This estimation is based on the appearance of the markers. If the markers are visible with sharp outlines and little

(23)

U. S. Department of Commerce. Federal Meteorological Handbook No. 1. Surface Observations. Revision No. 2: 1 January 1972.

blurring of color, the visibility is greater than the distance to the marker. If the marker can barely be seen and identified, the visibility is about the same as the distance to that marker (23).

Investigation has revealed that the visibility markers in use today are a heterogenous mixture of almost any man-made object. Due to the placement of such objects there can often be rather large gaps in reported visibilities. For instance, one observation station has established a hospital at 7-1/2 miles and a water tower at 13 miles. The water tower is the only object at this distance, consequently the visibility if over a few miles in any other quadrant can only be estimated.

In order to obtain a range of reasonably good visibility measurements, a number of objects at different distances are required. As visibility decreases, the objects tend to become more diffuse and grayer. Logically, then, a small dark object could be seen less clearly than a large dark object. Using this premise, Technology Incorporated designed the type of visibility marker shown in Test Results.

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TEST RESULTS

Visual Aid System

Results of the initial array elimination phase are shown in Table II. All of these arrays were tested at a simulated two miles and at an altitude of 900 feet. Due to the geometry of the array, the approach angles were different. For instance, the square could be viewed with two of the perimeter lights forming a straight line perpendicular to the visual path of the observer. This was called the 90° approach angle. The same term was applied to all other approaches when the arrays were oriented such that two perimeter lights formed a straight line perpendicular to the observer's line of sight. Again using the square as an example; the same geometry could be seen to repeat itself every 90° about the figure; every 90° a square or diamond would be seen so the three approach angles chosen for this figure were 90° (seen as square), 45° (seen as a diamond), and $57\text{-}1/2^\circ$. This same logic was followed for determining all other approach angles for the other arrays.

In terms of overall variability, the arrays are ordered from the greatest to the least in Table II. Generally, single line arrays (square, T, line, triangle) proved to be confusing because of their changing appearance as a person moved about the array. However, as the number of lights in the array was increased to 8 (octagon) and 16 (circle) the overall variability was rather markedly decreased. The overall variability is stressed here because of the possibility that a pilot may see the array from any approach angle, consequently the array that produces the least overall variability is the most desirable. This initial test phase demonstrated the fact that of the arrays investigated, the circle proved to be easier to interpret and to align horizontally than any other geometrical configuration of lights. These results lead to the second test phase in which a 12 light circle was intensively researched. The object of this phase was to define as many operational characteristics of the circle array as possible. In addition, a 40 light rectangular grid was also investigated. Many airports are closely surrounded by cities which present to the pilot a grid system made up primarily of street lights. The pilot's response to such an "artificial city" was the objective of this particular research phase.

Reference to Table III and IV reveals that the overall subject variability in response to the 12 light circle and rectangle is virtually identical and also virtually identical to the 16 light circle. Even so,

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TABLE II
COMPARISON OF LIGHT ARRAYS AT VARIOUS
HORIZONTAL ANGLES OF APPROACH

Array						Overall Variability
4 light square	approach	∠	90°	57½°	45°	
		s	2.085	1.942	10.988	7.592
		\bar{x}	2.020	2.060	10.300	4.796
10 light line	approach	∠	90°	45°	20°	
		s	3.541	4.974	6.958	6.653
		\bar{x}	2.389	8.778	12.000	7.722
20 light "T"	approach	∠	90°	45°	20°	
		s	0.866	5.280	7.410	5.847
		\bar{x}	0.840	4.960	7.060	4.287
3 light triangle	approach	∠	90°	45°	20°	
		s	5.458	5.524	3.238	4.727
		\bar{x}	3.537	3.981	2.925	3.481
8 light octagon	approach	∠	90°	80°	67½°	
		s	1.071	2.594	0.856	1.729
		\bar{x}	1.580	2.260	1.320	1.720
16 light circle	approach	∠	90°	78-3/4°		
		s	1.182	1.469		1.329
		\bar{x}	1.520	1.380		1.450

approach ∠ - The ground-plane angle from which the array is viewed

s - Standard deviation of the absolute tilt error

\bar{x} - Mean of absolute tilt error (measured in degrees)

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SUMMARY DATA FOR 12 LIGHT CIRCLE
 TABLE III
 Top Numbers = standard deviation of absolute tilt errors (degrees)
 Lower Numbers = mean of absolute tilt errors (degrees)

	Circle Diameter			Altitude		Distance to Circle				Approach Angle		TOTAL
	1/6 mi.	1/3 mi.	2/3 mi.	200 ft.	900 ft.	1/2 mi.	2 mi.	4 mi.	90°	75°		
Circle Diameter												
	1.164	1.353	1.283	1.059	1.369	1.389	1.314	1.043	1.247	1.355	1.283	1.279
	1.113	1.352	1.283	1.060	1.479	1.356	1.380	1.100	1.300	1.145	1.279	1.279
	1.113	1.352	1.283	1.109	2.010	2.322	0.895	0.920	1.529	1.920	1.641	1.641
	1.124	1.615		1.124	1.615	2.192	0.980	0.930	1.295	1.204	1.369	1.369
Altitude												
	1.113	1.059	1.109			1.230	1.007	1.056	1.135	0.975	1.015	1.015
	1.352	1.060	1.124			1.308	1.096	1.132	1.219	1.146	1.179	1.179
	1.214	1.369	2.010			2.070	1.194	1.183	1.423	1.705	1.577	1.577
	1.353	1.479	1.615			1.967	1.316	1.183	1.414	1.563	1.488	1.488
Distance to Circle												
	1.088	1.389	2.322	1.230	2.070				1.602	1.905	1.760	1.760
	1.358	1.356	2.192	1.308	1.967				1.568	1.641	1.605	1.605
	1.079	1.314	0.895	1.007	1.194				1.125	1.059	1.092	1.092
	1.258	1.380	0.980	1.096	1.316				1.205	1.207	1.205	1.205
	1.305	1.043	0.920	1.056	1.183				1.094	1.147	1.121	1.121
	1.442	1.100	0.930	1.132	1.183				1.176	1.139	1.157	1.157
	1.412	1.247	1.529	1.135	1.423	1.602	1.125	1.094			1.291	1.291
	1.351	1.300	1.295	1.219	1.414	1.568	1.205	1.176			1.316	1.316
	1.113	1.355	1.920	0.975	1.705	1.905	1.059	1.147			1.404	1.404
	1.355	1.145	1.204	1.146	1.563	1.641	1.207	1.139			1.354	1.354
	1.164	1.283	1.641	1.015	1.577	1.760	1.092	1.121	1.291	1.404	1.354	1.354
	1.353	1.279	1.369	1.179	1.488	1.605	1.205	1.157	1.316	1.354	1.316	1.316
TOTAL												

TABLE IV

SUMMARY DATA FOR 40 LIGHT RECTANGLE

Top Numbers = standard deviation of absolute tilt errors (degrees)
 Lower Numbers = mean of absolute tilt errors (degrees)

Distance	Approach Angle			Tilt			TOTAL
	0°	45°	57 1/2°	90°	Left Turn Bank	Level	
1/2 mi.				90°	++	0	--
	0.615	1.195	1.737	0.924	1.603	1.517	0.955
	1.222	1.333	2.111	1.375	1.750	2.042	1.292
2 mi				0.963	1.251	1.640	1.640
	1.375	0.881	1.727	1.333	2.000	1.417	1.631
	1.800	1.083	2.125		1.751	1.723	0.577
0°					2.750	1.167	1.850
	1.222	1.800			0.853	1.403	0.793
45°					1.000	1.833	0.917
	1.195	0.881			1.379	2.234	2.106
	1.333	1.083			2.417	2.583	1.667
57 1/2°					0.894	1.073	0.718
	1.737	1.727			2.000	1.333	0.833
	2.111	2.125					
90°							
	0.924	0.963					
	1.375	1.333					
	1.603	1.251	1.751	0.853	1.379	0.894	
Left Turn Bank	1.750	2.000	2.750	1.003	2.417	2.000	
	1.243	1.110	0.623	0.953	1.477	0.632	
	1.389	2.056	2.300	1.000	2.000	2.000	
Level	1.517	1.640	1.723	1.403	2.234	1.073	
	2.046	1.417	1.167	1.833	2.583	1.333	
Right Turn Bank	0.944	1.245	1.191	0.793	1.303	0.718	
	1.250	1.375	1.850	0.917	1.667	0.833	
	0.955	1.640	0.577	1.165	2.109	0.866	
	1.292	1.417	0.850	1.417	1.917	1.250	
TOTAL	1.256	1.422	1.268	1.641	1.718	0.956	1.345
	1.524	1.631	1.583	1.233	2.117	1.354	1.354
					1.210	1.594	1.095
					1.722	1.729	1.313
							1.382
							1.652

a careful study of these tables shows that the overall variability for the approach angles to the rectangle covers a larger range than the variability for approach angles to the circle (0.96 - 1.72 as compared to 1.29 - 1.40). This alone argues in favor of the circle as an orientation array. However, further reasons for the circle are that fewer lights would be required and that it would occupy less land.

Further study of Table III will show that within the experimental matrix the variability is at its lowest when a $2/3$ mile diameter circle is seen from a distance of 2 miles and highest when that circle is seen from $1/2$ mile. The altitude and approach angle shows some variability but not to the extent seen in the distance to circle-circle diameter comparison. A study of these data indicate that the approach angle and altitude up to and including 900 feet are not critical for this array.

When seen from two miles and up to and including 900 feet above ground level, all circles presented a flat ellipse to the pilot with the long axis oriented horizontally. The geometry of the array remained virtually identical regardless of the viewing angle. This was not the case with any other pattern tested. From four miles, the circle appeared to be a straight line regardless of the viewing angle and altitude up to and including 900 feet AGL.

In addition to the wing level indication, it is possible that, with practice, a pilot could perceive altitude information from the circle. This additional information is due to changes in the perceived thickness and shape of the ellipse as the pilot changes his altitude and consequently his vertical viewing angle. The same information could be obtained from any closed sided geometrical figure but only the circle allows both horizontal and altitude orientation from any point about the array.

Airport Hazard Evaluation

Field trials with the Visibility Meter have shown that it may have little if any applicability to daylight scenes. This is due primarily to the great range of brightness possible during these hours. The horizon can be obscured by the device but to do so during VFR flight conditions is virtually meaningless because the pilot has very little chance of disorientation when visual flight rules are in effect. He can in practically all cases distinguish an earth-sky horizon or sufficient ground features to maintain the aircraft relatively roll free.

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Night trails have shown the approximate correlations listed in Table V. Visibility Meter values were not correlated with actual visibility observations because the two are basically different (where meteorological visibility is distance, in miles, at which an arbitrary object can be seen, the Visibility Meter assigns an arbitrary value to horizon visibility as a function of brightness and contrast). The seemingly subjective assessments listed in Table V appear to be entirely appropriate and are simply based on whether enough lights were visible on the ground or the horizon to maintain a horizontal reference.

Table V was assembled in order to quantify the visibility meter values. This was done by correlating these values with actual observed visibility and a subjective assessment of the degree of disorientation hazard for that flight situation. The "Assessment of Horizon Visibility" (Column 2, Table V) was made from actual in-flight observations. Visibility meter values (Column 1, Table V) were also obtained at the same time as the visual assessments or within a few minutes of the visual assessments.

Figures 10, 11, and 12 show results of the evaluation of three distinctly different airport environments. Disorientation at San Antonio International Airport is very unlikely but is definitely more of a probability when departing in the northern circle segment bounded by 300° to the west and 80° to the east. To the south, the major portion of San Antonio is visible and disorientation due to loss of the horizon is virtually impossible. Even to the north, disorientation at this airport is unlikely because a slight turn will bring more lights into view. Due to the mass of lights in the San Antonio area, all data shown in Figure 10 were collected with a neutral density attenuator inserted into the Visibility Meter in addition to the neutral density wedge. This was necessary because even the darkest portion of the wedge would not obscure the mass of lights toward downtown San Antonio, thus indicating the need for more attenuation.

Disorientation at Cotulla (Figure 11) is more of a probability than at San Antonio. However, on a clear night, as long as the pilot is attentive to the few lights that are visible, he is not likely to become disoriented. The most hazardous direction of take-off here is toward the southeast. In this direction, a turn of approximately 45° to 90° would be necessary to see Cotulla and an even greater turn would be necessary to see the lights of San Antonio

TABLE IV
 VISIBILITY METER
 EVALUATION RESULTS

Visibility Meter* Value	Assessment of Horizon Visibility	Assessment of Disorientation Hazard
0 - 50	No horizon visible; no moonlight; no ground lights	Very high probability of disorientation
50 - 100	Few randomly scattered lights on horizon -- could be momentarily mistaken for stars	Disorientation probable but not likely as long as pilot is attentive to attitude of aircraft
100 - 200	Light of small towns or cities or horizon or larger towns (Austin, San Antonio) over horizon	Disorientation unlikely
200 - 300	Large expanse of lights in visual field very close to town or city	Disorientation due to loss of horizon virtually impossible

*These limits are not intended to be absolute but may serve as a guide to interpretation of the values obtained with the Visibility Meter.

which are, at pattern altitude, over the horizon. No additional light attenuation was used at this location due to the dimness and arceness of the available lights.

Evaluation of the Mustang Beach Airport proved to demonstrate a condition conducive to a high potential for disorientation. Take-off toward the southeast (over water) presents the pilot with absolutely no horizontal reference. A turn of at least 45° in either direction is necessary to pick up any useful horizon information. Execution of this turn by an inexperienced or unaware pilot could easily lead to an unusual altitude from which recovery at low altitude would be impossible. Take-off in the northwest half of the horizon circle presents no problem unless at VFR minimums. Take-off in this direction is over a shallow bay, the shore of which could be obscured by some atmospheric conditions. The additional light attenuator was used at this station because of the brightness of the lights of Corpus Christi.

Visibility Markers

A study of the method of determining horizontal visibility has shown that a requirement exists for a more objective method of determining this weather parameter.

The study conducted by Technology Incorporated has resulted in the tentative design of a potential visibility target and is shown in Figure 13. No dimensions were ascertained due to the limited time available for this work. The target is designed to be placed a fixed distance from the observation point. As the visibility worsens, the smaller shaft and blocks will be gradually obscured. The smallest square which can be seen should then give an indication of the visibility providing that a careful calibration has been performed.

Visibility at night may be determined by installing an unfocused lamp of desired brightness on top of the target. The lamp may then be wired back to the observation point and the brightness controlled by a potentiometer operated by the observer. The dial of the "pot" may be calibrated, thus allowing the observer to read the visibility directly when the lamp is adjusted to the visual threshold of the observer.

A second method of determining night visibility is to floodlight the target. The visibility could then be determined in the same manner as during the daylight hours.

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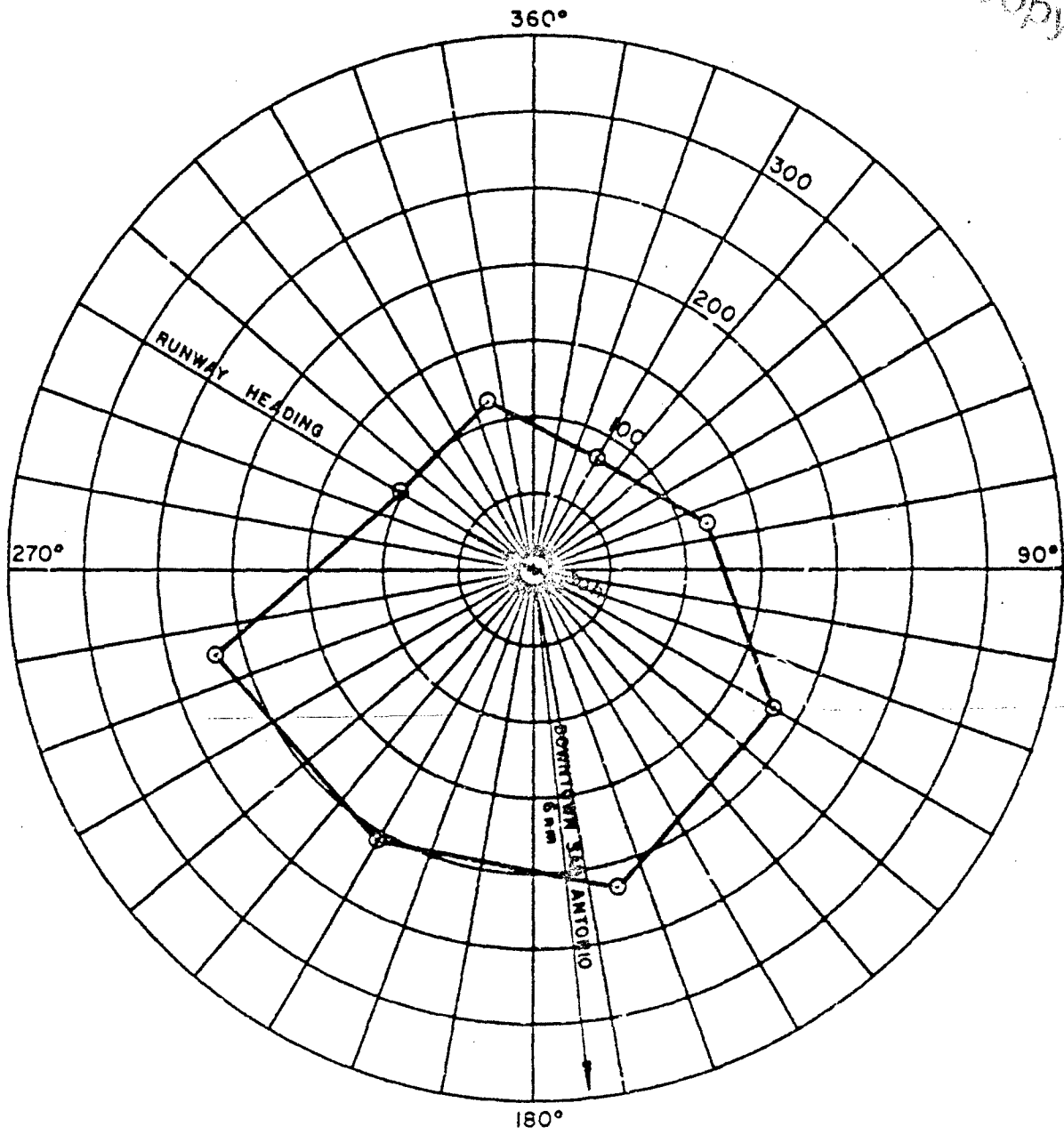
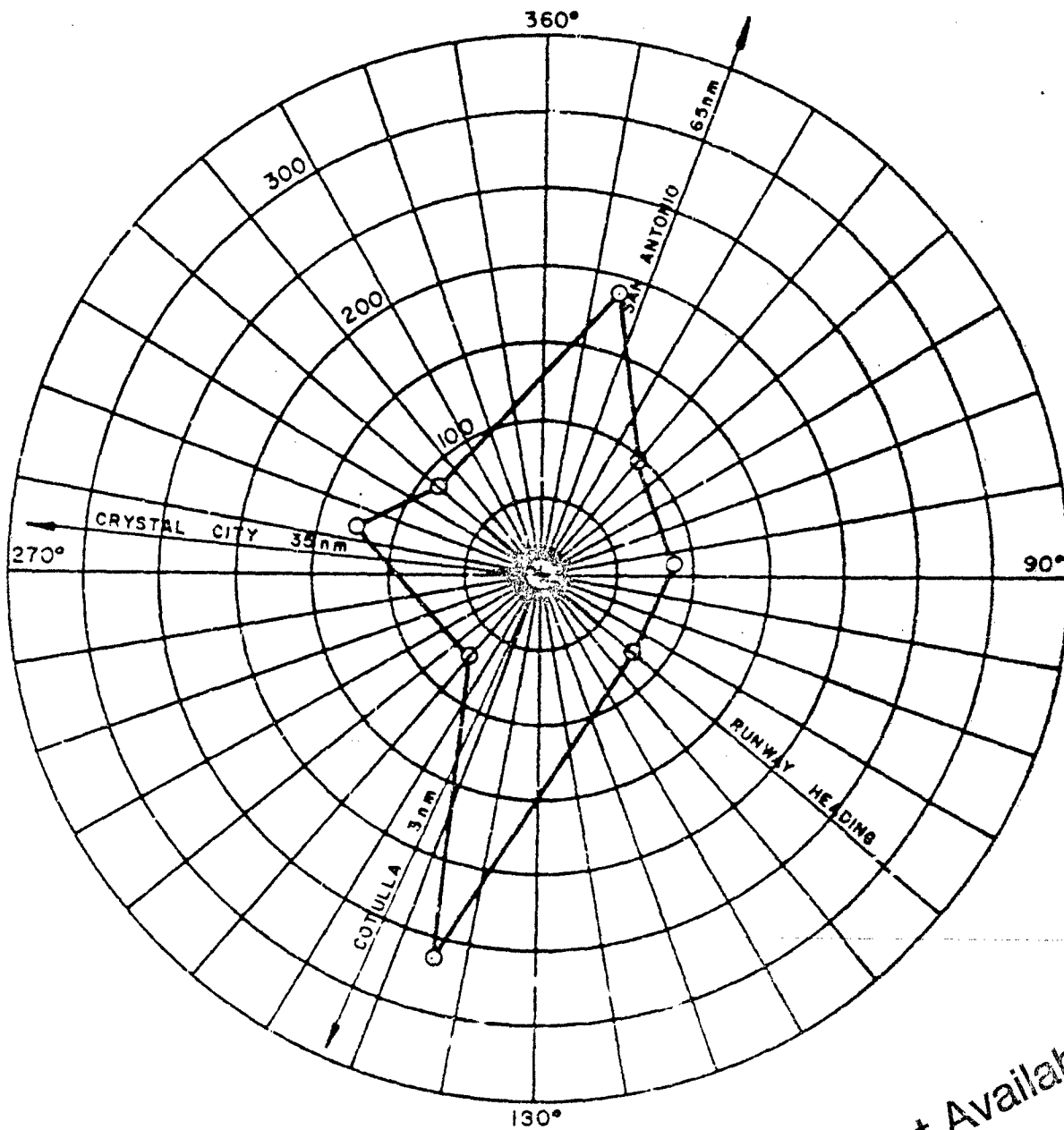


Figure 10. Visibility Meter evaluation of San Antonio International Airport, 26 December 1972, 1900 Hrs. Concentric circles indicate visibility meter values.



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Figure 11. Visibility Meter evaluation of Cotulla Airport, 26 December 1972, 1900 Hrs. Concentric circles indicate visibility meter values.

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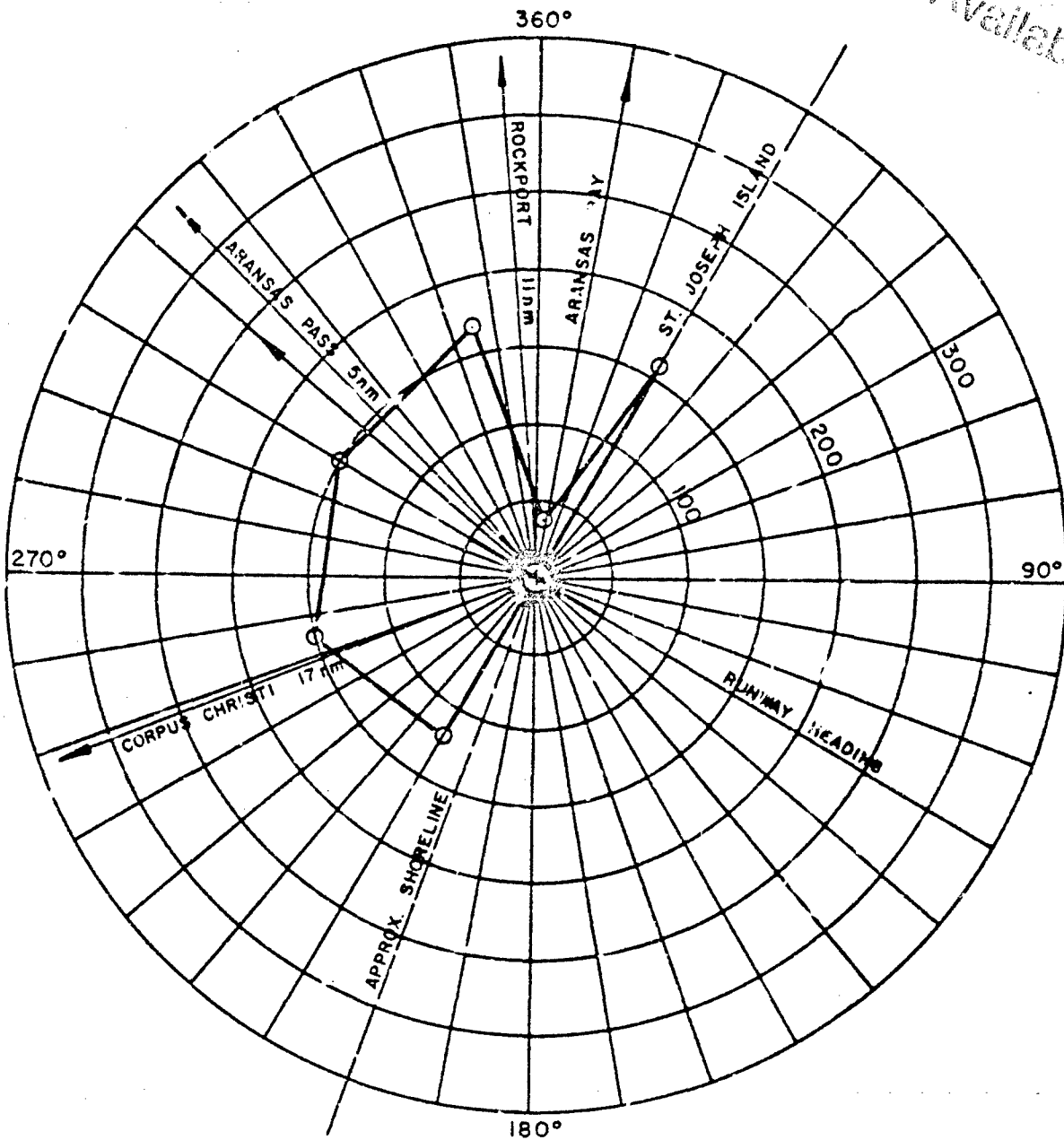


Figure 12. Visibility Meter evaluation of Mustang Beach Airport. 3 January 1973, 2000 Hrs. Concentric circles indicate visibility meter values.

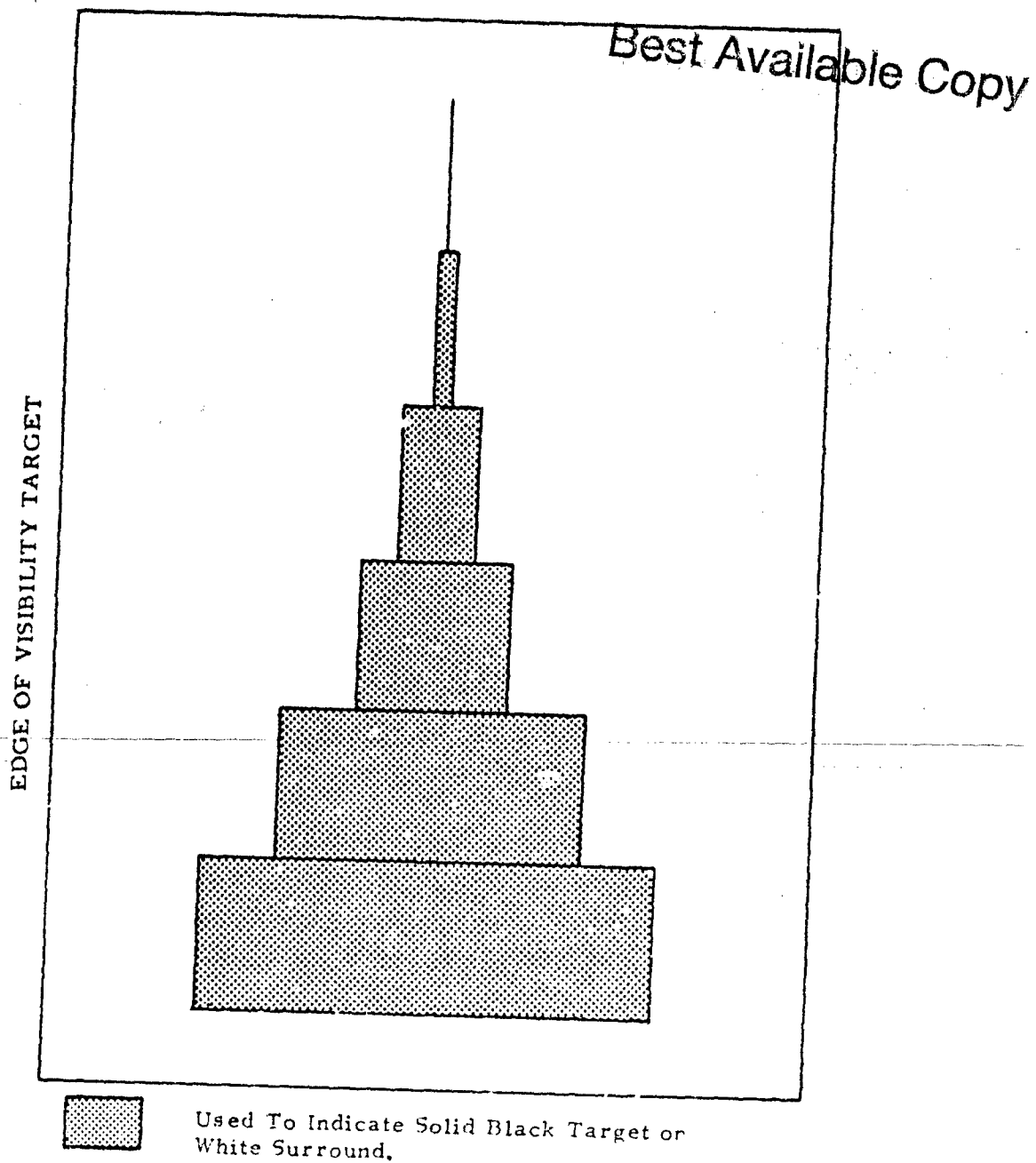


Figure 13- Tentative Visibility Marker Design.
Marker Dimensions have not yet been determined.

There are meteorological conditions in which these measurement techniques will not be useful. These conditions have not yet been determined but probably will include heavy fog, rain and snow. During these conditions, the targets will not be visible regardless of their size or contrast. Such conditions will probably necessitate use of alternative targets much like those in use today.

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CONCLUSIONS

Visual Aid System

Simulation experiments conducted by Technology Incorporated have shown that circle can provide a pilot sufficient information to maintain a wing-level altitude. Circles of three different diameters were investigated at two altitudes, three distances from the observer and five aircraft tilt (roll) angles. The simulator used in this work did not have completely desired "realism" but was felt to be sufficient under the contract limitation of funds.

Results obtained with this simulator indicate that a ground-based light array should be placed two miles from the end of the runway and one half to one mile from the centerline of the runway. This array should be 2/3 mile in diameter and should be composed of 12 lights spaced at 30° intervals about the circle.

The next step in the development of a ground-based light array would seem to be construction and deployment of such a system. However, it is felt that this alone would not serve to demonstrate the degree of effectiveness of this concept. While the ground based lights might prove to be better than nothing in a desolate area, installation of such arrays will not be feasible for many of the problem sites due to terrain conditions. The alternative to a ground system is use of aircraft instrumentation. Technology Incorporated believes that the probable solution to the problem of spatial disorientation is not a ground based visual aid although development of such a system was the contract goal.

Airport Hazard Evaluation

The method of airport hazard evaluation developed by Technology Incorporated appears to be adequate provided some logical judgement is exercised by the observer. The particular device designed and shown in Figure 9 is not intended to be a final deliverable item. Its sole function was to demonstrate the practicality of this approach to disorientation hazard evaluation.

A scale of 0 through 360 was arbitrarily chosen but 0 through 10 or 100 might be more applicable to a field instrument. Also, it is thought that a neutral density step wedge with perhaps ten discrete steps might be easier to operate and provide more consistent results than the continuously graded wedge used in the present device.

Visibility Markers

Technology Incorporated feels that the use of current visibility markers for the determination of meteorological visibility should be subjected to close scrutiny. The markers currently in use are not uniform in size or appearance and are usually poorly spaced about the observation station. It is felt that identical visibility targets should be designed and uniformly spaced about the station.

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30721