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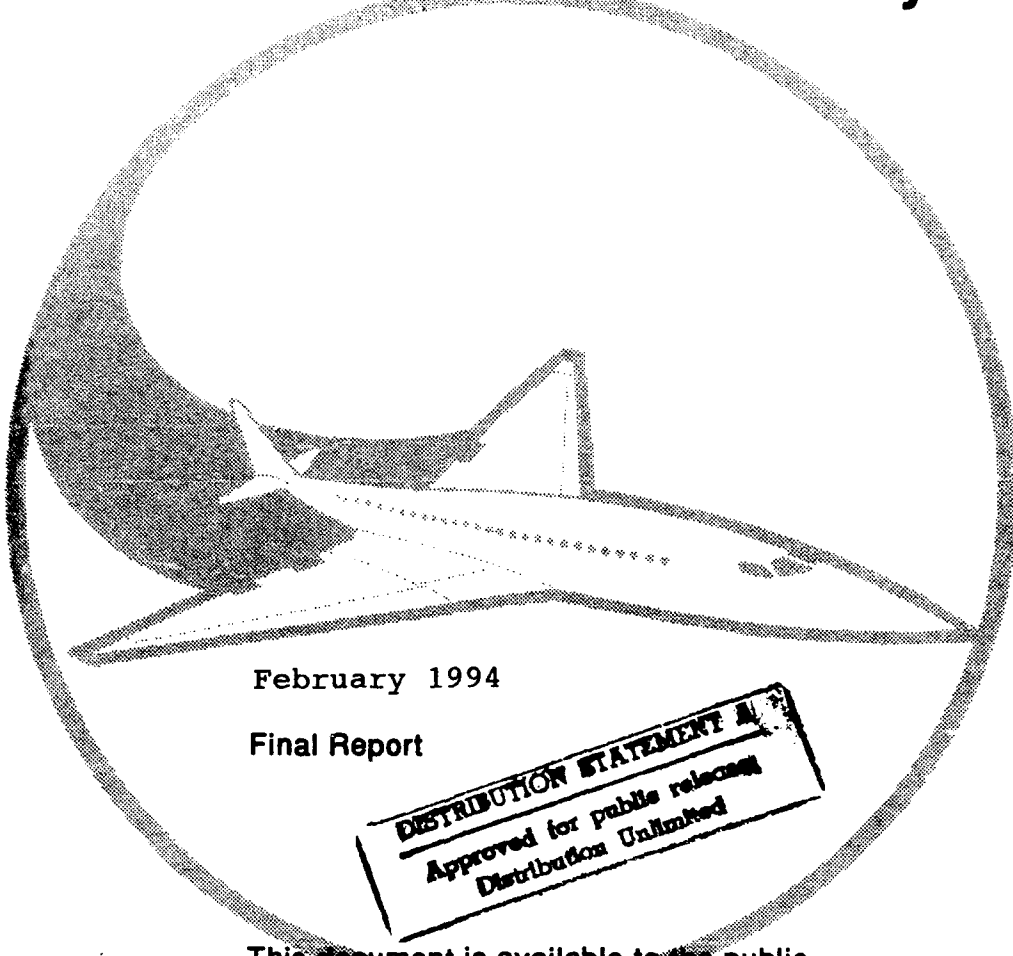
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DOT/FAA/CT-93/49

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Research Requirements for Future Visual Guidance Systems



February 1994

Final Report

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PREFACE

The authors wish to acknowledge all those who contributed to this report-- directly and indirectly. Specific thanks are due to the Aviation Lighting Committee of the Illuminating Engineering Society and the staff of the Federal Aviation Administration (FAA) Technical Center Library for their assistance in locating significant visual guidance documents.

This report was prepared for the Visual Guidance Section, Airport Technology Branch at the FAA Technical Center whose efforts are at the forefront of visual guidance research in this country.

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EXECUTIVE SUMMARY

Airport visual aids provide essential information to pilots to facilitate their tasks of taking off, landing, and maneuvering the aircraft on the airport surfaces. Visual cues are the essential means used to orient the pilot to earth. The visual aids that are currently used have been developed continuously throughout the history of aviation.

New technology applications are needed to provide better visual guidance for the pilot, thus enhancing safety and facilitating operations. Application of state-of-the-art technology can significantly improve the design and performance of the lighting, marking, and signage visual aids that provide the pilots with essential air and ground movement guidance.

This study was undertaken to identify deficiencies in existing visual guidance systems and to forecast or project needs of the future. It also describes possible applications of new technology for resolving existing deficiencies and developing state-of-the-art visual guidance systems of the future.

The following procedures were used: survey of literature, survey of existing visual guidance systems, pilot questionnaires, interviews with users, manufacturers and university researchers, and analysis of present and future requirements for visual guidance.

The study report identifies a number of potential research areas and new technologies of potential benefit to visual guidance. The recommended research areas are grouped by category according to phase of operation. The areas recommended for research include Approach and Landing Systems, Surface Guidance Systems, and Control and Monitoring Systems. Also included are State-of-the-Art Advances in areas recommended for specific incorporation into visual guidance programs.

1. INTRODUCTION

A safe and dependable air transportation system is directly related to the quality of supporting airport systems. Airport visual guidance systems are among the most important of the facilities on the airport, since these provide the visual cues necessary to maneuver the airplanes on the ground and in the air.

The air transportation system of the United States of America operates safely and reliably around the clock and in all types of weather. Such operations are greatly dependent upon the quality of visual guidance systems that have evolved over the years. Pilots making approaches require guidance in identifying runway orientation, threshold location, and centerline direction. While on the ground they require additional visual cues for safe taxiing operations. Operations at night and during periods of low visibility tax the resources of airline and general aviation pilots alike. Visual guidance systems are composed of a variety of elements: to include lighted aids, painted markings, signs, and the necessary power and control devices.

Recent rapid development of the air transportation system has placed increased demands upon the supporting facilities of the airport itself. Air traffic has increased dramatically with the advent of deregulation, and public demands have resulted in a need for virtually all-weather operations. Years ago, operations in certain restricted visibilities would have been unthinkable. Today, new technologies permit aircraft takeoffs and landings in very low visibilities. This has stimulated the need for improvements in the ground guidance systems to prevent airplane conflicts on the airport surface as well as in the air. New technology applications are also needed to provide better visual guidance to the pilot and thus enhance safety and facilitate operations. Application of state-of-the-Art technology can significantly improve the design and performance of the lighting, marking, and signage visual aids that provide the pilots with essential ground movement guidance.

Future research must take advantage of the latest technology advantages to insure that current concepts for design, equipment, and components are incorporated into visual guidance systems. This report attempts to provide current information that will assist in this effort.

2. AIRPORT VISUAL AIDS

2.1 PURPOSE OF THE STUDY.

The study is designed to identify future requirements for developmental research in airport visual guidance systems. It identifies areas for potential research, development, test, and evaluation work that will assist in the ultimate improvement of visual guidance systems and aviation safety.

2.2 OBJECTIVES.

The objectives of this study are to:

- . Identify existing problems in visual guidance:

Existing visual guidance systems have undergone modification and change over years of use. In some instances, however, they still exhibit deficiencies that require correction to attain optimum performance. These "problem areas" must be identified, and the need for corrective measures established. The problem areas and needs are identified by various techniques, weighed by relative merit and impact on safety and operational effectiveness, and assessed for desirability and technological risk factors.

- . Discover potential future requirements:

The identification of future requirements anticipates new technology developments in aircraft, avionics, and operational procedures which, in turn, generate the need for development and/or enhancement of visual aids. State-of-the-Art advances in the field of visual guidance must be recognized, so that they may be applied to the improvement of existing visual aid systems and to the fulfillment of requirements for new and unique systems.

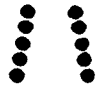


- . Identify Research Areas for resolution of problems:

A systematic approach is necessary to facilitate the development of recommendations, which may then be grouped into work areas for ease of management.

2.3 BACKGROUND.

Visual guidance aids provide information that a pilot needs for various purposes; to locate the airport itself, and to identify runway location, runway and taxiway edges, thresholds, centerlines of runways and taxiways, visual glide paths, and position on the airport, to name but a few. Airport visual aids provide this information in a variety of ways; through lighting aids, marking aids, and signs, in addition to numerous other miscellaneous aids. Table 2.1 depicts the various types of visual aids available to the pilot. Individual aids are discussed in greater detail in the following paragraphs.

TABLE 2.1 VISUAL AIDS - LIGHTING AIDS, MARKING AIDS, SIGNS, OTHER AIDS

			
CATEGORY	LIGHTING	MARKING	SIGNS
RUNWAY	EDGE	EDGE	DISTANCE-TO-GO
"	CENTERLINE	CENTERLINE	
"	TOUCHDOWN	FIXED DISTANCE	
"	THRESHOLD		
"	END		
TAXIWAY	EDGE	EDGE	DESTINATION
"	CENTERLINE	CENTERLINE	LOCATION
"	R/W ENTRANCE	R/W ENTRANCE	MANDATORY HOLD
"	R/W EXIT	R/W EXIT	ILS
OTHER	OBSTRUCTION	OBSTRUCTION	
"	APPROACH		
"	PAPI/VASI		
"	WIND CONES		
"	BEACONS		
"		POWERLINE BALL MARKERS	

2.3.1 Lighting Aids.

Aviation ground lights were among the earliest of visual aids used by aviators. Use of signal lights probably goes back to the days of the cave man, as light from fires was used to communicate information between locations. The first use of lights to illuminate runways was very likely makeshift, and undoubtedly involved the use of flare pots or automobile headlights to illuminate early unlighted landing strips. In the mid-1940's the Civil Aeronautics Administration (CAA) sponsored research into lighting improvements, performing work at the Newark, New Jersey airport (reference 1). Additional work was performed at other locations as well (reference 2). The CAA established a Technical Development and Evaluation Center at Indianapolis, Indiana, to support research activities. At the same time experimental work was also underway at the National Bureau of Standards Landing Aids Experimental Station located at Arcata, California. Here fog formation characteristics and visibility effects were subjected to detailed scientific analysis from the aviation perspective. Today airport lights are numerous. Arrays of lighted visual aids outline the runway and taxiway edges to identify the airport uniquely from the air and to facilitate ground movement. These systems are described in FAA Advisory Circular 150/5340-24, Runway and Taxiway Edge Lighting Systems (reference 3). In low visibility conditions and at night, high intensity approach lights lead the airplane to the desired runway. Lighting aids are usually available in variable intensity designs, and are provided with various means for control.

2.3.2 Marking Aids.

"Runway and taxiway markings are essential for the safe and efficient use of airports..." as stated in the FAA Advisory Circular Marking of Paved Areas on Airports (150/5340-1) (reference 4). The marking of pavements is especially important in providing guidance for daytime airplane movements. Pavement markings are also very useful at night, although lighting guidance becomes relatively more important in darkness and under low visibility conditions. Runway designations, touchdown and fixed distance markings, and sideline delineations represent but a few of the significant markings on runway surfaces. Taxiway holding position markings provide warning of the approach to runway/taxiway intersections, while centerlines and edge stripes define the useable surface. Obstructions near to flight paths are a recognized threat, and markings provide the means for their identification and avoidance. Marking research has been multi-modal over the years with the vast majority accomplished by state and federal highway organizations. Various types of marking materials are currently in use in the United States including water-borne paints; solvent-borne paints; thermoplastics; epoxy thermoplastics; thermosets; polyesters; tapes; beads; and raised markers. Solvent-borne paint is by far the most commonly used material because of its durability and ease of application. Water-borne paints are being carefully examined by several states and the Federal Highway Administration (FHWA) because of increasingly stringent environmental restrictions.

2.3.3 Signs.

Signs are among the most basic, but also most important, visual aids used on airports and as, on highways, provide the viewer with critical information. The use of signs on airports has expanded since the 1940's, when signs were few and far between. Today there are several categories of signs, as described in the FAA Advisory Circular Standards for Airport Sign Systems (150/5340-18) (reference 5). The various types include; mandatory signs for identifying critical areas such as runways, information signs to identify taxiways and destinations, and miscellaneous signs for other purposes such as defining runway distance remaining. The color of such signs differ relative to purpose. It was only in the late 1940's, as air operations increased significantly, that signs began to proliferate on airports. The CAA Taxiway Sign Evaluation Committee visited a number of airports in the early 1950's to develop recommendations for signs (reference 6), and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1952 the United States Navy commissioned an airport lighting and signage study by Dunlap and Associates (reference 7), that laid much of the groundwork for the "L-829" sign specification that was issued by the CAA in 1955. With the advent of the jet age in the 1960's, and attendant higher speeds and aircraft sizes, improvements in signage became imperative. The John F. Kennedy (JFK) Airport in New York was a leading sponsor of research that led to recommendations for use of different colors for differing sign messages (reference 8). During this period the FAA Technical Center in Atlantic City (under its former designation as National Aviation Facilities Experimental Center (NAFEC)) was also exploring the advantages of various sign color combinations (reference 9). Following the publishing of these research results, the standardization of unique colors for specific sign purposes was adopted by FAA and the International Civil Aviation Organization (ICAO). Subsequent sign designs have followed these guidelines. Recently there has been a resurgence of interest worldwide in improving sign effectiveness, with a new emphasis on correct and uniform signage as a result of several widely publicized accidents involving runway incursions. Since effective sign systems significantly reduce the occasion of pilot disorientation, they play a key role in preventing inadvertent runway incursions. It may be expected that the number and types of signs on airports will increase in the next few years. In addition, the expansion of low visibility operations in Category IIIB, and even IIIC, conditions has mandated a need for more effective signs.

2.3.4 Other Visual Aids.

Several other types of visual aids provide essential information to aviators. These include such diverse visual devices as obstruction lights, airport beacons, and ball markers for high tension wires. Unfortunately these aids are not conveniently categorized although they are, by definition, lights or marker devices. Many such visual aids are installed throughout the nation.

2.3.5 Integration of Visual Aid Systems.

As we have seen, an integrated and sometimes sophisticated system of visual aids has been developed over the years since the birth of aviation. The various components work in synergy to compliment one another, with lighting and marking aids, as well as signs, being essential in the total aviation environment. The interrelationship of individual components must be considered each time a change is made. The question "Will changes designed to enhance one aspect of the system reduce or restrict effectiveness of another?" must be asked. Thus it is essential that an analysis of these factors be accomplished to ensure that overall effectiveness of the system is maintained.

Visual guidance research activities have been conducted at the Technical Center over the past thirty-three years. During this time the Technical Center has been a leader in the development of new systems for visual guidance. These FAA activities have traditionally included research and development (R&D) efforts involving runway and taxiway lighting, obstruction lighting, distance-to-go markers, painted markings, and other aids. Visual guidance research and development activities conducted during the past five years have involved each of these activities. Recent major projects of significance have included evaluation of taxi sign effectiveness under low visibility conditions (reference 10), development and testing of "hold-short" lighting systems for identification of runway intersections (reference 11), and testing efforts underway on a new stop bar lighting system (first in the United States) for Category IIIB operations at SEATAC International Airport in Washington.

Future research efforts will be needed to develop surface guidance systems that will assist air traffic control (ATC) in maintaining physical separation between taxiing aircraft in low visibility conditions. Computerized controls can assist in improving reliability and flexibility, and provide a monitor capability for continually assessing the status of outages and operational effectiveness. State-of-the-art developments in airport lighting, control and guidance systems today offer the opportunity for significant improvements to runway and taxiway surface guidance systems.

Recent advances in state-of-the-art avionics now permit aircraft operations in dramatically lower visibility weather conditions at many airports. Landings and takeoffs can be accomplished now under virtually all weather conditions. To keep pace with these rapid technological advances, visual aids intended to support such operations must be upgraded and enhanced. Unique new developments in aircraft engineering and design have led to novel forms of aircraft, such as the tiltrotor, and to an attendant need for specially configured landing facilities. Introduction of such aircraft will undoubtedly require the development of new visual guidance systems to support their unique operational capabilities. Other aircraft, currently on the drawing boards, will present special demands in the future. These range from the giant 777 aircraft to the hypersonic transport. Their evolution will require corresponding improvements to visual guidance and control systems. Future visual guidance system research and development efforts must thus proceed at such a pace as to match the needs of the rapidly developing aviation system.

3. FACTORS THAT AFFECT VISUAL AIDS

3.1 OPERATIONAL AND HUMAN FACTORS.

Improvement of aircraft operational safety and effectiveness is one of the primary goals of the FAA. To this end the FAA has developed a system of visual aids designed to enhance the ability of the pilot to adapt him/herself to the aviation environment. The need for such aids is rooted in the physiology of the human being, and in the nature of the sea of air within which the aircraft must maneuver. Man is, by nature, a two-dimensional animal whose vestibular organs of sense are designed to be used on the ground. Once in the air, man is operating in a three-dimensional fluid, with only limited ability to make sensual determinations of position in relation to the earth. Pilot judgements are also greatly dependent on the physical properties of the human eye and the atmospheric characteristics prevailing. The Airman's Information Manual, published for pilots, contains some of the physiological characteristics and pitfalls associated with such human factors as visual illusions (reference 12). In spite of these limitations, the pilot is tasked with making numerous critical judgements while accomplishing the various maneuvers required to fly the airplane off the ground and return for a safe landing. Visual aids provide the essential additional information required to facilitate the aviator's tasks.

3.2 FUNCTIONAL CHARACTERISTICS.

Visual aids have certain essential characteristics, and an excellent discussion of these characteristics for lighting aids is presented in the International Civil Aviation Organization (ICAO) Aerodrome Design Manual (Part 4-Visual Aids) (reference 13). A few significant elements constitute the major characteristics that together comprise an effective system. These are the elements of configuration, color, intensity, and visual coverage. Together these elements provide the visual information that is necessary for the pilot to perform the tasks of pilotage. Each of these components is discussed individually below.

3.2.1 Configuration.

The configuration of the lights and markings involves the arrangement of the individual components of a system into a logical, organized grouping that allows for intuitive recognition by the pilot. Thus the runway lights outline the runway for night and low visibility operations, and markings are organized in a similar logical fashion to denote the basic runway dimensions during the day. The approach light, touchdown zone, and centerline lighting arrays provides a unique recognizable pattern for pilots to identify and follow during instrument landing conditions. These systems are standardized so as to provide similar visual presentations to pilots at landing facilities around the world.

3.2.2 Color.

Lights and markings are color-coded to convey specific meanings to aviators, just as they do for motorists on the highway. Individual colors are used for different applications on the airport; i.e., white (clear) lights are used to identify runways, green lights for thresholds and taxiway centerlines, blue lights for taxiway edge definition, and red lights for obstructions. The use

of colored filters is most often employed to produce the desired color effect, and specific color chromaticity is essential to provide standard color presentations to the aviator. Chromaticities are generally expressed in terms of the standard observer and co-ordinate system adopted by the International Commission on Illumination (CIE) at its eighth session at Cambridge, England in 1931. Table 3.1 includes the colors specified for selected aeronautical lights. Figure 3.1 provides a color range chart appropriate for aeronautical ground lights. Information on the various color ranges is depicted in nanometers. With regard to the color range charts, they will be seen to contain all of the colors of the visible spectrum. Therefore, there will be areas of transition between the basic colors which will be included within those boundaries designated as defining the limits of a particular color. Furthermore, it is virtually impossible to reproduce the color range charts for report purposes with complete accuracy. As a result, the charts provided herein are approximations for illustrative purposes only.

The colors of surface markings are also standardized to provide specific information to pilots. Taxiway markings are yellow, while runway markings are white. Surface markings may be highlighted with black borders on light colored pavements to improve contrast. These are detailed in AC 150-5340-1, Marking of Paved Areas on Airports. Colors of paint generally are detailed in standard government paint chip specifications. Figure 3.2 provides a color range chart appropriate for aeronautical surface markings.

3.2.3 Intensity.

The intensities of lights used for aviation purposes on airports vary widely, from 10 to 2,000,000 candelas. The level of illumination required for a particular purpose varies, depending on the use and the atmospheric transmissivity to be anticipated during a particular type of operation. Allard's Law (reference 14) defines the relationship between atmospheric transmissivity, distance and intensity for achieving a desired level of illuminance at the observer's eye. Atmospheric restrictions can have very significant effects on the intensity requirements for light sources, since they may cause very large attenuations over relatively short distances. Brighter lights may thus provide only very small benefits and can even, in some instances, produce undesirable glare.

TABLE 3.1 COLORS OF AERONAUTICAL LIGHTS

TYPE LIGHT	WHITE	BLUE	GREEN	RED	YELLOW
RUNWAY EDGE	X				X(1)
RUNWAY CENTER	X			X(2)	
TOUCHDOWN	X				
THRESHOLD			X		
APPROACH	X			X(3)	
RUNWAY END				X	
TAXIWAY EDGE		X			
TAXIWAY CENTERLINE			X		
Stop Bar				X	
LEAD-ON/OFF			X		X(4)
OBSTRUCTION	X(5)			X	
CLEARANCE BAR					X
AIRPORT BEACON	X		X		
HELIPORT BEACON	X		X		X
SEAPORT BEACON	X				X
AIRWAY BEACON	X			X	
MIL.APT. BEACON	X(6)		X		

- X(1) - Last 2,000' Yellow for Precision Approach Runway.
- X(2) - Last 1,000' Red; with 2,000' before last 1,000' alternating red/white for Precision Approach Runway.
- X(3) - Red side row barrettes within last 1,000' for Cat.II/III Approach Lighting System (ALSF-2).
- X(4) - Lead-Off centerline lights alternating green/yellow within obstruction free area.
- X(5) - Tall Structure Obstruction Lights may be white condenser discharge (Strobe) lights.
- X(6) - Military Airport Beacons display split (double) white flash.

CHROMATICITY DIAGRAM

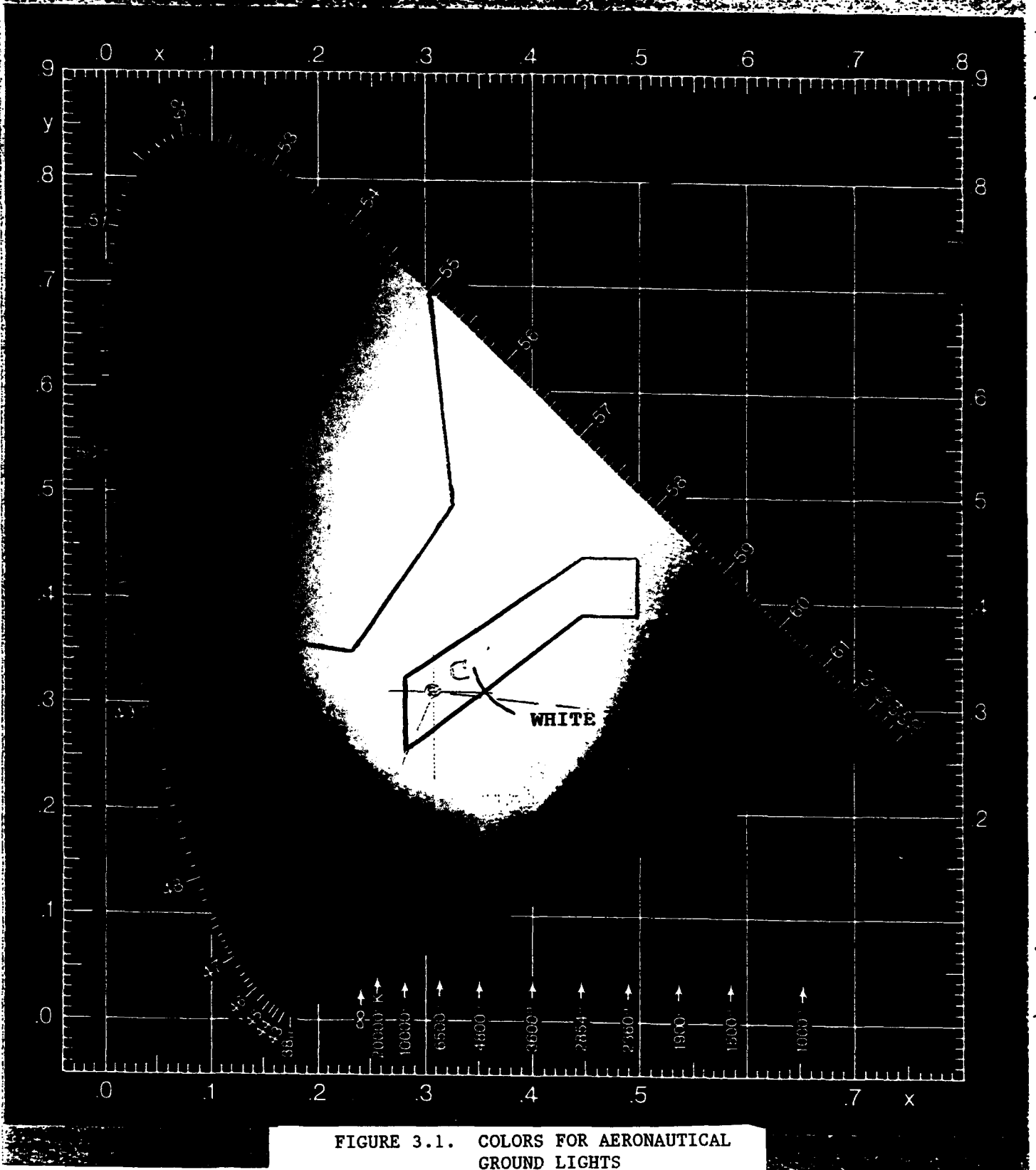


FIGURE 3.1. COLORS FOR AERONAUTICAL GROUND LIGHTS

CHROMATICITY DIAGRAM



FIGURE 3.2. COLORS FOR SURFACE MARKINGS

3.2.4 Visual Coverage.

The emission of light from a given source may be random or focused. Early airport lights were essentially omni-directional, since pilots of the day used multiple approach paths and landing directions to essentially "Runwayless" landing fields. The ability to focus a signal light was achieved well before the Wright Brothers' pioneered manned flight, and is exemplified by use of the fresnel lens in lighthouse applications. Such lenses were first adapted to aviation needs as airway beacons identifying early navigation routes and airport beacons, to assist pilots in identifying airport locations. As airplanes became more sophisticated, landing in lower visibilities and at higher speeds, increased performance demands have stimulated the need for improvements in focused lighting. Aeronautical lights have become highly sophisticated as a result, and the beam characteristics of aeronautical lights have been optimized to match the demands of particular phases of flight or surface movement. This includes customizing both horizontal and vertical coverage for the specific need.

3.3 CONSIDERATIONS AND LIMITATIONS.

Work in the field of visual aids is limited by the physical laws of nature. As previously discussed, Allard's Law is a basic determinant of the visual aid's limitations. The reader should be cognizant of additional constraints that limit what can be done to improve the pilot's situation. An excellent discussion of some of these limitations was presented by Mr. A.J. Smith of the U.K. Defense Research Agency during a London seminar in 1991 (reference 15). Frequently, application of what may appear to be a simple and obvious solution can involve the introduction of complex problems that may totally invalidate use of that solution. For example, increasing intensity of a visual aid seems the ideal method for achieving enhanced performance under increasingly reduced visibility conditions. More often than not, however, the attendant glare condition encountered will render this simple modification ineffective, and may even reduce usefulness of the aid under all conditions. Similarly, a decision to modify a "hard-to-acquire" visual aid, by introducing a "flashing" mode of operation, may cause confusion and even a diminishing of effectiveness of other nearby visual guidance systems. For these and numerous other reasons, developments and improvements in the arena have tended to be evolutionary rather than revolutionary.

4. GENERAL FRAMEWORK FOR STUDY DESIGN

4.1 PROCEDURES.

A variety of information sources were used during the course of the study. A composite group of aviation sources was selected based on their potential contribution to the study effort, and table 4.1 provides a general outline of these sources.

4.2 DATA GATHERING.

Various techniques were employed during the course of the study to obtain the necessary information, including interviews, questionnaires and panel discussions at conferences and seminars. Interviews were accomplished in person and on the telephone, and questionnaires were developed and distributed as necessary to assist in gathering data on current needs. Attendance and participation in seminars, conferences, and panel discussions was also most rewarding in establishing the direction of future technology development.

4.2.1 Interviews.

Personal and telephone interviews were conducted with virtually all of the organizations identified in table 4.1. They were organized in semi-structured fashion, with an initial overview of the study purpose, followed by questions designed to elicit specific information from the subjects on visual guidance issues. These were effective in gaining the desired information.

4.2.2 Questionnaires.

A questionnaire was developed to gain key information from specific user groups about current needs, concerns, and future requirements. These questionnaires were distributed to pilots and the responses used for identification of problem areas and to determine future program direction from a user perspective. Refer to the appendix for details of the questionnaire.

4.2.3 Panel discussions.

Panel discussions offered a unique opportunity to gain significant information from a large number of technically knowledgeable sources. Engineering conferences and gatherings of technical societies highlighted the latest in technological breakthroughs and aviation visual guidance applications. During the course of this study, the authors participated in a number of major panel discussions. These included the following:

TABLE 4.1 GENERAL SOURCES OF INPUT

- **PILOT UNIONS AND ASSOCIATIONS**
ALPA, APA, AOPA, NBAA, GAMA
- **U.S. GOVERNMENT VISUAL GUIDANCE EXPERTS**
FAA-FLIGHT STANDARDS, AIRPORTS, AIR TRAFFIC, SAFETY
- **MANUFACTURERS OF VISUAL GUIDANCE EQUIPMENT**
CROUSE-HINDS, STANDARD SIGNS, GODFREY, ADB
- **MANUFACTURERS OF LIGHTING AND OPTICAL PRODUCTS**
ADB, CROUSE-HINDS, MULTI-ELECTRIC, KOPP GLASS
- **MANUFACTURERS OF COMPUTER BASED CONTROL SYSTEMS**
AIRPORT TECHNOLOGY-SWEDEN, ADB-SIEMENS
- **UNIVERSITY AND RESEARCH FACILITIES INVOLVED IN VISION,
LIGHTING, AND COMPUTER VISUAL SIMULATION**
MIT LINCOLN LABORATORY, NAVAL AIR WARFARE CENTER
(NAWC), UNIVERSITY OF ALABAMA, HUMBURG MT.
LABORATORIES, VOLPE TRANSPORTATION SYSTEMS CENTER
- **MANUFACTURERS OF AIRCRAFT AND AIRCRAFT EQUIPMENT**
BOEING
- **AIRPORT OWNERS, OPERATORS AND MANAGERS**
AAAE, AACI
- **NATIONAL AND INTERNATIONAL COMMITTEES CONCERNED WITH
AIRCRAFT AND AIRPORT OPERATION**
ICAO, CAA (U.K.), DEFENSE RESEARCH AGENCY, BEDFORD,
UK
- **SAFETY ORGANIZATIONS**
AVIATION SAFETY INSTITUTE, FLIGHT SAFETY FOUNDATION,
NATIONAL TRANSPORTATION SAFETY BOARD

- . Illuminating Engineering Society 1991 Annual Meeting, London, United Kingdom
- . IES Aviation Lighting Committee Government Contacts Subcommittee Semi-Annual Meeting, Washington DC
- . Hershey Airports Conference, Hershey, Pennsylvania
- . AACI Airports Conference, Seattle, Washington

4.3 INDIVIDUAL SOURCES OF INPUT.

Individual contributors and participants to the study were varied, with contributions from airline, general aviation and business aviation pilot groups, airport operators, and airport equipment manufacturers. Research organizations that were involved included the Department of Transportation Volpe Transportation Systems Center, MIT Lincoln Laboratory, Department of Defense Naval Air Warfare Center in Lakehurst, New Jersey; and the United Kingdom (UK) Defense Research Agency, Bedford, England. Regulatory contacts included members of the Airports, Air Traffic, Flight Standards, and Systems Maintenance Services of the Federal Aviation Administration, as well as representatives of the FAA regional offices.

Significant user contributors included the major airlines, and business and general aviation segments of the industry. Manufacturers include producers of a variety of visual devices, to include marking materials, lighting equipment, and signage products. These diverse elements represent the most knowledgeable sources of current information within the industry. User organizations are detailed in table 4.2. A list of international contacts is contained in table 4.3. Manufacturer's organizations are detailed in table 4.4 and Governmental/Regulatory organizations are detailed in table 4.5. A list of contacted Universities is also included in table 4.6.

TABLE 4.2 AVIATION USER ORGANIZATIONS

- AIR LINE PILOTS ASSOCIATION
- AIR TRANSPORT ASSOCIATION
- AIRCRAFT OWNERS AND PILOTS ASSOCIATION
- AIRPORT ASSOCIATION COUNCIL INTERNATIONAL
- ALLIED PILOTS ASSOCIATION
- AMERICAN ASSOCIATION OF AIRPORT EXECUTIVES
- GENERAL AVIATION MANUFACTURERS ASSOCIATION
- HELICOPTER ASSOCIATION INTERNATIONAL
- NATIONAL ASSOCIATION OF STATE AVIATION OFFICIALS
- NATIONAL BUSINESS AIRCRAFT ASSOCIATION
- WASHINGTON DIVISION OF AERONAUTICS

TABLE 4.3 INTERNATIONAL ORGANIZATIONS

- INTERNATIONAL CIVIL AVIATION ORGANIZATION-ICAO
MONTREAL, CANADA
- UKCAA
DEFENSE RESEARCH AGENCY
BEDFORD, ENGLAND
- TRANSPORT CANADA-AKPE
OTTAWA, ONTARIO, CANADA
- CIVIL AVIATION AUTHORITY
GATWICK, W. SUSSEX, UNITED KINGDOM
- CANADIAN AVIATION SAFETY BOARD
OTTAWA ONTARIO, CANADA
- SERVICE TECHNIQUE DE LA NAVIGATION
PARIS, FRANCE
- ORGANISMA AUTONOMO AEROPUERTOS NACIONALES
MADRID, SPAIN

TABLE 4.4 MANUFACTURERS

- ADB-SIEMENS
- AIRPORT TECHNOLOGY
- APOLLO LIGHTING
- APOLLO-KEMLITE LABORATORIES
- CROUSE HINDS LIGHTING
- DAVIS AIRFIELD FIBER-OPTICS LIMITED
- DETECTOR SYSTEMS
- ESCO
- ELECTRO FIBER OPTICS FABRICATION
- GODFREY ENGINEERING
- HUGHEY AND PHILLIPS
- HUMAN FACTORS
- JAQUITH INDUSTRIES
- JESS HOWARD ELECTRIC COMPANY
- LANGEN INFRARED INC.
- LIGHTING SCIENCES INC.
- MONAIRCO, INC.
- MULTI-ELECTRIC MANUFACTURING CO.
- SIEMENS AG.
- STANDARD SIGNS INC.
- TASSIMCO
- VISION ENGINEERING LABS INC.

TABLE 4.5 GOVERNMENTAL/REGULATORY ORGANIZATIONS

FAA HEADQUARTERS

- AFS-400, FLIGHT STANDARDS TECHNICAL PROGRAMS DIVISION
- AAS-200, AIRPORTS ENGINEERING AND SPECIFICATIONS DIVISION
- AAI-100, ACCIDENT INVESTIGATION DIVISION
- ATP-100, AIR TRAFFIC PROCEDURES DIVISION
- ANN-200, NAS PROGRAM MANAGER FOR LANDING
- ANN-300, NAS PROGRAM MANAGER FOR NAVIGATION
- ASM 100, SYSTEMS MAINTENANCE ENGINEERING DIVISION
- ASC-100, AIRPORT CAPACITY PLANNING AND DEVELOPMENT
- ARD-50, RUNWAY INCURSION WORKING GROUP
- AAS 100, AIRPORTS DESIGN AND OPERATIONS CRITERIA DIVISION
- ASM 200, SYSTEMS MAINTENANCE OPERATIONS DIVISION

FAA FIELD ORGANIZATIONS

- FAA, FAA AERONAUTICAL CENTER, OKLAHOMA CITY, OK
- FAA, GREAT LAKES REGION, DES PLAINES, IL
- FAA, NORTHWEST MOUNTAIN REGION, SEATTLE, WA
- FAA, SOUTHERN REGION, ATLANTA, GA
- FAA, FAA TECHNICAL CENTER, ATLANTIC CITY, NJ

TABLE 4.6 UNIVERSITIES

•	ALABAMA A&M UNIVERSITY
•	CARLETON UNIVERSITY
•	DREXEL UNIVERSITY
•	EMBRY-RIDDLE UNIVERSITY
•	FLORIDA INSTITUTE OF TECHNOLOGY
•	GEORGIA INSTITUTE OF TECHNOLOGY
•	JOHNS HOPKINS UNIVERSITY
•	LAFAYETTE UNIVERSITY
•	LEHIGH UNIVERSITY
•	MASSACHUSETTS INSTITUTE OF TECHNOLOGY
•	NEW JERSEY INSTITUTE OF TECHNOLOGY
•	NEW YORK UNIVERSITY
•	NORTH CAROLINA STATE UNIVERSITY
•	PENNSYLVANIA STATE UNIVERSITY
•	PRINCETON UNIVERSITY
•	PURDUE UNIVERSITY
•	RENSSELAER POLYTECHNIC INSTITUTE
•	RUTGERS UNIVERSITY
•	STEVENS INSTITUTE OF TECHNOLOGY
•	UNIVERSITY OF ALABAMA-HUNTSVILLE
•	UNIVERSITY OF CALIFORNIA-SAN DIEGO
•	UNIVERSITY OF CENTRAL FLORIDA
•	UNIVERSITY OF NEBRASKA
•	UNIVERSITY OF NORTH DAKOTA
•	UNIVERSITY OF WASHINGTON
•	VIRGINIA POLYTECHNIC INSTITUTE
•	WORCESTER POLYTECHNIC INSTITUTE

5. DISCUSSION AND RESULTS

5.1 DISCUSSION.

Many problem areas, as well as promising technology applications, were identified during the course of this study. From the preceding chapters it is evident that there was a wealth of available information to be sifted and organized. With such a wide diversity of source material, the problem becomes that of distilling the available material to provide a concise summary of results. While only a brief description of the sources utilized is given here, details of the information obtained are provided in the appendix of this report.

The data obtained from all sources have been incorporated into the visual guidance research needs detailed in the following Chapter 6 of this report.

5.2 QUESTIONNAIRE.

In April 1992, a questionnaire was distributed by the Air Line Pilots Association to member pilots. The questionnaire was developed to identify significant visual aids issues as viewed from the commercial airline pilot's perspective, and to provide user input into the Visual Guidance Study. A sample questionnaire is included as figure 5.1.

Of approximately 400 questionnaires that were distributed, 148 were completed and returned, for a response rate of 37 percent. This must be considered excellent for this type of survey.

5.3 USER ORGANIZATION CONTRIBUTION.

Many sources were surveyed during the course of the study to identify areas requiring improvement. These included pilot groups, manufacturers, safety organizations, and representatives of organizations such as the Helicopter Association International. These groups identified various problem areas in need of research solutions. While not all input was specific enough to be useful, even the general comments are included to establish the tone of user organization opinion as to "state-of-the-visual-art" in aviation.

5.4 UNIVERSITY TECHNOLOGY RESEARCH.

A large amount of the nation's research base is resident within the university structure. While most of this effort is concerned with basic rather than applied research, the material obtained was useful in identifying individuals and groups engaged in technological development efforts that may find application in airport visual guidance systems of the future.

PILOT QUESTIONNAIRE

1. During which one of the following four phases of the Approach and Landing operation do you experience the most difficulty due to visual guidance system deficiencies?

- A. Approach_____
- B. Touchdown_____
- C. Rollout_____
- D. Turnoff/Exit_____

2. With reference to your answer above, what basic problem have you encountered most often, and which visual system (lights, markings, signs, etc.) seems most lacking in effectiveness?

3. During surface movements, which one category of visual devices seem to be least effective in providing taxiing guidance?

- A. Lighting System_____
- B. Sign System_____
- C. Paint Markings_____

4. Considering only the category of visual aids that you selected above, in what manner or way do they seem inadequate?

5. Up until now apron areas have been comparatively neglected in the effort to standardize airport visual aids. Do you feel strongly that more R&D activity should be devoted to this area?

Yes _____ No _____

Why so? _____

6. Finally, and from your own experience, would you mention any other visual guidance problems or deficiencies that appear in need of correction?

FIGURE 5.1. PILOT QUESTIONNAIRE

5.5 INDUSTRY TECHNOLOGY RESEARCH.

Industry research programs constitute the largest areas of research in the country, and Government sponsorship of research is closely intertwined with private sponsorship. Much of the marking materials research, as might be expected, is sponsored by state highway departments. Lighting research is primarily focused on potential market penetration and is profit orientated. Sign technology is fairly stable, although fiber-optic applications are being investigated as a means of increasing effectiveness.

5.6 OVERSEAS RESEARCH.

A number of foreign agencies and companies were contacted during the course of the study and provided valuable input. These are depicted in table 5.1.

TABLE 5.1. OVERSEAS ORGANIZATIONS

- . INTERNATIONAL CIVIL AVIATION ORGANIZATION-ICAO
MONTREAL, CANADA
- . UKCAA
DEFENSE RESEARCH AGENCY
BEDFORD, ENGLAND
- . TRANSPORT CANADA-AKPE
OTTAWA, ONTARIO, CANADA
- . CIVIL AVIATION AUTHORITY
GATWICK, W. SUSSEX, UNITED KINGDOM
- . CANADIAN AVIATION SAFETY BOARD
OTTAWA ONTARIO, CANADA
- . SERVICE TECHNIQUE DE LA NAVIGATION
PARIS, FRANCE
- . ORGANISMA AUTONOMO AEROPUERTOS NACIONALES
MADRID, SPAIN
- . SIEMENS AG. - GERMANY
- . DAVIS FIBER OPTIC SIGNS - CANADA
- . TASSIMCO - CANADA
- . AIRPORT TECHNOLOGY - SWEDEN

5.7 NON-FAA GOVERNMENT RESEARCH.

Various agencies conduct research for the Federal Government. As mentioned earlier, the National Bureau of Standards (NBS) was at the forefront of much of the earlier aviation lighting research conducted at Arcata, California. Federal standards development is currently the province of the National Institute of Standards and Technology (NIST). The NIST has conducted extensive research on the effects of color and geometric shapes on the visibility of objects in various environments. Additional work has been accomplished in the field of photometry. Considerable other visual guidance research is being done at government laboratories throughout the United States.

The Air Force Engineering Center at Tyndall Air Force Base in Florida, is the focal point for marking and lighting research in the United States Air Force (USAF). In recent years the principal focus has been on portable lighting systems, and on development of visual aids for use in combat areas. Past testing has involved radio-luminescent lighting aids, retro-reflective markings, and tone down color schemes. At the current time testing is being conducted on improved painted markings for enhanced performance and reflectivity.

The United States Navy is also performing research, and is in the process of developing an upgrade to its current shipboard visual guidance system, the Fresnel Lens Optical Landing System (FLOLS). The new system will employ laser technology to increase effective range in acquiring and employing visual cues. Other enhancements include the provision of azimuth information to accompany the traditional glide slope cues, and a unique new integration of radar information with the visual signal to provide optical rate of descent cues. Thus far the effective range for the system use is approximately 10 miles, as compared with 1 to 2 miles for the traditional FLOLS system. Separate lasers are used in the system to provide individual corridors of light.

Another organization is the Volpe Transportation System Center (VTSC). The VTSC is a major participant in the Airport Surface Traffic Automation (ASTA) project. While the air traffic control aspect is pre-eminent, a portion of the effort is devoted to establishing automated visual aids at runway entrances and to runway status lights on the runway itself.

6. VISUAL GUIDANCE RESEARCH NEEDS

6.1 DISCUSSION.

Determination of current needs was accomplished through data analysis and with inputs from the various sources involved in the study. The ability to forecast future deficiencies and needs is somewhat dependent on the ability to foresee the direction in which the aviation industry is proceeding, and therefore the nature of increased capabilities that will be required. Nonetheless, it appears that there will be increased emphasis on low visibility operations, and on the attendant requirement for improvements to visual guidance systems to be used under these more critical conditions. Future research activities must therefore be oriented in this direction.

Future systems may be expected to be automated to a far greater degree and, eventually, integrated into control systems such as airport movement area safety systems (AMASS) and airport surface traffic automation (ASTA). Airport aids and air traffic control will become even more closely aligned. Separation of aircraft on the ground, long the sole responsibility of the individual pilot, is even now being transferred to the air traffic control function during Category III operations. Pilots, however, will still require some forms of visual aids to maintain their orientation on both the movement area and on the ramp.

The most significant deficiencies identified during the course of the study involved airport surface guidance systems, particularly those used in the low visibility realm. Incursion prevention is a particularly important function of visual guidance systems, and improvements are needed in markings, low visibility sign systems and apron/wide area guidance. Automated surface movement control systems offer particularly rewarding opportunities for new technology applications, and the designated demonstration airports will serve as valuable showcases for state-of-the-art technological advances.

6.2 NEW TECHNOLOGY APPLICATIONS.

There are a number of new and emerging technologies offering potential enhancements to visual guidance systems. Improvements that occur will offer significantly improved performance, as well as expanded capabilities. Some of these advances will result in improvements to economy of operation through a reduction in required maintenance effort and improved reliability. Relevant technologies include lasers, fiber optics, electro-luminescent light sources, piezo and fiber-optic sensors, power cable signalling, automated surface movement control systems, addressable signs, portable photometric devices, and pavement marking materials.

6.2.1 Lasers.

Lasers offer potentially beneficial improvements in several areas of airport lighting and visual aids. The power of laser light sources may be harnessed in many different applications, and potential benefits stem from their limited scattering effect as compared to traditional light sources. An obvious application is in the development of a laser-based visual landing aid as a

replacement for existing precision approach path indicator (PAPI)/visual approach slope indicator (VASI) systems. The United States Navy is already experimenting with such Laser systems as their improved carrier landing system (ICOLS) while, overseas, the potential for improvement has also been explored by the Russians in their "Glacada" system.

Other lasers may be employed in airport surface lighting applications for low-visibility, since concentrated laser power might offer a solution to atmospheric attenuation of visual signals in Category III weather conditions. High cost factors are the primary negative aspect of their employment at the present time.

6.2.2 Fiber-optics.

Fiber-optic technology offers significant potential enhancements to airport lighting technology. Fiber material is inherently cheap to produce, chemically neutral, and has been used in the communications industry for many years. Fibers may be fused together, bundled in groups, and is offered in a wide range of sizes and lengths. Benefits of fiber networks also include immunity to lightning strikes, a major source of problems with conventional systems. Use of fiber optic "light pipes" also offers potential for siting traditional light sources remotely, allowing ease of maintenance for aids mounted in difficult locations.

Fiber-optic airport signs have been developed in Canada and are already installed in a number of locations. The Canadian signs utilize traditional light sources with message characters illuminated by light delivered through fiber-optic bundles. While not problem-free, the Canadian signs do offer the benefits of lower energy consumption and potentially greater effectiveness under circumstances of low-visibility, a potential solution to a problem of increasing magnitude.

Fiber-optics thus offer a multitude of potential benefits in visual guidance applications. Therefore research efforts to explore these possibilities may prove extremely worthwhile.

6.2.3 Electro-luminescent Lighting.

Electro-luminescent (E/L) lighting is yet another emerging technology, and limited work in this area has already been accomplished by the United States Air Force (reference 16) and the FAA at the Technical Center. In the past electro-luminescent lighting progress has suffered from relatively low attainable light output and the high expense of constructing the E/L panels. They are composed of very thin sheets of phosphor material, which phosphors are then excited by means of an electrical current to produce visible light. The advantages of the technology lie in low energy consumption, lack of heat produced, and the capability of creating unique shapes from the material. In recent years the use of higher excitation voltages and improved phosphors has served to increase the amount of light output attainable from the EL panels, significantly increasing the potential for effective application on airports. A recent news article produced by the Los Angeles Times News Service highlighted a new application of E/L lighting as a replacement for conventional light bulbs. A magnetic coil is used to generate a radio signal, to exciting a plasma which makes the phosphor glow. The article reported that a "Sunnyvale, California

company has developed a revolutionary light bulb that will last up to 20,000 hours, fit into ordinary sockets and use 75 percent less electricity than conventional electric lights. The bulb is hailed as the first major advance in electric lighting in 60 years (reference 17)." An industry working group has been formed recently to develop new standards for this type of lighting technology. The claims, if verified, would indicate that greatly increased economy of operation might be expected through use of E/L sources.

Future research and development efforts should be cognizant of Electroluminescent technology and its potential applications.

6.2.4 Sensor Technology.

Sensors are employed as supporting devices for actuation of visual guidance systems. Sensors have undergone continuing development over the years in response to differing requirements. Microwave sensors have been used for many years in security applications, proving effective in nighttime and low-visibility detection efforts. Technology advances in sensors now allow their use in airport applications. Piezoelectric sensors offer advantages of inexpensive retrofit and reliability, while Fiber optic sensors currently under development may provide the optical sensitivity necessary to identify specific types of aircraft at multiple locations on the airport. Research on this type of application is being conducted at the University of Alabama/Huntsville (reference 18). Installation of systems using sophisticated sensors is underway at several modern airports including Toronto, Munich, and Rome.

Research and development efforts may benefit from this new technology through application in position awareness systems, particularly in the low-visibility realm. Surface movement control systems will need a variety of these devices, and they should find unique applications in airport guidance systems of the future.

6.2.5 Power Cable Signal Technology.

Electronic control technology has evolved significantly in the past few years. Traditional airfield lighting systems utilize isolation transformers to power individual lights on the airport, and replacement of these transformers with individually addressable electric modules would allow individual control and monitoring of each lighting device. Communication is accomplished through a master computer over existing power cables, eliminating the need to install additional cable for controlling new airport lighting systems on the airport. Power cable signal technology was developed and employed in railroad systems and power line switching for many years, but the first successful use in airport applications was at Gothenburg Airport in Sweden in the late 1970's and 1980's (reference 19). The Swedish system, called Airport Smart Power (ASP), offers selective control of individual units with built in intensity control and monitoring. The ASP concept was tested at the FAA Technical Center in 1991-92 (reference 20).

In 1992, the FAA initiated an evaluation program at the SEATAC Airport in Washington State. Because of frequently occurring low-visibility conditions, SEATAC was considered an ideal location for the testing of controlled stop bars, a visual guidance system that is essential for safe operations in bad weather.

Previously, testing of non-standard stop bars had been carried out in the United States at JFK Airport in New York in the late 1980's (reference 21). The costs of retrofitting the SEATAC airport with control cable were determined to be excessive, thereby making it a prime candidate for use of power cable signal technology. The system that was selected for use at SEATAC is produced by a United States company, ADB/ALNACO, based in Ohio. The system was installed and became operational for testing in December, 1992. This testing is the first actual evaluation of power cable signal technology at a major airport in the United States.

Many future uses for power cable signal technology remain to be discovered but, if the demonstration at SEATAC is successful, the technology may prove ideally suited to use in numerous airport applications. The FAA must explore its potential for operating various other devices on the airport, both visual and non-visual. In addition to controlling components of surface movement and guidance systems, it has potential applicability to individual brightness control, operation, and monitoring of conventional signs and lights.

6.2.6 Surface Movement Control Technology.

Surface movement control technology is in its infancy today, but may be expected to grow rapidly in the next few years. Studies on surface movement concepts were conducted in the 1960's at the FAA Technical Center, focusing on traffic signal utilization in the airport environment (reference 22). Later studies included evaluation of the VICON system at Bradley Field in Connecticut, the basic component of which was a traffic signal device on the runway activated by the controller in conjunction with verbal clearance for takeoff (reference 23). These early efforts proved unsatisfactory due to the level of involvement (workload) required of the ATC controller. Later studies in the 1970's offered the possibility of automated solutions to the surface movement problem, and included the Volpe Transportation Systems Center's study on surface movement in 1975 (reference 24). In the 1980's computer chip technology and the development of the personal computer offered control automation possibilities that were previously unattainable. Surface movement systems began to be developed for airports overseas, such as Luton Airport in England, and Munich in Germany. In addition, interest in stop bar control systems increased in the United States in the late 1980's, with tests of a prototype stop bar conducted at JFK International Airport in New York (reference 25). In the 1990's, new programs have been proposed that would provide enhanced surface movement automation. The ASTA 3 specification provides for integration of controller planning information regarding surface movement with radar based location information (reference 26).

The newest airports, such as Munich in Germany, are presently incorporating some degree of surface movement automation into their visual aids design. The Munich airport uses a combination of loop sensors imbedded into the pavement combined with automated computer tracking and prioritization algorithms to provide segmented sectional lighting control. Similarly, the Rome Campino Airport is being configured with a new surface movement system that will provide sectionalized taxiway visual guidance. The Denver airport currently under construction is being equipped with stop-bar lighting systems. The United States Automated Surface Movement Surveillance System (AMASS) and Airport Surface Traffic Automation (ASTA) programs are also attempts to provide a degree of automation to surface movement.

The advent of Category IIIB operations has stimulated the need for automation of some tasks previously performed by pilots and controllers. Runway incursion accidents have stimulated the development of Surface Movement Guidance and Control System (SMGCS) requirements for selective lighting control. Dedicated low-visibility routes are essential for safe and efficient surface movement under ultra low-visibility. The integration of sensor technology, radar data, and Mode S data link offers the potential for the totally integrated and automated surface movement system of the future. Research efforts should focus on providing improvements to lighting and signing to assist in safe movement under these conditions. The effort must also focus on the integration of all airport visual aids, as well as the development of new and unique individual systems. New concepts in equipment, materials and design configuration are necessary to improve performance of the guidance systems of the future.

6.2.7 Addressable Sign Technology.

The use of addressable signs on airports has, to date, been limited to landside application, as well as to certain apron applications such as docking guidance systems. Addressable signs are, however, finding common usage in other transportation applications, particularly on highways. The use of addressable sign technology offers potential benefits on the airport airside as well, particularly at complex taxiway intersections and at locations where traffic congestion is a problem. In the case of fiber optics, there are benefits to be derived from the inherent wide viewing angles and relatively high intensity attainable. Addressable signs are particularly well suited for use with Surface Movement Control Systems. Research should take advantage of the benefits of highway department experience with developmental projects, and in particular with those dealing with the traditional twin problems of sign visibility and conspicuity.

6.2.8 Portable Photometry Technology.

New technology has recently become available that offers potential benefits to visual aids research. Enhanced photometric measurement of light sources is beneficial from the research as well as the user perspective. Field measurements validate manufacturer's performance claims and provide comparisons with those obtained in the laboratory. The problem is in obtaining these measurements accurately and quickly in the field, so as to minimize time spent on the active airport surfaces. This field measurement capability has been lacking up to now but, recently, several, potentially beneficial techniques have been developed that offer promise in this area.

The Scripps Oceanographic Institute in San Diego California has been developing a technique called "whole sky imaging" that uses a "Horizon Scanning Imager" to determine beam transmittance (reference 27). A calibration scheme is incorporated into the software to provide real-time measurement with concurrent recording of results. Similar work is also being done in Ottawa, Canada, by Carleton University. The Carleton project is termed Visible Spectrum Image Analysis (VSIA) System.

The United States manufacturers have also been working toward development of portable photometric devices. One manufacturer has developed a device which is vehicular mounted for ease of operation, and the prototype device has been operationally tested at several airports. It employs 16 photosensors whose inputs are recorded on a computer disk for later analysis in the laboratory. Alignment of the system is the most time consuming aspect of operation. Following setup, test measurements must be correlated with a hand-held photometer. Once ready to begin operation, the sequence is fairly rapid, taking only 20 to 30 seconds per fixture. This should permit completion of measurements for a 10,000 foot runway in less than hour. Another manufacturer is developing a portable device that measures retroreflectivity of marking materials, and intends to have the device ready for demonstration within several months.

6.2.9 Pavement Marking Technology.

New technology developments in pavement marking materials offer potential enhancements to performance of existing marking systems. Some products, such as environmentally acceptable new paints and thermoplastics, appear to offer superior friction quality, improved nighttime visibility, and better resistance to weather and traffic deterioration when compared to conventional products. Reflective tapes and pavement markers are now offered in a variety of types. Regular tapes are preformed plastic strips made of polyvinyl chloride resin binders, and usually have a pre-applied adhesive with protective paper backing. However, in some cases, epoxy primers must be applied to the surface for tapes not having contact adhesives. Pavement markers come in various shapes and sizes, of which the most commonly used are non-reflective raised markers made of ceramics with glazed surfaces. Reflective markers utilize cube-cornered acrylic lenses, tempered glass lenses, or glass beaded lenses mounted in plastic, ceramic, or metal bases. These materials offer significant potential for improving the conspicuity of existing surface markings, principally by raising the marking devices above the traffic surface and clear of standing water, snow, etc.

6.3 RECOMMENDATIONS FOR FUTURE VISUAL GUIDANCE RESEARCH EFFORTS.

Visual Guidance R&D Programs have traditionally been organized into three basic categories of effort: "Lighting", "Marking", and "Signage" systems. However it is believed that this traditional categorization of efforts may be too simplistic, and not the best for use in presenting the results of our study. Accordingly, we have elected to group our recommended research efforts into the following general categories:

1. Approach and Landing Systems.
2. Surface Guidance Systems.
3. Control and Monitoring Systems.
4. State-of-the-Art Advances (Technological Innovations).

The recommended expanded research effort for future years reflects the changing operational environment and includes increased emphasis on low-visibility operations and potential operations at vertiports. It also reflects an increased level of effort to support new technology initiatives such as fiber optics, holography, and computer control applications. The recommended efforts are presented as research areas within each of the following categories:

Some repetition of "Background" material may be evident in the research area descriptions that follow. This has been deemed necessary so as to maintain the integrity of each description, and to allow each to be used independently if desired.

6.3.1 Approach and Landing Systems.

This category includes airport identification, approach and landing systems. It encompasses all Visual aids such as lighting, marking, and signs, as well as other devices.

Table 6.1 depicts suggested research areas devoted to improvement of approach and landing systems:

TABLE 6.1 APPROACH AND LANDING

● ENHANCED RUNWAY TURNOFF (EXIT) LIGHTING	6.3.1.1
● AIR-CARRIER AIRPORT IDENTIFICATION BEACON	6.3.1.2
● PILOT CONTROLLED LIGHTING SYSTEM STATUS VERIFICATION	6.3.1.3
● VERTIPOINT LIGHTING AND MARKING AIDS	6.3.1.4
● APPROACH LIGHT SYSTEM COMPONENT REDUCTION	6.3.1.5
● ENHANCED VISUAL GLIDEPATH AIDS	6.3.1.6
● VISUAL AIDS FOR GENERAL AVIATION AIRPORTS	6.3.1.7
● CLOSED RUNWAY VISUAL AIDS	6.3.1.8
● INEXPENSIVE VISUAL GUIDANCE AIDS HELIPADS	6.3.1.9
● TEMPORARY PAPI SYSTEM	6.3.1.10

6.3.1.1 Enhanced Runway Turnoff (Exit) Lighting.

Background and Past Studies: Positive identification of runway turnoff (exit) locations is a basic task for the pilot following landing. Past research has addressed the orientation of exit taxiways, installation of additional light

fixtures at taxiway exits, and optimum exit sign locations, along with other allied subjects. In the 1970's, the FAA Technical Center (then NAFEC) performed evaluations of a runway exit identification device (reference 28). Additional testing was also performed on a Canadian concept involving flashing of taxiway exit lights (reference 29). These evaluations were unsuccessful in identifying any satisfactory means of highlighting runway exits.

High speed taxiway exits were added as enhancements to capacity, and generated additional need for exit distinction. Green high speed exit centerline lighting, where installed, has been successfully used to identify such turnoffs. Alternate color coding (green/yellow) of exit centerline lights for normal (low-speed) exits appeared promising during tests conducted at the FAA Technical Center (reference 30). Subsequent adoption of this same color coding, by ICAO, to identify obstruction free areas near the runway, cut short consideration of this concept. Furthermore, only the relatively few and best equipped major airports are equipped with runway/taxiway centerline lighting systems. Identification problems at other airports are compounded by the relatively weak output of the blue-filtered conventional elevated taxiway edge lights. Small airports are a particular problem as the typical general aviation airplane is so low to the ground that cockpit visibility restrictions present a problem.

The need for adequate runway exit identification is an important issue, for both safety and capacity reasons. Pilots must slow down to a safe speed prior to turnoff and, if their speed is excessive, they may miss the paved surface entirely. Equally critical is the excessive time consumed in searching visually for the turnoff; resulting in excessive time on the runway, a possible "go-around" maneuver, and reduced capacity.

Deficiencies/Enhancements: Presently the visual guidance systems available, in service or contemplated for use, are insufficient to perform this critical function. The requirement includes not only a means for indicating an exit location, but also for identifying it specifically (i.e., Taxiway "A", High-Speed Exit "B-1", etc.) as that which the pilot may have been directed to use.

Sources of Information: The problem was mentioned by multiple sources including AOPA and ALPA. In addition the problem was identified frequently by pilots during a recent questionnaire on visual aids issues.

Future Research: The work effort should focus on the development of new systems for turnoff identification. Such systems could involve lights, signs and markings. Alternate flashing lights activated by power cable signal control systems are among the possible areas to be explored. The approach should involve modifications to existing systems or development of totally new systems.

6.3.1.2 Air-Carrier Airport Identification Beacon.

Background and Past Studies: Beacons have served the traveler since the early days of navigation. Lighthouses were an important source of guidance to sailors in identifying dangerous shoals and safe harbors (reference 31). The fledgling aviation industry adopted the use of lighted beacons for navigation from point to point prior to the advent of electronic aids (reference 32), and airports throughout the United States were equipped with lighted beacons to identify their exact location to arriving pilots. In order to discriminate military airports from civilian airports and seaports, two distinct signal codes were

adopted, with the difference being dual-white/single-green flashes for the military and single-white/single-green flashes for civilian facilities (reference 33). This system was adequate for many decades. However, over the years airports located adjacent to one another within densely populated areas (urban and suburban) have proliferated, to the extent that it has become virtually impossible to discriminate the major airport from other reliever and general aviation airports nearby.

The pilot must make a judgement, in many cases, as to which of the several identical civilian airport beacons identifies his desired destination. Not infrequently the pilot suffers confusion and even, occasionally, the embarrassment of landing at the wrong location. At larger airports the pilot may be assisted by radar vectoring from an approach control facility; but, at many smaller air carrier airports, he must continue to rely on visual approaches with the attendant identification problem being a significant factor.

Deficiencies/Enhancements: Navigation aids available today can easily place the pilot in the vicinity of the airport he seeks, but cannot precisely indicate to the pilot the exact location of his destination airport. Present standards do not provide for a unique difference between identification beacons for air-carrier and Non-air-carrier airports.

Sources of Information: Staff personnel of the Air Line Pilots Association provided this input during telephonic interviews in November 1991. This was confirmed during personal interviews with pilot representatives at their Washington DC headquarters in January, 1992.

Future Research: The work effort should focus on the development and testing of unique identification devices. Studies would need to be accomplished on possible solutions through alternate configurations. New systems or modifications to existing systems should be considered.

6.3.1.3 Pilot Controlled Lighting System Status Verification.

Background and Past Studies: At lighted airports in the United States, control of airport lighting systems is normally located in the airport control tower (if one is situated at the airport) or at a facility chosen by the airport operator. Since aviation is a 24 hour a day activity, lighting must be available for nighttime and low visibility operations. Airports traditionally would turn the lights off at night or leave them on when the airport was unattended. Over the years a number of situations have arisen which stimulate the need for a remote controlled system. Budget restrictions prevented control tower manning at many locations and around the clock at other locations. Increased cost for generating electrical power mandated conservation. Finally, the growth in aviation activity stimulated demand for availability of lighting at all hours. At many locations the airport operator provides full services during limited hours, but chooses to make other facilities available during the remainder. One solution was to leave the airport lights on, but this was wasteful and expensive for the level of traffic served. A requirement thus developed for operating airport lighting remotely by the user pilot. During the 1960's and 1970's air-to-ground lighting technology progressed, and in 1977 an advisory circular was published on Air-To-Ground Control of Airport Lighting Systems (reference 34). The number of airports with these systems installed has significantly expanded over the years.

The current pilot controlled lighting systems were developed in the 1960's to 1970's. They are somewhat deficient, however, in that no verification of lighting system status is included in the system design. New advances in control system design might now allow addition of a device to aurally confirm the selected setting of pilot-controlled airport lighting systems. Over the years the number of airports equipped with pilot controlled lighting has increased dramatically. Today many airports have these systems installed. To operate these systems remotely the pilot "clicks" the microphone several times to select a specific position and/or level of lighting intensity. A problem exists with regard to the actual status of the selected system - the pilot has no means of knowing what intensity the lights are at, or even whether they have been activated.

Deficiencies/Enhancements: A system enhancement is needed to provide the pilot with confirmation that the selected system status has been activated.

Sources of Information: The engineering and air safety staff of the Air Line Pilots Association (ALPA) provided this input during meetings at the Washington Headquarters of the organization in January, 1992. This was subsequently corroborated at meetings with the Aircraft Owners and Pilots Association (AOPA) staff at their facility in Frederick, Maryland. Airline and General Aviation Pilots believe an identification of actual lighting system status to be a desirable feature for all pilot controlled lighting systems.

Future Research: The work plan should focus on the development of either a totally new system for pilot control of lighting systems or the modification of existing systems. An initial approach to developing a feedback signal for pilots would be to survey manufacturers of radio control technology to determine possible aural codes that could be incorporated as responses from the ground equipment. The confirmation signal could take the form of an aural tone or synthesized voice response to the pilot via ground-to-air radio. Current radio control technology is such that this should require a relatively unsophisticated return signal, but would, of course, require addition of a simple transmitter at the ground site.

6.3.1.4 Vertiport Lighting and Marking Aids.

Background and Past Studies: FAA visual guidance (Airport Lighting and Marking) developmental and evaluational activities have traditionally included efforts in the areas of runway and taxiway lighting and marking, obstruction lighting, distance-to-go markers, and other airport visual aids. Testing has been concentrated, for many years, at the FAA Technical Center in Atlantic City, and has only recently included the development of approach lighting systems for heliports and helipads (reference 35). While some of this work has involved improvements and enhancements for common systems, ever increasing emphasis has been placed on developing and testing visual systems intended to provide better guidance under decreasing visibility airport operations. Rapid and wide-ranging improvements to commercial aircraft electronic navigation and guidance systems, along with the enhancement of aircraft performance capabilities, have brought us to the point where landing and takeoff operations can be conducted almost independently of weather visibility restrictions. The pilot, in many instances, serves only to monitor proper functioning of automatic control systems in the aircraft and rarely, if ever, is called upon to manually control the aircraft. These state-of-the-art control and guidance systems are, however,

found only on the most sophisticated aircraft, i.e., those manufactured during recent years. These "smart" aircraft constitute only a very small percentage of the total commercial air carrier inventory at the present time. In terms of helicopter operations, recent developments in aircraft such as the tiltrotor offer opportunities for lower visibility operations with vertical takeoff/landing (VTOL) vehicles. Vertiport lighting and marking systems will be essential in providing the enhanced visual guidance required by the pilot to either maneuver the aircraft or, at least, to visually monitor performance of automatic guidance systems.

Vertiport lighting and marking, at least with regard to systems intended to support instrument approach and landing operations, is still in its infancy, and much developmental work remains to be done. The FAA Technical Center has led the world in creating prototype visual systems to support helicopter instrument flight rules (IFR) operations, while the International Civil Aviation Organization (ICAO) has yet to speak on the subject except in the most basic terms. In fact, it seems quite possible that the imminent introduction of commercial tilt-rotor and tilt-wing aircraft may overshadow the importance of pure helicopter usage. Therefore, development of visual aids for vertiports will be a major effort within the immediate future, and will involve considerable expansion of the work already accomplished in designing systems for pure heliports. Increasingly sophisticated airborne avionics are permitting aircraft operations (i.e., approach, landing, takeoff and taxi) in dramatically lower visibility weather conditions and, to keep pace with these rapid technological advances, the visual aids provided to support vertiport operations must be continually improved and enhanced.

Deficiencies/Enhancements: Existing visual guidance systems were developed originally for fixed wing operations. While somewhat compatible with the unique operating characteristics of aircraft capable of vertical flight (i.e., steep approach angles, hover taxiing, etc.), they do not support maximum effectiveness. Restricted land areas available at most vertiport locations limit the extent to which conventional visual systems may be utilized, necessitating the development of more compact configurations.

Sources of Information: Conversations with Helicopter Association International, Alexandria VA, June 1992.

Future Research: The approach to development and proving (testing) of vertiport lighting and marking systems should involve the following: Consideration of the guidance requirement (what information must we transmit to the pilot) and a determination of methods (devices) available for accomplishing this.

Evaluation of evolved systems should be accomplished in conjunction with the military, as a joint effort, since concentrated populations of potential civilian evaluators are virtually non-existent. Furthermore, the military will, without doubt, be the first to field true vertical take-off and landing (VTOL) aircraft, and will be the sole users of these sophisticated vehicles for some time to come.

6.3.1.5 Approach Light System Component Reduction.

Background and Past Studies: Approach lighting is an essential component of the overall airports lighting system, with these lights particularly important in instrument conditions. The first approach lights were used by the Navy in World War II. In the mid-1940's the Civil Aeronautics Administration (CAA) sponsored research into approach lighting improvements, performing work at the Newark, New Jersey airport. Additional work was performed at other locations as well. The CAA established a Technical Development and Evaluation Center at Indianapolis, Indiana, to support research activities. At the same time experimental work was also underway at the National Bureau of Standards Landing Aids Experimental Station located at Arcata, California. Here fog formation characteristics and visibility effects were subjected to detailed scientific analysis with emphasis on the aviation perspective (reference 36). Approach lighting aiming angles were determined through long periods of observation and testing (reference 37). In the 1980's, the British began a program to investigate the possibility of reducing the total number of lights in systems designed to support approach and landing operations (reference 38). Little research however has been done on the degradation effects of loss of individual light barrettes on the total effectiveness of the system. The problems of illusory perceptions are magnified during the critical transition from approach to landing, and such research is needed to establish the effects on landing minimums and to improve maintenance procedures. Conversely, it may be possible to reduce the number of lights in certain systems without degrading effectiveness, and thereby lowering both installation and maintenance costs.

The system effectiveness of an approach lighting system may be degraded by the loss of multiple individual segments of the system. Similarly loss of a single barrette may not be of significance in reducing system effectiveness. Lack of an empirical data base precludes such determinations at the present time. It is not known if the light beam orientations provide enough overlap between individual barrettes to offer coverage without degrading the system. Jet aircraft are particularly vulnerable to any reduction in visual cues because acceleration is slow in the event that course corrections are necessary. The approach lighting system represents an extension of the runway itself and, at the low visibilities where this system is most important, allows the pilot to make the final judgements necessary for a safe landing.

Deficiencies/Enhancements: Existing approach lighting systems are comprised of a high density of individual light sources. It is most likely that elements of the system, either individual lights or entire segments of the system, can be eliminated without jeopardizing the effectiveness of the overall configuration. The extent to which this reduction in components can be accomplished is not presently known. A need exists to determine the effects of reduced system performance. The result will be a more efficient system that will produce savings in power consumption and overall costs.

Sources of Information: The concern was identified during meetings with the staff of the Air Line Pilots Association. Adequacy of the present aiming criteria for the medium intensity system (MALSR) was identified as a concern of Transport Canada.

Future Research: Research efforts should be directed toward analysis of the effectiveness of approach lighting system from the perspective of the pilot at various points within the system. The approach should incorporate human factors analysis to determine the limitations of human performance. Factors to be considered include the vertical and horizontal beam spreads at station locations and intensity distribution of the selected lamps. The test effort should include proof of results testing following analysis, and should be of sufficient duration to establish recommendations of effects on landing minima.

6.3.1.6 Enhanced Visual Glidepath Aids.

Background and Past Studies: Signal Lights have been used since the early days of aviation. Signal lighting such as Visual Approach Slope Indicators provide a visual path for the pilot to fly the airplane safely to the runway pavement. For many years the VASI was the standard visual approach aid and many are still in use today. In the late 1970's and early 1980's, research work at the Royal Aircraft Establishment located in Bedford, England resulted in the development of a new device, the Precision Approach Path Indicator (PAPI) (reference 39). This device provides specific selectable glide path increments of 20 minutes of arc. The system is identified as the future FAA and ICAO standard for approach indicators (reference 40). The PAPI system while a major advance over the VASI, remains limited in acquisition distance with typical daytime effectiveness of about five miles. Increasing the effective acquisition and utilization distance will require new lamp technology such as a laser can provide. Past studies, utilizing Laser technology, have been accomplished by the Russians in the mid 1980's using a system termed "Glacada". The U.S.Navy is currently evaluating a laser -based system for carrier aircraft. This program is termed the Laser Visual Landing Aids (LVLA) program and incorporates a laser localizer and a laser glideslope indicator (reference 41). Low powered visible lasers are used to provide visual approach path information.

The most difficult task of the pilot when flying the airplane visually is to effectively judge the approach and landing. An accurate approach slope indicator is essential for the performance of the landing task. The primary current systems for depicting visual glide path information for pilots are the PAPI and VASI systems. These systems have proven useful over the years in providing essential visual cues for pilots to be able to land safely.

Deficiencies/Enhancements: Existing systems have a limited acquisition range, typically providing daytime effectiveness of about five miles range. A need exists to extend the current acquisition distance miles to 10 miles or greater. Airline pilots, in a recent survey on visual needs, identified the lack of these devices on certain runways as the largest approach deficiency in visual aids on airports (reference 42). This deficiency, however, is not an R&D problem, but rather one of funding shortfalls.

Sources of Information: Naval Air Engineering Center personnel provided information on their test activities during meetings at that location in November 1991. Air line pilots confirmed the need for new and improved Visual Glide path Systems through questionnaires completed during April, 1992. Additional information was provided by officials at Humbug Mountain Laboratories and various universities.

Future Research: The work effort should focus on development and testing of enhanced light source systems. Some studies need to be conducted to identify the best potential configurations and modifications to existing devices. Modification of existing and/or totally new systems may be employed. Conduct of a joint research effort with the Navy might be considered, to take advantage of work with laser devices that they have already accomplished.

6.3.1.7 Visual Aids for General Aviation Airports.

Background and Past Studies: Small Airports have unique visual guidance requirements. While the basic needs of a pilot for visual guidance cues in approach and landing are similar for all airport environments, the simplicity of the small airport's layout, the lack of sophisticated instrument approaches, and the limited variety of aircraft that may use the facility often means that fewer visual aids are required. Over the years a variety of research efforts have occurred involving visual systems for smaller (i.e., non air-carrier) airports. Focus on the evolving differences between the more and less sophisticated airports began to receive attention in the 1960's, as jet aircraft began to dominate at the larger airports. Enhanced aids were developed for use at the larger airports in order to provide increased safety at the higher speeds of jet aircraft. At the same time general aviation was expanding significantly with the great majority of the 18,000 United States airports also requiring visual aids of less expense and sophistication. In response to these expanding but diverse requirements, various studies were conducted. In 1961, The National Bureau of Standards conducted a study on lighting requirements specifically for small non-commercial airports (reference 43). In 1970 the FAA Technical Center (then NAFEC) performed a study of visual aids for secondary airports that resulted in specific recommendations for a variety of devices (reference 44). Concurrently, the FAA published a change to the advisory circular on Economy Approach lighting Aids, which circular had been last published in 1967 (reference 45). Later, in the 1970's, a variety of research projects were performed at the FAA Technical Center on visual aids for smaller airports, with special emphasis on systems for use with turf runways (reference 46). Additional research and development has been accomplished on marking and lighting of unpaved runways (references 47 and 48), as well as for economical lighting aids such as low cost omni-directional lights (reference 49) and unlighted retro-reflective distance remaining markers (reference 50). In December 1992, the FAA included new criteria for visual guidance systems to support unpaved runway operations in a new draft revision to the marking advisory circular (reference 51). While previous research has been extensive, small airport operators have expressed a need for additional work on inexpensive beacons, signs, and lighting aids.

The limited budgets provided for many, if not most, small airports restrict the procurement of standard signs and other expensive lighted aids. Despite this dearth of funds, these visual guidance devices are necessary to support general aviation as well as commercial airport operations.

Deficiencies/Enhancements: The limited budgets provided for many, if not most, small airports restrict the procurement of standard signs and other expensive lighted aids. Because smaller airports do not have the resources to afford sophisticated visual guidance systems, at the current time effective visual

aids do not exist at many locations. Despite this shortage of funds, these visual guidance devices are necessary to support general aviation as well as commercial airport operations. Simplified, economical, and adequate aids standardized by the FAA are needed to be developed at low cost and made available to smaller airports.

Sources of Information: General Aviation Manufacturers Association, Aircraft Owners and Pilots Association, NASAO.

Future Research: The research effort should be tailored to the broad needs of secondary and small airports, bearing in mind that economy of cost and maintenance is a paramount consideration. This includes approximately 15,000 facilities around the country. The initial effort should survey the small airport operators and supporting professional organizations to determine various needs, with follow-on efforts structured to meet the requirements that have been identified. The work efforts should include such efforts turf runway markings, use of highway reflectors on pavements, reflectorized (non-powered) signs, and development of a low cost airport identification beacon.

6.3.1.8 Closed Runway Visual Aids.

Background and Past Studies: The development of visual guidance devices for warning pilots of closed runways and taxiways probably goes back at least to the 1940's. The use of an "X" as a marking device on the runway is common to both military and civilian applications. As an example, the United States Air Force prescribes a 60 foot cross for use on closed runways and a 30 foot cross for closed taxiways (reference 52). The cross is painted on permanently closed runways and may be fabricated of plywood, canvas, or picket fences for temporarily closed runways. The FAA, in Advisory Circular 150/5340-1, Marking for Paved Areas on Airports, provides similar dimensions for closed runway crosses, as well as providing elongated versions up to 120 feet in length for identifying closed pavements. In addition crosses are placed in the center of the segmented circle, or in the center of the airport if the entire airport is closed. Pavement markings for the closed runway condition are thus well established, and effectively depict runway closure.

Problems arise however when runways are lighted during periods of temporary runway closure for snow removal operations or runway inspection. At these times some form of lighted aid is desirable to provide additional warning of the closed runway condition. The need for portable aids was addressed in the 1980's when a temporary runway closure device was developed at the FAA Technical Center (reference 53). These devices will be included in the next revision to the marking advisory circular and are now being manufactured for sale.

The need to identify closed runways is a safety issue, a necessity to protect aviators and ground personnel alike. Surfaces under construction have caused damage to airplanes landing inadvertently in the past. In addition, incidents have occurred wherein closed runways have been used by pilots unable to see snow covered painted closure markings. Additionally, some airport operators feel that there is a need for a more rapid means of indicating runway status changes, particularly during snow removal, and that permanently installed devices should be developed for airport installation.

However, in cases where multiple runways are involved in frequent closures, a need has been expressed for development of a large, permanent runway closure indicator. The primary application of such devices would be for large air carrier airports conducting frequent snow removal operations.

Deficiencies/Enhancements: No standard exists for permanently installed visual aids intended to identify and warn of temporarily closed runway status. Further, no device or visual aid configuration has been developed that might serve this purpose as a standardized item.

Sources of Information: Airport Association Council International, Air Line Pilots Association, Manufacturers.

Future Research: The work effort should focus on development and testing of a permanently installed device to indicate closure of a runway. Past research work on portable devices should be considered to facilitate the development effort and avoid duplication. Incorporating and integrating the design into existing approach lighting systems might reduce costs and facilitate retrofitting such a device at existing airports. Initial work should be to develop the configuration for the device and to determine its placement.

6.3.1.9 Inexpensive Visual Guidance Aids For Helipads.

Background and Past Studies: Helipads, as opposed to full service vertiports, are unique in their visual guidance requirements. While the basic pilot needs for visual guidance cues in approach and landing are similar for all aviation environments, the small dedicated use (hospital, emergency, police, etc.) helipad is often provided with only a minimal array of visual aids. Over the years a variety of research efforts have addressed vertiport visual guidance. Testing has been conducted, for many years, at the FAA Technical Center in Atlantic City, and has only recently included the development of approach lighting systems for heliports and helipads (reference 54). While some of this work has involved aids suitable for use at smaller landing facilities, most has been oriented toward the more sophisticated vertiport landing facility. In the 1970's, the FAA Technical Center (then NAFEC) flight tested IFR landing aids at the Center (reference 55), and, in the 1980's, conducted simulation tests of new approach lighting systems for helicopter operations. Recently, the Visual Guidance Section of Airport Technology has been evaluating new visual approach guidance devices for helicopter operations on helipads. Other areas of concern, however, have been identified by helicopter organizations, with such being the lack of conspicuity of helipads when surrounded by city lights. Another problem for small helipad owners is the expense of traditional visual guidance devices. Several thousand helipad landing sites exist around the country, and inexpensive aids are needed to enhance conspicuity and safety of operations.

The visual aids provided to support helipad operations must be continually improved and enhanced. Limited budgets are a fact of life for procurement of signs and other expensive lighted aids. At the same time visual guidance devices are necessary for helicopter pilots operating at night into many helipads.

Deficiencies/Enhancements: Aids, such as visual glide path indicators, helipad beacons, and other visual guidance systems presently available, are frequently too costly and/or complex for use at basic helicopter facilities. Restricted land areas available at most vertiport locations limit the extent to which conventional visual systems may be utilized, necessitating the development of more compact configurations. The limited budgets provided for many, if not most, small helipads restrict the procurement of standard signs and other expensive lighted aids. Because smaller heliports do not have the resources to afford sophisticated visual guidance systems, at the current time effective visual aids do not exist at many locations.

Sources of Information: Conversations with Helicopter Association International, Alexandria VA, June 1992.

Future Research: The initial effort should include a survey of typical small, dedicated use helipads to determine the areas of greatest need for visual aids. Once the requirements are established, a logical follow-on effort would be to examine the existing, more sophisticated standard vertiport visual aid systems for possible simplification. It is anticipated that work efforts will be conducted on specific sub-areas such as: inexpensive markings, use of highway reflectors in lieu of lights, reflectorized signs, and development of a low cost helipad identification beacon as a minimum.

6.3.1.10 Temporary PAPI System.

Background and Past Studies: For many years the Visual Approach Slope Indicator (VASI) had been the standard approach slope device used for visual guidance by pilots, with thousands of these devices remaining in use today. In the late 1970's and early 1980's research work at the Royal Aircraft Establishment, located in Bedford, England, resulted in the development of a new device, the Precision Approach Path Indicator (PAPI). The PAPI is designed to provide sharper and better defined indicators of glide path than VASI. This device provides five discrete glide path increments of 20 minutes of arc, and has been established as the future FAA and ICAO standard for approach indicators. Current specifications for the PAPI do not include temporary PAPI criteria (reference 56), although other nations have already developed temporary PAPI specifications. The British made extensive use of such "quick set-up" systems during their invasion of the Falkland Islands in the 1980's, and a similar form of PAPI system would prove most useful for use with temporarily displaced thresholds during construction activities.

Since the most difficult task of the pilot when flying the airplane visually is to effectively judge the proper approach angle prior to landing, an accurate approach slope indicator is essential to the performance of the landing task. During construction the normal approach slope systems frequently are disabled, with displaced thresholds established to allow operations to continue. Air Line pilots have repeatedly identified the lack of approach slope indicators on air carrier runways as a major safety deficiency, and provision of such systems at locations having construction activities in the approach zone may be even more critical.

Deficiencies/Enhancements: No current criteria exist for the installation of temporary PAPI systems. During construction the use of such systems is beneficial in the event of displaced thresholds made necessary by construction activity. Lack of definitive standards may result in temporary PAPI installations that fail to provide the necessary visual guidance or, in the worst case, project false and/or misleading information to the pilot.

Sources of Information: Air Line Pilots Association, Manufacturers.

Future Research: The work effort is expected to be minimal. Initial effort would be a study to identify the best temporary PAPI configuration (probably a two-unit abbreviated system) and equipment modifications that would be required to permit temporary set-up. Focus should be on a system that requires the minimum amount of equipment modification and, ideally, one that can be assembled using PAPI components already on site. Initial developmental testing should evaluate simplicity, reliability, and ease of siting and establishing proper aiming angles. Testing should evaluate these factors objectively. The PAPI system specification (150/5345-28) should then be revised to incorporate the necessary changes. Manufacturers might be encouraged to develop and market temporary installation "kits" for conversion of standard PAPI systems as the need arises.

6.3.2 Surface Guidance Systems.

This category covers surface movement guidance systems on the airport, to include those serving runways, taxiways, and apron areas. It includes marking, lighting, signs and other visual aids.

Table 6.2 depicts potential research areas intended for improvement of surface guidance systems:

TABLE 6.2 SURFACE GUIDANCE SYSTEMS

● LOW VISIBILITY SIGN SYSTEMS	6.3.2.1
● IMPROVED METHODS FOR DEFINING LOW VISIBILITY SURFACE CLEARANCE LIMIT LOCATIONS (MARKING, SIGNS, ETC.)	6.3.2.2
● ADDRESSABLE SIGNS	6.3.2.3
● BASIC SIGN RESEARCH TECHNOLOGY	6.3.2.4
● ALTERNATIVE MARKING MATERIALS FOR AIRPORTS	6.3.2.5
● SPECIAL VISUAL AIDS FOR LARGE PAVED AREAS	6.3.2.6
● APRON VISUAL GUIDANCE AIDS	6.3.2.7
● DOCKING GUIDANCE AIDS	6.3.2.8
● TAKEOFF HOLD BARS	6.3.2.9
● FLASH CHARACTERISTICS OF "WIG-WAG" LIGHTS	6.3.2.10

6.3.2.1 Low Visibility Sign Systems.

Background and Past Studies: Signs are among the most basic, but also most important, visual aids used on airports and as, on highways, provide the viewer with critical information. The use of signs on airports has expanded since the 1940's, when signs were few and far between. Today there are several categories of signs as described in the FAA Advisory Circular Standards for Airport Sign Systems (150/5340-18). The various types include mandatory signs for identifying critical areas such as runways, information signs to identify taxiways and destinations, and miscellaneous signs for other purposes such as defining runway distance remaining. The color of such signs differ with regard to purpose. It was only in the late 1940's, as air operations increased significantly, that signs began to proliferate on airports. The CAA Taxiway Sign Evaluation Committee visited a number of airports in the early 1950's to develop recommendations for signs, and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1952 the United States Navy commissioned an airport lighting and signage study by Dunlap and Associates that provided much of the groundwork for the "L-829" sign specification that was issued by the CAA in 1955. With the advent of the jet age in the 1960's, and attendant higher speeds and aircraft sizes, improvements in signage became imperative. John F. Kennedy Airport in New York was a leading sponsor of research that led to recommendations for use of different colors for differing sign messages. During this period the FAA Technical Center in Atlantic City (under its former designation as NAFEC) was also exploring the advantages of various sign color combinations. Following the publishing of these research results, the standardization of unique colors for specific sign purposes was adopted by FAA and the International Civil Aviation Organization (ICAO). Subsequent sign designs have followed these guidelines.

In 1992, the sign depiction location guidelines were revised with the promulgation of Change 1 to the 18C edition of AC 150/5340-18. Increased interest in the prevention of runway incursions has focused attention on improving sign performance. Low visibility performance is a particular concern. The new emphasis on sign performance is a result of several widely publicized accidents involving runway incursions, almost certainly resulting from pilots becoming lost on the airport in bad weather. Since effective sign systems significantly reduce the occurrences of pilot disorientation, they play a key role in preventing inadvertent runway incursions. New technology offers potential for significant sign improvement.

Deficiencies/Enhancements: Present standard airfield signs are adequate for providing taxi and warning guidance during reduced visibility conditions to a lower limit of Category II. They cannot be considered effective for operations conducted in Category III conditions, however, since existing designs require placement well clear of the taxiway so as not to constitute an obstruction. Some form of sign that may be located on the taxiway surface, within the pilot's immediate field of view is needed to satisfy the low-visibility guidance requirement.

Sources of Information: ALPA, Runway Incursions Working Group, Pilot Questionnaires.

Future Research: Research efforts should focus on hardware and light source improvements to the L-858 sign (reference 57). An ideal objective would be to produce a sign visible at 500 feet in visibility of 300 RVR, although this may well be unattainable. Allard's Law defines the relationship between atmospheric transmissivity, distance and intensity for achieving a desired level of illuminance at the observer's eye. The restrictions of the effects of reduced visibility inherently depicted in Allard's Law will limit what can be achieved. The work effort should thus focus on exploring new means to increase light output through improvements to existing systems and development of totally new systems.

New technology may be of benefit and should be explored. Possible applications include use of laser light sources and fiber optic pipes to provide enhanced performance.

6.3.2.2 Improved Methods for Defining Low Visibility Surface Clearance Limit Locations (Marking, Signs, etc.)

Background and Past Studies: The expansion of low visibility operations in Category IIIB, and even IIIC, conditions has mandated a need for more effective systems to identify specific locations on the airport. Pilots must be able to accurately inform Air Traffic Control (ATC) of their position at all times, since ATC will have sole responsibility for aircraft separation on the ground. Signs are among the most basic, but also most important, visual aids used on airports and as, on highways, provide the viewer with critical information. The use of signs on airports has expanded since the 1940's, when signs were few and far between. Today there are several categories of signs as described in the FAA Advisory Circular Standards for Airport sign Systems (150/5340-18). The various types include mandatory signs for identifying critical areas such as runways, information signs to identify taxiways and destinations, and miscellaneous signs for other purposes such as defining runway distance remaining. The color of such signs differ with regard to purpose. It was only in the late 1940's, as air operations increased significantly, that signs began to proliferate on airports. The CAA Taxiway Sign Evaluation Committee visited a number of airports in the early 1950's to develop recommendations for signs, and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1952 the US Navy commissioned an airport lighting and signage study by Dunlap and Associates that provided much of the groundwork for the "L-829" sign specification that was issued by the CAA in 1955. With the advent of the jet age in the 1960's, and attendant higher speeds and aircraft sizes, improvements in signage became imperative. John F. Kennedy Airport in New York was a leading sponsor of research that led to recommendations for use of the present color standard for differing sign messages. During this period the FAA Technical Center in Atlantic City (under its former designation as NAFEC) was also exploring the advantages of various sign color combinations. Following the publishing of these research results, the standardization of unique colors for specific sign purposes was adopted by FAA and the International Civil Aviation Organization (ICAO). Subsequent sign designs have followed these guidelines. Recent major projects of significance have included evaluation of geographical hold point location markings (reference 58), a determination of sign effectiveness under low visibility conditions, development and testing of "hold-short" lighting systems for identification of runway intersections, and testing efforts underway on a new stop-bar lighting system (first in the United States) for Category IIIB operations at SEATAC International Airport in Washington.

Deficiencies/Enhancements: Painted taxiway surface markings, exemplified by the "pink spot" concept mentioned above, have proven to be relatively ineffective when aircraft taxi lights are reflected over a broad area by standing water on the taxiway surface. Taxiway in-pavement holding position lights serve to indicate a holding position, but do not identify it as a unique location. A simple system for providing precise location information to pilots, under low visibility conditions, is essential for maintaining aircraft separation on taxiways. The ability to define clearance limit locations adequately has received emphasis as a result of several widely publicized accidents involving runway incursions. Since effective marking and sign systems significantly reduce the occasion of pilot disorientation, they play a key role in preventing inadvertent runway incursions. Low visibility operations are now being conducted at 300 RVR which is beyond the parameters for which current visual aids were designed.

Sources of Information: ALPA, Runway Incursions Working Group, Pilot Questionnaires.

Future Research: Work effort should focus on exploring new means to identify hold points, to include improvements to existing systems and possible new systems. Existing systems to be improved encompass lighting, markings and signage systems. New technology may be of benefit and should be explored. Possible applications include use of lasers and fiber optics to provide enhanced performance to lights and signs. New retro-reflective and internally lighted markings may also be of benefit.

6.3.2.3 Addressable Signs.

Background and Past Studies: Sign guidance has evolved over the years since the first signs appeared on airports. Today there are several categories of signs as described in the FAA Advisory Circular Standards for Airport Sign Systems (150/5340-18). The various types include mandatory signs for identifying critical areas such as runways, information signs to identify taxiways and destinations, and miscellaneous signs for other purposes such as defining runway distance remaining. The color of such signs differ with regard to purpose. It was only in the late 1940's, as air operations increased significantly, that signs began to proliferate on airports. The CAA Taxiway Sign Evaluation Committee visited a number of airports in the early 1950's to develop recommendations for signs, and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1952 the United States Navy commissioned an airport lighting and signage study by Dunlap and Associates that provided much of the groundwork for the "L-829" sign specification issued by the CAA in 1955. With the advent of the jet age in the 1960's, and attendant faster speeds and larger aircraft sizes, improvement in signage became imperative. John F. Kennedy Airport in New York was a leading sponsor of research that led to recommendations for use of different colors for differing sign messages. During this period the FAA Technical Center in Atlantic City (under its former designation as NAFEC) was also exploring the advantages of various sign color combinations.

In the 1970's, the development of fiber optics enabled the variable message sign to be manufactured for traffic applications. Subsequently, sign manufacturers developed variable message and later programmable message signs using computers

to display the desired messages on large signboards. Large addressable signs became common in sports facilities, auditoriums and on highways. These addressable signs have potential uses in complex intersection signage on airports.

Increased interest in sign performance is a result of several widely publicized accidents involving runway incursions, almost certainly resulting from pilots becoming lost on the airport in bad weather. Since effective sign systems significantly reduce the occurrences of pilot disorientation, signs play a key role in preventing inadvertent runway incursions. Addressable technology offers potential benefits for significant sign improvement in applications involving complex intersections and in variable traffic control situations.

Deficiencies/Enhancements: Addressable signs, while widely used in highway applications, are not available in forms suitable for use on airports. Since the most critical application on airports would obviously be for use under low visibility conditions, when surface traffic patterns are subject to frequent change, current addressable sign technology must be modified to provide the required enhanced capability.

Sources of Information: Manufacturers, FAA Regulatory Personnel, Universities

Future Research: Initial testing of available production or prototype signs should identify any performance deficiencies in low visibility conditions by determining actual acquisition and identification distances. A detailed study should be performed on beneficial uses of the technology at complex airports and intersections. Other potential applications may include such diverse uses as apron taxilane control and docking aids, among others. After performance criteria are established, and potential applications specifically identified, test configurations should be developed and installed for evaluation. The evaluation should determine effectiveness of the following characteristics; color, hue, size, light output, contrast, and shape. Follow on work should include development of new standards for addressable sign applications on airports.

6.3.2.4 Basic Sign Research Technology.

Background and Past Studies: The effectiveness of airport signs has been the subject of considerable research over the years. Early signs were primitive, unlighted, and conveyed minimal information. As airport operations became more complex and sophisticated, the number of signs began to proliferate. Signs helped reduce early Air Traffic Control frequency congestion, but the proliferation of signs, conversely, created the need for standardization among airports and sign manufacturers. In the early 1950's, the CAA Taxiway Sign Evaluation Committee visited a number of airports to develop recommendations for signs, and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1952 the US Navy commissioned an airport lighting and signage study by Dunlap and Associates that laid much of the groundwork for the "L-829" sign specification that was issued by the CAA in 1955. In later years, as improvements in signage again became imperative, John F. Kennedy Airport in New York became a leading sponsor of research that led to recommendations for use of different colors for differing sign messages. During this period the FAA Technical Center in Atlantic City (under its former designation as NAFEC) was also exploring the advantages of various sign color combinations.

Early work on sign effectiveness focused on the issues of conspicuity versus legibility. In 1950, an IES Aviation lighting Sign Subcommittee observed signs under various weather conditions at various distances, and it was decided to place emphasis on conspicuity. The consensus was that it was most important to attract attention to signs prior to actually being able to read them. In addition, the IES Committee recommended that signs should be recognizable in 1/16th mile visibility at 500 feet. It was later decided by the CAA that the a more realistic criteria would be for recognition at 500 feet under 1/2 mile visibility conditions.

In the 1960's the issue of color began receiving greater recognition, and the New York Port Authority found that color recognition conspicuity exceeded legibility distances by 30 percent. Standards were subsequently developed for new signs that require 800 foot recognition distance as in the L-858 sign specification. Color coding was later implemented, and led to the 1970 Advisory Circular on signs for the color schemes currently in use. Since that time little work has been done in this particular area. Of late the importance of low visibility operations has focused attention on the basic issues of conspicuity and legibility. New studies are now needed to formulate low visibility sign requirements for the more critical present day airport operating conditions.

Deficiencies/Enhancements: Various characteristics contribute to the effectiveness of signs. These include color, hue, size, light output, contrast, and shape. Sign size, configuration, and color attributes are currently based on studies performed in the 1950's and 1960's. The present L-858 sign criteria is based on theory and assumptions that may now be outdated due to marked increases in aircraft size and occurrences of lower visibility operations. More research is needed on these basics.

Sources of Information: Air line Pilots Association, Sign Manufacturers.

Future Research: The work effort should focus, initially, on identifying required recognition distances for differing operational conditions (weather). This data can best be obtained from user pilot organizations and the FAA operational services, and must be available before any type of hardware evaluation can be undertaken. Variations in sign dimension, illumination, and color significantly affect performance, and should be the subject of early evaluation efforts to achieve improved performance. Considerable valuable information resulting from work already accomplished may be gathered from both domestic and overseas sources.

6.3.2.5 Alternative Marking Materials for Airports.

Background and Past Studies: Surface markings are essential visual aids for safe movement on airports and are traditionally applied with paint. Advisory Circular 150/5340-1G (Marking of Paved Areas on Airports) specifies marking configurations, but does not specify materials to be used. Material specifications are included in Advisory Circular 150/5370-10 (Standards for Specifying Construction on Airports) (reference 59). Many studies have been accomplished over the years on effectiveness of markings, and a great deal of work has been done by highway departments as well as aviation organizations in attempting to develop improved performance (reference 60). Recent work indicates that no one type of marking or application technique is suitable for

every situation (reference 61). Aviation marking standards in Part 139 do not require any level of reflectivity or performance, but rather simply state that markings, if provided, must be maintained in good order. New materials may offer significant advantages in aviation applications.

Deficiencies/Enhancements: Current marking systems have been criticized for inadequate performance under low visibility circumstances and during periods of runway contamination, particularly under standing water conditions at night. New standards for adequate levels of reflectivity are therefore required for runway and taxiway pavement markings. Alternative materials are now available for use on airports, which new materials may enhance runway and taxiway conspicuity under adverse weather circumstances and during night operations.

Sources of Information: Questionnaire presented to airline pilots-April, 1992.

Future Research: An evaluation of various reflective and non-reflective paints is necessary to determine the minimum level of pavement marking reflectivity necessary to support safe aircraft operations on airports. Tasks will include a review of past studies in this area. Other activities to be performed include the analysis of various reflective and non-reflective materials to determine likely candidates for evaluation. These may include glass-beaded, plasticised materials, and reflective tapes, as well as paint varieties. Environmental considerations should be included as a major concern among the factors to be evaluated. Work efforts should focus on the development and testing of unique identification devices. Studies would need to be accomplished on possible solutions/configurations.

6.3.2.6 Special Visual Aids for Large Paved Areas.

Background and Past Studies: Large paved areas offer particular concern for developers of visual guidance systems due to the lack of contrast on broad expanses of pavement. Contrast is a function of brightness difference and of the size of the area. Normally taxiways are bordered by grass or dirt areas which provide definition and contrast for visual cues. Vast expanses of pavement area, conversely, do not offer natural definition, and all guidance must be artificial. Additional lights, signs, and markings must be provided to guide aviators and ground support personnel alike.

A variety of techniques have been employed over the years to highlight the taxi lanes to be followed on large paved surfaces. The most common is to paint edge markings that outline the traversable surface. This technique (use of continuous double yellow lines) is discussed in FAA Advisory Circular 150/5340-1. Another technique is to mark non-traversable areas with 3-foot stripes perpendicular to the edge stripes, up to a length of 25 feet. These techniques are adequate, to a certain extent, but are for use primarily in daytime and good visibility conditions.

Because of continuing problems with pilots becoming disoriented, certain airports have gone to great lengths to solve the wide paved area delineation problem. Physical barricades have even been employed at certain airports, as a last resort. In some cases the solution has been to tear up sections of concrete in an attempt to eliminate the problem entirely. This of course is very expensive and can adversely affect capacity by reducing air traffic control options. In other cases, the problems have led to local solutions that, while

innovative, have seldom proven totally successful. As an example, one major air carrier airport has painted sections of pavement green simulating grass to define the taxi surfaces (reference 62). Other airports are using edge reflectors on wide area surfaces. St. Louis' Lambert Field has experienced problems at a wide area intersection and, several years ago, installed wig-wag lights to identify the runway entrance area. This has proven effective in reducing runway incursions. The use of flashing lights to identify specific locations within wide areas are among the aids proposed for these types of locations. Some research material may be available from such overseas sources as the Spanish government, since they have accomplished considerable work toward solving this problem at Madrid Barajas Airport.

Deficiencies/Enhancements: Efforts to resolve this problem in the past have been relatively ineffective since they relied upon painted markings and/or lights to define the useable movement surface. Painted markings frequently "disappear" in the presence of standing surface water, and lights identifying the desired path often merge into those of other paths when viewed from low cockpit heights. Conventional systems, such as point source edge and centerline lights and surface markings, have not provided the solution to the problem since standing water on the surface reflects all ambient light, with the result that markings become virtually invisible. Therefore, a comprehensive investigation of the large pavement problem is needed, to include problem analysis, human factors issues, possible uses of new technology, and evaluation of proposed solutions.

Sources of Information: Air Line Pilots Association, St Louis Lambert Airport, National Transportation Safety Board.

Future Research: The approach to development and testing of wide area lighting and marking systems is relatively straight forward, and involves the following: Consideration of the guidance requirement (what information must we transmit to the pilot) and a determination of methods (devices) available for accomplishing this. It is here that elimination of unsuitable solutions, based on past experience, is most important in eliminating false and unfruitful solution paths. The final stage is development and installation of prototype systems for evaluation and, more than likely, subsequent modification to eliminate proven deficiencies.

New technology may be of benefit and should be explored. Possible applications include use of controlled flashing lights, electro-luminescent markings, and fiber optic pipes to provide enhanced performance.

6.3.2.7 Apron Visual Guidance Aids.

Background and Past Studies: Apron visual guidance systems (marking, lighting and signs) have not been the subject of much FAA attention for many years, simply because these areas are not an FAA responsibility, from an air traffic control perspective, at airports. Early sign studies for airports did consider the apron movement areas. As an example, in the early 1950's, the CAA Taxiway Sign Evaluation Committee visited a number of airports to develop recommendations for signs, and early work on sign research was performed at the CAA Technical Development and Evaluation Center in Indianapolis. In 1962 the United States Navy commissioned an airport lighting and signage study by Dunlap and Associates that laid much of the groundwork for the "L-829" sign

specification that was issued by the CAA in 1955. It included some signing recommendations for apron guidance but, in recent years, airports have developed their own individual apron visual guidance systems in concert with their local air carriers. This has resulted in diverse and varying types of systems and levels of performance.

Other countries meanwhile have been performing research on apron visual guidance aids, and the International Civil Aviation Organization (ICAO) includes recommendations on apron systems in the Aerodrome Design Manual (Part 4-Visual Aids) (reference 63). In Germany, the new airport that recently opened at Munich features state-of-the-art control systems for apron surface movement, featuring loop detectors and computer control of surface lighting for aircraft guidance (reference 64). Methods for controlling overall airport surface movement include apron guidance as well as traditional taxiway visual aids. In Canada, a surface movement control system is presently being installed at Toronto International Airport, to be used for ramp traffic guidance. It employs a combination of piezzo sensors, stop-bar lights, and computer control apparatus to provide segmented lighting control within the ramp area. The unique nature of the system lies in its software control logic and in the types of sensors and switching combinations employed to sequence aircraft.

Deficiencies/Enhancements: Individual airports have each developed visual guidance devices and systems for the apron areas, since virtually no FAA guidance on the subject was available. While they are frequently effective, especially when used by pilots intimately familiar with the particular airport, the lack of standardization all too often results in pilot confusion and the potential for incidents or accidents. At least a minimum standard for apron guidance must be established to prevent a proliferation of essentially different concepts and systems.

Sources of Information: International Civil Aviation Organization, Air line Pilots Association, Manufacturers, Transport Canada.

Future Research: The work effort should focus on the development of new visual control systems and devices to support surface movement on apron areas. A system of integrated visual aids is required to assist pilots in maneuvering between the movement area and the gate. Lighting, marking and signage aids intended for this purpose should take advantage of the latest technology available.

The work effort on visual aids to assist in traffic separation will require close coordination and liaison with those technical organizations responsible for developing automated systems. Sensor applications and software development for controlled lighting and sign systems must be addressed in achieving the necessary total system performance. Power cable signal control technology could be employed to help keep costs of retrofitting new switchable visual guidance systems at a minimum. An initial approach would be to contact vendors of control systems for interest in cooperative development and, concurrently, to survey airports with projected increases in low visibility operations.

6.3.2.8 Docking Guidance Aids.

Background and Past Studies: Docking guidance systems (marking, lighting and signs) have received only limited FAA attention for many years simply because the apron areas on which they are used are not, from an air traffic control perspective, a specific FAA responsibility. Other countries meanwhile have been performing research on apron visual guidance aids, and the International Civil Aviation Organization (ICAO) includes recommendations on docking systems in the Aerodrome Design Manual (Part 4-Visual Aids). In Germany, the new airport that recently opened at Munich features state-of-the-art control systems for apron surface movement and docking, featuring loop detectors and computer control of surface lighting for aircraft guidance.

In the United States, gate signage and docking systems are considered deficient at many airports by airline pilots. Signs are often unlighted, too small, and confusing, with no standard existing to determine sufficiency. Docking guidance is considered essential to indicate closure rates and stop commands in the lower visibilities, but varies considerably. Parking area floodlighting also runs the gamut from excellent to poor depending upon airport choices of systems. Past research on ramp lighting has primarily been from a security perspective, and often did not consider work tasks to be performed and the sometimes critical effects on pilot vision.

Deficiencies/Enhancements: Docking systems at United States airports are designed and installed by the airline company assigned to the gate position or, in some instances, by the airport authority itself. Therefore a wide diversity of systems already exist, with attendant user pilot confusion sometimes resulting from non-standardization. ICAO is attempting to resolve the issue, and the United States will have to adopt a position on international standardization in the future.

Sources of Information: International Civil Aviation Organization, Air line Pilots Association, Manufacturers, Transport Canada.

Future Research: The work effort should focus on investigation of current visual guidance systems to support maneuvering on the apron area and docking at the gate, with a view toward determining the most suitable for adoption as standard systems. A minimal level of effort is anticipated, focusing on gate signage and visual devices for parking. Optimal size of gate signs should be determined for various aircraft up to the Boeing 747. Lighting, marking and signage aids intended for this purpose should take advantage of the latest technology available, and fiber optics may be especially suited presenting for addressable messages to docking pilots.

6.3.2.9 Takeoff Hold Bars.

Background and Past Studies: The concept of takeoff hold bars as signal lights to indicate takeoff clearance is not a new development. Limited studies on surface movement control techniques were conducted in the 1960's at the FAA Technical Center, focusing on traffic signal utilization in the airport environment. Later studies included evaluation of the VICON system at Bradley Field in Connecticut, involving a traffic signal device (flashing green lights) on the runway which was activated by the controller concurrently with verbal clearance for takeoff. These early efforts proved unsatisfactory due to the

level of involvement (workload) required of the Air Traffic controller. Later studies in the 1970's suggested the possibility of automated control as a solution to the surface movement problem. This included the Volpe Transportation Systems Center's study on surface movement in 1975. Today, in the 1990's, the Airport Surface Traffic Automation (ASTA) program proposes use of a takeoff hold bar as one of the automated visual components of the ASTA 3 System. Research is on-going at laboratories such as Lincoln Laboratory of MIT. Landing and takeoff collision accidents are particularly hazardous. The aircraft collisions at Tenerife and in recent years at Anchorage and Los Angeles involved accidents that could have been prevented with the automated air traffic control systems presently under development.

Deficiencies/Enhancements: Automated surface movement guidance and control systems now under development anticipate the use of visual devices (lights/signs) to provide information and warning signals to pilots. Adequate visual devices may not exist now, and probably will have to be developed in time to be mated with the automated systems as they are deployed to the field.

Sources of Information: Runway Incursions Working Group, AACI Technical Committee, Air Line Pilots Association.

Future Research: The work effort should focus on the development of new visual systems and devices to support automated air traffic surface control systems. The approach must emphasize the human factors aspects of Air Traffic Control, and provide visual aids for pilots and controllers that are effective in providing visual takeoff clearance verification. The testing effort should make use of previous experience involving the VICON system and, hopefully, could employ off-the-shelf fixtures. New technology such as signals superimposed on existing power circuits could be employed for the required control of the visual system components.

6.3.2.10 Flash Characteristics of "Wig-Wag" Lights.

Background and Past Studies: The L-804 "Wig-Wag" light was developed in the mid-1980's to enhance identification of entrances to active runways at intersections with traffic conflict problems. The device functions much the same as a railroad crossing signal, with alternate flashing of two yellow lamps sited adjacent to the holding position. Only two companies are currently approved by the FAA for production of these units (ADB-Alnaco and Crouse Hinds) (reference 65). The current generation "Wig-Wag" devices flash 55 to 60 times per minute, and have a minimum average intensity of 600 candelas. Lambert Field in St Louis was among the first of the U.S. airports to be equipped with these devices, since a number of runway incursion incidents at a particular runway/taxiway intersection had occurred there. The L-804 specification was developed specifically in response to this need. As a result of actual experience with the devices in the 1980's, the Air line Pilot's Association has expressed concern with the specification for, and the design of, these early units. The problem is lack of effectiveness in the higher visibility conditions as a result of intensity reduction at lower step settings of the powering circuit. Additionally, some concern as to the adequacy of the specified flash rate has been expressed. In 1992, the Visual Guidance Section of the FAA Technical Center conducted tests at the FAA Technical Center on the optimal location of the devices in conjunction with stop-bars. At the time of the tests

it was noted that "toeing in" Wig-Wag lights could lead to some adverse affects on the perceived color of the stop-bars (reference 66). Also in 1992, Airports Division of the FAA began an effort to revise the L-804 specification.

Deficiencies/Enhancements: The present standard L-804 "Wig-Wag" device does not provide adequate warning signals when operated directly from the associated runway edge lighting circuit. Both intensity and flash characteristics appear to be deficient whenever the "Wig-Wag" lights are powered from circuits operated at minimum current levels (low intensity settings).

Sources of Information: Air line Pilots Association, Manufacturers.

Future Research: The problem of insufficient intensity when powered from an airport lighting circuit set to a low regulator current value can only be solved by the manufacturers. Addition of a compensating circuit, similar or identical to those used in conventional airport signs, will serve to maintain constant intensity regardless of input current levels.

It may be that the other concern, that of inadequate flash rate, is really only a result of the diminished intensity problem, and that maintaining constant intensity will resolve the issue. At least one manufacturer possesses an experimental "Wig-Wag" device havin readily adjustable light characteristics (flash rate, flash duration, intensity, etc.), and it would appear prudent that further testing be conducted to insure that the present FAA specifications provides for the most effective system visual presentation.

6.3.3 Control and Monitoring Systems.

This category includes all aspects of monitoring and control system design, to include surface movement automation, control panels, detector systems, and remote activation devices.

Table 6.3 depicts potential research areas required for improvement of control and monitoring systems:

TABLE 6.3 CONTROL AND MONITORING SYSTEMS

● POWER CABLE SIGNAL TECHNOLOGY	6.3.3.1
● ADVANCED CONTROL SYSTEMS FOR SURFACE MOVEMENT	6.3.3.2
● STOP BAR CONTROL TECHNOLOGY	6.3.3.3
● STOP BAR LIGHTING CONTROL PANEL AND REMOTE ACTIVATION	6.3.3.4
● SENSOR APPLICATIONS IN SURFACE MOVEMENT SYSTEMS	6.3.3.5

6.3.3.1 Power Cable Signal Technology

Background and Past Studies: Electronic control technology has advanced significantly in the past few years. Traditional airfield lighting involves the use of isolation transformers to power individual lights on the airport. The replacement of these isolation transformers with individually addressable electric modules allows individual control and monitoring of each lighting device. Communication is accomplished through a master computer over existing power cables, eliminating the need to install additional cable for controlling new airport lighting systems on the airport. Power cable control signal technology was developed and employed in rail systems for many years, but its first successful use in airport applications was at Gothenburg Airport in Sweden only in the late 1970's and 1980's. The Swedish system, called Airport Smart Power (ASP), offers selective control of individual units with built in intensity control and monitoring. The ASP concept was tested at the FAA Technical Center in 1991-92.

In early 1992, the FAA initiated an evaluation program at the SEATAC Airport in Washington state. Because of frequently occurring low-visibility conditions, SEATAC was considered an ideal location for the testing of controlled stop bars, a visual guidance system that is essential for safe operations in bad weather. Previous testing of abbreviated stop bars had been carried out in the United States at JFK Airport in New York in the late 1980's. The costs of retrofitting the SEATAC airport with control cable were determined to be excessive, thereby making it a prime candidate for use of power cable signal technology. The system that was selected for use at SEATAC is produced by a United States company with manufacturing facilities in Ohio. At the present time the system has been installed and is operational for testing in restricted visibility conditions as they occur. This testing will be the first actual evaluation of power cable signal technology at a major airport in the United States.

Numerous other applications for power cable signal technology may exist on airports. These need to be explored to identify ways that visual aids may be made to operate more effectively and efficiently.

Deficiencies/Enhancements: The power cabling signal systems presently being introduced for airport use are, essentially, first generation designs and, as such, do not necessarily take advantage of the full concept potential. A determination of possible future airport applications is needed to discover areas within which existing system capabilities should be expanded, and to encourage designers and manufacturers to introduce greater flexibility and utilization into such systems.

Sources of Information: Manufacturers, American Association of Airport Executives, SEATAC International Airport.

Future Research: Many future applications for power cable signal technology remain to be discovered. However, if the demonstration at SEATAC is successful, the power cable signaling technology may well be ideally suited to use in many applications. The FAA must explore its potential for operating various other devices on the airport, both visual and non-visual. Power cable signal technology, in addition to controlling components of surface movement and guidance systems, has potential applicability to individual brightness control,

operation, and monitoring of conventional signs, runway lights, and may even facilitate retrofitting of sequentially segmented taxiway centerline light routing systems. The first effort involves the analysis of results from the SEATAC test, and should be followed closely by a study of potential applications at various categories of airports.

6.3.3.2. Advanced Control Systems for Surface Movement.

Background and Past Studies: The concept of automated aircraft surface operations is relatively new in the airport scheme of surface movement. Collision avoidance on the ground has traditionally fallen upon the pilot's shoulders (i.e., see and avoid). With the advent of very low visibility landing and takeoff operations the distinction between established separation responsibilities has become blurred, and new mechanisms are needed to assist in surface movement. Additionally, areas on the airport airside have been historically divided into distinct sectors of FAA and airport responsibility. With low visibilities operations a need has emerged to provide positive handoffs from gate to takeoff, and from touchdown to gate. With the present limited number of such operations the problem is not yet critical, but it is anticipated that the demand will increase as more airlines and aircraft add the necessary equipment to operate in Category III conditions. In order to generate capacity and provide safe surface movement, automated surface movement systems will have to be developed rapidly to meet this demand. Limited studies on surface movement control techniques were conducted in the 1960's at the FAA Technical Center, focusing on traffic signal utilization in the airport environment. Later studies included evaluation of the VICON system at Bradley Field in Connecticut, involving a traffic signal device (flashing green lights) on the runway which was activated by the controller concurrently with verbal clearance for takeoff.²³ These early efforts proved unsatisfactory due to the level of involvement required by the Air Traffic controller. Later studies in the 1970's suggested the possibility of automated control as a solution to the surface movement problem. This included the Volpe Transportation Systems Center's study on surface movement in 1975. In the 1980's computer chip technology and the development of the economical but sophisticated computer offered control automation possibilities that were previously unavailable. Automated surface movement system development took place at airports overseas such as Luton in England and Munich in Germany. In addition, interest in stop-bar control systems developed in the United States, in the late 1980's, tests of prototype stop-bars conducted at JFK International Airport in New York. During the early 1990's, new programs have been proposed that would provide enhanced surface movement automation. The ASTA 3 specification provides for controller traffic planning for surface movement to be integrated with radar separation information. The desire for automation in surface movement control has thus become increasingly evident. Particular requirements are for sensor applications and software integration to automatically separate both vehicular and aircraft traffic on the surface.

Deficiencies/Enhancements: No investigative work has been done on developing relatively unsophisticated automated surface movement control systems for smaller airports where installation of a full-blown Surface Movement Guidance and Control System is not anticipated. There is a need for a less complex, but yet effective, system for maintaining aircraft separation on these airports.

Sources of Information: Runway Incursions Working Group, AACI Technical Committee, Air Line Pilots Association.

Future Research: The work effort should focus on the development of new visual systems and control devices to support simplified automated surface movement control. The approach must emphasize the human factors aspects of air traffic control, and provide integrated visual aids to assist pilots in maneuvering about the airport. This will certainly require close coordination and liaison with those technical organizations responsible for developing the more complex automated systems.

Sensor applications and software development for controlled lighting and sign systems must be addressed in achieving the necessary total system performance. Power system control signal technology could be employed to help minimize the cost of retrofitting new switchable visual guidance systems. An initial approach would be to contact vendors of control systems for interest, and, concurrently, to survey airports with projected increases in low visibility operations. A suitable evaluation airport could thus be identified, ideally one of the existing FAA "Demonstration" locations, and a test system designed to suit the particular airport's needs. The evaluation effort should be of sufficient duration to allow "fine tuning" of the system and a determination of whether it might have broader application throughout the NAS.

6.3.3.3 Stop Bar Control Technology.

Background and Past Studies: Stop bar systems were developed in the 1980's in response to the increase in the number of lower visibility operations and advances in aircraft equipment that allow aircraft operations under Category III conditions. European nations, due to the predominance of low visibility weather conditions, were pioneers in the installation of surface movement guidance systems to assist pilots and air traffic controllers in providing ground separation. Traditional air traffic control depended on the pilots alone to guarantee separation on the ground. In lower visibility conditions enhanced support systems are required. Stop bar Systems were initially installed at airports in London (Heathrow) and Frankfurt, Germany. These systems provided information to the controller on position of an aircraft and were integrated into the operation of the stop-bars. The first systems were hard-wired control systems coupled with loop detectors installed at critical locations on the airport.

Other stop bar systems are now under development, and testing of abbreviated stop bars was accomplished in the United States at JFK Airport in New York in the late 1980's. In Europe, power cable control signal technology was developed and employed in rail systems for many years. Its first successful use in airport applications was at Gothenburg Airport in Sweden in the late 1970's and 1980's.¹⁹ The Swedish system, called Airport Smart Power (ASP), offers selective control of individual units, with integral intensity control and monitoring. The ASP concept was tested at the FAA Technical Center in 1991-92.

In early 1992, the FAA initiated an evaluation program at the SEATAC Airport in Washington state. Because of frequently occurring low-visibility conditions, SEATAC was considered an ideal location for the testing of controlled stop bars, a visual guidance system that is essential for safe operations in bad weather.

The costs of retrofitting the SEATAC airport with control cable were determined to be excessive, thereby making it a prime candidate for use of power cable signal technology. The system that was selected for use at SEATAC is produced by a United States company with manufacturing facilities in Ohio. At the present time the system has been installed and became operational for test in December, 1992. This testing will be the first actual evaluation of power cable signal technology at a major airport in the United States. This test is a simple one however, involving only two stop bars, and additional research will be needed to address the more complex problem of control systems at airports having a great number of stop bar installations.

Deficiencies/Enhancements: Although stop bars will ultimately be controlled automatically, as use of automated surface movement and control systems becomes common, for the immediate future they will continue to be activated manually by ATC personnel. Continued evaluation of the first generation stop bar installation and control designs is necessary to optimize operational techniques and equipment used. Installation of more complex stop bar configurations, at major airports, is imminent; and the inevitable problems that develop will have to be addressed as they occur.

Sources of Information: Air line Pilots Association, Discussions on stop-bar control timing, January 22, 1992.

Future Research: The work effort should focus on testing and evaluation of various control systems for stop bar applications. Limitations of different types of control systems should be established to determine relative benefits of each type. It may be that simulation of stop bar control situations, with active controller participation, will be the only valid means of anticipating operational problems at complex airports.

Initial developmental testing should be followed by evaluation of equipment and operational techniques in the field at airports having new stop bar installations. Optimal activation/ deactivation times and maximum numbers of stop bars that can be effectively controlled by air traffic are some of the variables that should be determined during testing and will, in many cases, be site specific.

6.3.3.4 Stop Bar Lighting Control Panel and Remote Activation.

Background and Past Studies: Surface movement control technology may be expected to progress rapidly in the next few years. Early studies on surface movement control concepts were conducted in the 1960's at the FAA Technical Center, focusing on traffic signal utilization in the airport environment. Later studies included evaluation of the VICON system at Bradley Field in Connecticut which involved a traffic signal type device (flashing green lights) on the runway activated by the controller concurrently with the issuance of a verbal clearance for takeoff. These early efforts proved unsatisfactory due to the level of involvement by an already busy ATC controller. Later studies in the 1970's offered the possibility of automated solutions to the surface movement problem. This included the Volpe Transportation Systems Center's study on surface movement in 1975. In the 1980's, computer chip technology and the development of the compact computer offered control automation capabilities that were previously unattainable. Advanced surface movement systems have recently been developed for use at airports overseas, such as Luton in England and Munich

in Germany, and similar interest in stop-bar control systems is increasing in the United States. In the late 1980's, tests of a prototype stop bar system were conducted at JFK International Airport in New York. Completion of these tests was followed by installation of an ICAO-configured full stop bar system at the SEATAC "FAA Demonstration" Airport in 1992. Testing of this system commenced in December, 1992.

An integral part of the stop bar control system is the panel design and layout for ATC controller use. Since the design of the panel must be functionally intuitive, and simple in providing easily manipulated controls, human factors expertise will be essential for optimizing the ergonomic features.

Deficiencies/Enhancements: No guidance material relative to stop bar control panel design and layout exists. Experience gained with prototype stop bar system installations now being fielded must be utilized to provide basic information to airport consultants having little or no expertise in this area of design.

Sources of Information: Air Traffic Controllers, Runway Incursions Working Group, Manufacturers.

Future Research: Since this is a relatively new requirement, a survey of potential test airport layouts should be accomplished. Standard panel designs should be developed that will fit common runway configurations, with the complex runway layout having many stop bars being of particular concern. It is obvious that no single panel layout will be suitable for all airports, but providing general guidance material, in the form of examples, will go a long way toward easing the task of individual airport equipment designers. Testing should be conducted to evaluate the influence of such factors as display organization, alarm signal format, inadvertent activation prevention, and indicator illumination. Use of remote activation devices (walk-around capability) to provide for controller freedom of motion should be investigated.

6.3.3.5 Sensor Applications in Surface Movement Systems.

Background and Past Studies: Stop bar systems were developed in the 1980's in response to the increase in the number of lower visibility operations and advances in aircraft equipment that allow aircraft landings down to Category 3 conditions. European nations, due to the predominance of low visibility weather conditions, were at the forefront in the installation of surface movement guidance systems to assist pilots and air traffic controllers in providing ground separation. Traditional air traffic control depended on the pilots eyes to guarantee separation. In lower visibility conditions enhanced support systems are required. Detection systems such as the imbedded loop system were adapted from highway applications to provide locational feedback for surface movement control. Systems were initially installed at airports in London (Heathrow) and Frankfurt, Germany. These systems provided information to the controller on position of an aircraft and were integrated into the operation of the stop bars. ICAO developed criteria for SMGCS (Surface Movement Guidance and Control Systems) in 1975 and updated it in 1986 (reference 67). Meanwhile other types of sensors have been under going development over the years in response to differing requirements. Microwave sensors have been used for many years in security applications, proving effective in detection efforts. Piezoelectric sensors offer advantages of inexpensive retrofit and reliability. Fiber optic

sensors are currently under development to provide the optical sensitivity necessary to identify specific types of aircraft at multiple locations on the airport. Research on this type of application is being conducted at the University of Alabama-Huntsville. Advanced use of sensors is underway at several modern airports including Toronto, Munich, and Rome, Italy. Future surface movement systems will need even better sensors for use in identifying position of specific aircraft and performing control functions.

Deficiencies/Enhancements: While the capabilities of available sensor devices to detect highway traffic (cars, trucks, etc.) and security breaches (personnel movement) are widely known and understood, their potential for use on airport aircraft movement areas is relatively unappreciated. Essential information relative to capabilities such as discrimination between vehicle types, detection of motion direction, and even the ability to identify particular aircraft (flights) is not presently available.

Sources of Information: Air line Pilots Association, Discussions on stop bar control timing, January 22, 1992. Toronto airport discussion, May, 1992. Discussion on optical transmissometers, University of Alabama-Huntsville, May 1992.

Future Research: The work effort should focus on testing and evaluation of enhanced sensor systems for airport control applications. Different types of sensors should be procured and integrated into existing control and guidance systems to determine relative benefits of each type.

6.3.4 State-of-the-Art Advances.

This category is intended to focus on developing and applying new technology innovations in light sources, control techniques, and power systems to improve performance and simplify maintenance. It incorporates new technologies to develop enhanced systems for visual guidance.

Table 6.4 depicts suggested research areas for implementing state-of-the-art technology:

TABLE 6.4 STATE-OF-THE-ART RESEARCH AREAS

● FIBER-OPTIC TECHNOLOGY	6.3.4.1
● REFLECTIVITY MEASUREMENT DEVICE	6.3.4.2
● HOLOGRAPHIC SIGN TECHNOLOGY	6.3.4.3
● SOLAR POWER APPLICATIONS FOR AIRPORTS	6.3.4.4
● REFLECTIVE ENHANCEMENTS TO PAVEMENT MARKING TECHNOLOGY DURING CONTAMINATED CONDITIONS	6.3.4.5
● ELECTRO-LUMINESCENT LIGHTING APPLICATIONS	6.3.4.6
● LASER TECHNOLOGY APPLICATIONS	6.3.4.7
● LAMP TECHNOLOGY APPLICATIONS	6.3.4.8
● SYSTEM RELIABILITY AND ASSESSMENT TECHNOLOGY	6.3.4.9
● FLIGHT SIMULATOR VISUAL DISPLAY ENHANCEMENT	6.3.4.10
● DEVELOPMENT OF PORTABLE PHOTOMETRIC DEVICE	6.3.4.11

6.3.4.1 Fiber-Optic Technology.

Background and Past Studies: Fiber-optic technology has a variety of potential uses in the airport environment. The fiber-optic concept provides for the transmittance of light through clear glass fibers. The fibers are cheap to produce, and the technique offers the advantage of allowing the light source to be remotely displaced from the display location. Fiber-optic lighting has been long been used in commercial sign applications, since the 1970's, and has proven most effective for this use over the years.

Fiber-optic airport signs have been developed in Canada and are already installed in a number of locations. The Canadian signs utilize traditional light sources with the message characters illuminated by light delivered through fiber-optic bundles. While not problem-free, the Canadian signs do offer the benefits of lower energy consumption and claimed increased effectiveness under low visibility conditions - a potential solution to a problem of increasing magnitude. The ICAO Visual Aids Panel met in 1991 for its twelfth meeting and considered adopting standards for these devices. Specifications for fiber-optic signs were not adopted, but the panel agreed to continue to monitor developments in the use of this technology (reference 68).

Another application of fiber optics is in their use as lightpipes to conduct light from remotely located sources. Work in this area is being done in Canada and other locations. This usage is especially applicable for visual devices sited in hard to reach locations, such as obstruction lights on tall towers.

User of fiber-optic sensors is another area of potential benefit in airport visual aids. This technology is being explored at the University of Alabama/Huntsville where photonics is a major focal technology. Optical sensors imbedded in the pavement have sufficient sensitivity to discriminate between types of airplanes and, when coupled to computer software, may be of great benefit in automated surface movement applications.

Deficiencies/Enhancements: Although manufacturers of fiber optic signs claim significant advantages over the more conventional visual guidance devices, no evaluations of such equipment in the airport environment have been accomplished. Airport installations of available fiber optic signs have been undertaken outside of the continental United States, but no definitive information as to their effectiveness has been forthcoming thus far.

Sources of Information: ICAO, Transport Canada, University of Alabama-Huntsville, Virginia Polytechnic Institute.

Future Research: Research efforts should address the full range of potential applications. Existing fiber optic sign products should be evaluated to verify stated performance claims and considered as potential remedies to solve specific visual guidance problems (such runway exit identification in low visibility). Remote light sources, coupled by fiber to the display fixture should be examined as potential solutions to shock problems (i.e., touchdown and threshold in-pavement lights). Optical sensors could be incorporated into surface movement control systems and, ultimately, whole fiber-optic airfield lighting systems could be developed on an experimental basis. While expensive, a centrally located single laser source might eventually power an entire airport lighting system. The benefits in energy conservation and immunity from lightning strikes might be significant. While this may appear unattainable within the immediate future, smaller segmented applications of the same principles are certainly reasonable.

6.3.4.2 Reflectivity Measurement Device.

Background and Past Studies: The measurement of reflectivity of airfield markings cannot be accomplished quickly and objectively in the field at present. Serviceability of markings must be determined subjectively by visual observations in accordance with Part 139. If markings are present, they indeed must be serviceable, but a problem exists in that the individual's judgement of serviceability may vary significantly from person to person. A recent questionnaire confirmed that the poor quality of painted markings is the largest single irritant to airline pilots. Current marking systems have been criticized for inadequate performance under low visibility circumstances and during periods of runway contamination, particularly under standing water conditions at night. Past work in the development of reflective measurement devices has concentrated on small hand-held devices, such as the Mirolux and Ecolux. Some studies have been accomplished by highway departments and the Transportation Research Board on effectiveness of these devices (reference 69). The development of mobile equipment, suitable for use on airfields, has only recently been addressed, and

Carleton University of Canada has been investigating techniques (reference 70) employing video photometry. Additional exploration work in video-photometry is being accomplished in the United States, with a major effort underway at the Marine Physical Laboratory in San Diego, California. Also, individual manufacturers are pursuing technology for measurement of contrast and other indicators of marking material performance.

Deficiencies/Enhancements: A problem exists in establishing the level of deterioration of marking performance beyond which active rejuvenation or replacement is required. Current visual inspection is imprecise, time consuming, and fails to measure performance objectively. A simple means of measuring marking material performance is needed, one that can be accurately and rapidly accomplished with vehicular mounted devices. To minimize downtime, vehicle speed should be in the 10-12 mile per hour (MPH) range to permit testing of a 10,000 runway in approximately 10 minutes.

Sources of Information: ALPA, Manufacturers, Pilot Questionnaire.

Future Research: The first part of the work effort should focus on the development of a "breadboard" system for mobile reflectivity measurement; a working model assembled, possibly, from "off-the-shelf" components. Use of a device of this sort, on a periodic basis at airports, would be beneficial in establishing projected levels of performance for specific materials and for predicting reapplication scheduling requirements.

6.3.4.3 Holographic Sign Technology.

Background and Past Studies: The emerging technology of holography may be of benefit on airports of the future. Holographic images have a potential use in various applications, to include such uses as signs, non destructive inspection, and alignment/docking systems. A number of articles for the Society of Photo-Optical Instrumentation Engineers and the Holography Newsletter have appeared recently relating to this technology. Mr. Quiang Huang and Dr. H. John Caulfield are among these who have done considerable work in this field (reference 71). Work has been accomplished on both the two and three-dimensional types of holograms, created by exposing special holographic film of the subject backlighted by a laser light source. Color properties of the hologram are determined by the properties of the laser light. The hologram image may then be mounted on a substrate material which can be illuminated by an incandescent or neon source. This type of hologram may have some application as display and highway signs in the immediate future.

Deficiencies/Enhancements: There has apparently been little or no attempt to adapt current holographic technology to airport visual guidance applications, even though it offers potential enhancement for existing sign and marking systems. There is a need to, at the least, maintain continuing liaison with individuals and organizations working in this arena, and even to conduct some practical evaluation of the limited capability devices currently available.

Sources of Information: University of Alabama-Huntsville, SPIE, Optical Society of America.

Future Research: At the present time the only display holograms that have been produced have been smaller than that required for aviation applications. In order to make a larger size hologram, of a size adequate for airport sign experimentation, it will be necessary to utilize a very large laser. The cost for such a large laser may be a limiting factor, although use of incandescent lighting sources for the edge-lit holograms would appear to be practical. Contrast problems are another issue to be resolved, since effective edge-lit holographic signs must be conspicuous and have effective acquisition ranges during both daylight and night operations. A test program to evaluate this technology should be conducted in a controlled environment to determine relative effectiveness as compared to traditional sign devices. Potential applications should be explored for use in the future, since holographic costs will be diminishing as commercial applications proliferate.

6.3.4.4 Solar Power Applications for Airports.

Background and Past Studies: Solar power has been used in various applications since the 1950's. Photovoltaic cells are the basic component of solar systems, and are produced by slicing silicon into thin wafers of charged material which respond to light sources. Early uses were in satellites and aerospace, but proved very expensive. The United States Coast Guard was an early user of solar power, primarily for remote beacons and buoy applications (reference 72). Solar arrays typically are made up of a number photovoltaic cells, organized in an array and coupled to a rechargeable battery. These arrays may be used to power hazard beacons, low power communications equipment, and navigation aids. In the 1970's and 1980's use of solar power became widespread in marine applications in the United States and Canada. Transport Canada has led the way in developing specific solar powered applications for remote hazard beacons throughout Canada (reference 73). Self contained power supplies are needed at airports for a variety of reasons. First, and most significant, is the expense of importing power into remote locations where none is readily available. Transport Canada in the early 1980's estimated costs to be as high as \$35,000 Canadian Dollars per kilometer. Airports generally comprise large expanses of acreage, and the cost to install new power cables for each new application may be prohibitive. Solar power offers benefits of minimum site preparation, minimum operating cost, high reliability, environmental suitability, and total independence from other sources. Additionally, there are many situation, such as in mountainous terrain, where it is the only alternative. States such as Alaska have a demonstrated need for independently powered visual guidance devices.

Deficiencies/Enhancements: Information as to the state-of-the-art capabilities of solar power sources/supplies for airport applications is lacking. There is a need to determine which airport aids might be more economically powered by solar energy sources when initially installed.

Sources of Information: Aircraft Owners and Pilots Association, NASAO, Transport Canada.

Future Research: Research effort should focus on specific applications such as obstruction lighting and lighting of remotely located aids. Studies must first be accomplished on candidate systems/configurations, with development and installation of prototype systems for evaluation following. As a suggestion, joint evaluation efforts with Transport/Canada might be considered, since the Canadians have already accomplished much developmental work in this area.

6.3.4.5 Reflective Enhancements to Pavement Marking Technology During Contaminated Conditions.

Background and Past Studies: Surface markings are essential visual aids for safe movement on airports. Markings traditionally are applied with paint, although Advisory Circular 150/5340-1 (Marking of Paved Areas on Airports) specifies only configuration and not the materials to be used. Materials specifications, however, are included in Advisory Circular 150/5370-10 (Standards for Specifying Construction on Airports). Many studies have been accomplished over the years on effectiveness of markings, and a great deal of work has been done by highway departments as well as aviation organizations in attempting to develop improved performance. Recent work indicates that no one type of marking or application technique is suitable for every situation. Aviation marking standards in Part 139 do not currently require any measure of reflectivity or performance, but rather simply state that markings, if present, must be maintained in good order. Beads and ground glass are currently used as additives to traditional paints to provide enhanced reflectivity. Retro-Reflective tape is also being proposed as a paint substitute, with other new materials offering the promise of significant improvements to existing materials in aviation applications.

Pavement marking systems have long been criticized for inadequate performance under low visibility circumstances and during periods of runway contamination, particularly under standing water conditions at night. Adequate reflectivity has been effectively achieved during normal night and low visibility conditions through the addition of beads and ground glass additives to the carrier medium. Standing water, however, negates the effectiveness of these traditional products, mainly because of the glare condition resulting from the smooth water surface. The addition of larger beads may offer improved effectiveness with standing water present, but friction characteristics may suffer. At the same time retention of beads in the carrier medium presents a potential problem. Among the promising new products are long lasting multi-layered products that are under development in the United States and United Kingdom.

Deficiencies/Enhancements: Investigative efforts are presently underway to evaluate state-of-the-art improvements in marking materials, with a view toward adopting specifications for environmentally acceptable materials possessing enhanced durability and reflective characteristics. Being surface applied, however, the problem of standing water reflections obliterating the marking guidance information will remain, even with use of these new materials. A requirement for development of some other technique or device for providing dependable taxi guidance under all weather conditions is indicated.

Sources of Information: Air Line Pilots Association, Manufacturers, State Highway Departments, Federal Highway Administration.

Future Research: The research effort should focus on evaluation of new materials that enhance reflectivity in surface contamination conditions. This includes testing of better beads, surface retro-reflectors, and new technology products. Most promising may be the use of materials that create a surface rising above the standing water level. Initial efforts should be to identify the most promising products and techniques available for enhancing airport pavement markings. Review of specifications for marking materials (including glass beads, thermoplastics, epoxies, and reflective devices) should be

accomplished to determine the potential for success of the system. Evaluation, under actual weather conditions, must then be accomplished on test pavement surfaces to validate anticipated performance. Selected pavement surfaces should include both flexible and rigid pavements. Following completion of testing, changes to specifications should be accomplished to incorporate testing results.

6.3.4.6 Electro-Luminescent Lighting Applications.

Background and Past Studies: Electro-luminescent visual devices have been available for many years. In 1982 the United States Air Force evaluated electro-luminescent (E/L) lighting for portable airfield lighting (reference 74) and, recently, the Visual Guidance Section evaluated an electro-luminescent heliport lighting system at the FAA Technical Center. While the evaluation offered mixed results, some significant improvement was noted over previously tested first generation electro-luminescent devices. The Midland-Ross Company has developed a product lamp/panel for use in heliport applications (reference 75). Insufficient light output has been a continuing problem using this technology, with some improvement evident with the newer systems. The advantages of E/L technology lie in low energy consumption, no heat emitted from the panels, and the capability to create unique shapes with the material. In recent years the application of higher excitation voltages and improved phosphors have served to increase the light output from the E/L devices, significantly increasing the potential for effective use on airports and vertiports. A recent news article produced by the Los Angeles Times News Service highlighted a new application of E/L Technology as a substitute for the conventional light bulb. A magnetic coil is used to generate a radio signal, exciting a plasma to make the phosphor glow. The article reported that a "Sunnyvale, California company has developed a revolutionary light bulb that will last up to 20,000 hours, fit into ordinary sockets and use 75% less electricity than conventional electric lights. The bulb is hailed as the first major advance in lighting in 60 years."

Deficiencies/Enhancements: The fact that earlier E/L devices provided insufficient light output for airport/heliport use should not eliminate improved E/L devices presently under development from consideration and evaluation. Given the potential for future application in airport systems, efforts should be made to maintain liaison with E/L manufacturers in order to keep abreast of advances as they occur.

Sources of Information: Midland-Ross Corporation, Underwriter Laboratories, Byrne industries.

Future Research: Research should be conducted on the potential use of E/L technology in limited aviation lighting applications, to include internally lighted markings for airports and helipad/heliport applications. The internally lighted marking concept may be of particular benefit in providing guidance for low visibility operations. The work effort should be oriented toward evaluation of these devices as substitutes for currently used painted markings. If this R&D testing effort is successful, other applications for E/L technology may well suggest themselves.

6.3.4.7 Laser Technology Applications.

Background and Past Studies: Lasers offer many potential improvements in several areas of airport lighting and visual aids enhancement. The power of laser light sources may be harnessed in many different ways, and potential benefits stem principally from their limited scattering effect as compared to that of traditional light sources. An obvious application is in the development of a laser-based visual landing aid as a replacement for existing PAPI/VASI systems. The United States Navy is already experimenting with such Laser systems as their Improved Carrier Landing System (ICOLS) while, overseas, this same concept has also been explored by the Russians in their "Glacada" system.

Other lasers may be employed in airport surface lighting systems for low-visibility operations, since concentrated laser power promises a solution to atmospheric attenuation of visual signals in Category III weather conditions. High cost factor is the primary negative aspect restricting their use at the present time.

The Virginia Polytechnic Institute in Blacksburg VA is performing research on combining fiber-optic and laser applications in airport lighting. Their work displays promise through use of various light sources (including lasers) in combination with optical fiber networks to light runways. Centralized light sources may be used to illuminate lighted fixtures at remote locations, with such lighting systems being virtually lightning proof as well as centralized for maintenance purposes.

Deficiencies/Enhancements: Currently installed visual guidance systems, utilizing conventional light sources almost exclusively, are limited by the inability of the light source to overcome atmospheric attenuation, especially under low visibility conditions. Since very little investigation into the potential for system enhancement through use of laser sources has been conducted, with the exception of some limited work by the United States Navy, some evaluation of commercially available laser devices integrated into existing visual aid systems would be worthwhile.

Sources of Information: Manufacturers, Naval Air Warfare Center, University of Alabama, Virginia Polytechnic Institute, Aircraft Owners and Pilots Association.

Future Research: The research effort should focus on potential improvements to existing systems through the use of laser light sources. Initial efforts should examine various applications for feasibility and potential benefits. An obvious application is as a visual approach slope indicator of the form developed earlier by the Russians and currently being tested by the United States Navy. Other potential applications are the use of lasers as remote light sources for in pavement lights, rendering the system relatively insensitive to shock damage from landing aircraft. When coupled to fiber optic light pipes, single laser sources could also illuminate multiple runway edge lights and, with filtering, provide colored light for a variety of applications. Use of laser equipment already developed by the Navy would, if it could be made available, significantly reduce start-up costs.

6.3.4.8 Lamp Technology Applications.

Background and Past Studies: The airport lighting systems of today employ lamp technology developed primarily in the 1940's and 1950's, and, during this period, the performance aspects of the selected lamps were of paramount importance to the designers of the systems. The first approach light systems were developed and used by the Navy in World War II. In the mid-1940's the Civil Aeronautics Administration (CAA) sponsored research into approach lighting improvements, performing work at the Newark, New Jersey airport, with additional work performed at other locations as well. The CAA established a Technical Development and Evaluation Center at Indianapolis, Indiana, to support research activities. At the same time experimental work was also underway at the National Bureau of Standards Landing Aids Experimental Station located at Arcata, California. Here fog formation characteristics and visibility effects were subjected to detailed scientific study from the aviation perspective.

In the 1960's, energy consumption became a significant issue and, in the United States, led to the development of the Medium Intensity Approach Lighting System (MALS). In the 1980's, the British began a program to investigate the possibility of reducing the total number of lights in systems designed to support approach and landing operations. These efforts were all directed towards lowering operational costs for approach lighting systems.

The development of alternative lamp technologies in recent years has increased the potential for their effective application on airports. As an example, a recent news article produced by the Los Angeles Times News Service highlighted a new application of E/L lighting as a replacement for conventional light bulbs. A magnetic coil is used to generate a radio signal, exciting a plasma to cause the phosphor to glow. The article reported that a "Sunnyvale, California company has developed a revolutionary light bulb that will last up to 20,000 hours, fit into ordinary sockets and use 75 percent less electricity than conventional electric lights. The bulb is hailed as the first major advance in electric lighting in 60 years." The claims, if verified, would indicate that greatly increased economy of operation might be expected through use of this type of light source. Quartz lamps used in conjunction with high technology reflectors also offer opportunities for performance and economical advantages over sealed beam units.

Deficiencies/Enhancements: Lamps presently used in airport visual guidance systems are, for the most part, technologically obsolescent, and do not provide the enhanced performance and reliability advantages now available through use of advanced technology light sources. Efforts must be made to investigate the efficacy and practicality of retrofitting these new light sources to existing visual systems.

Sources of Information: Manufacturers, Universities, Maintenance and Logistics Services, Naval Air Engineering Center.

Future Research: The work effort should focus on finding and adapting modern, energy efficient lamps to replace less desirable older types in airport lighting systems. It is also most important that such new lamps may be retrofitted to existing fixtures without undue modification or cost. A survey of lamp manufacturer products should be followed by field trials to verify performance. Various lamp applications should be developed to produce a total energy austere system. Follow on efforts should be directed toward revision of specifications.

6.3.4.9 System Reliability and Assessment Technology.

Background and Past Studies: Reliability of the airport lighting system is becoming increasingly important as lower visibility operations expand. Reliability is directly related to the quality of the equipment and the design of the system, as well as to the overall age of the components. Failure of the system can be a serious safety hazard, as well as a cause for cessation of operations and revenue loss.

New concepts in materials, equipment and design are being developed to provide improved reliability to systems. As these advanced components are introduced into existing systems, some method for determining their effect on overall performance must be provided. This same technique will serve not only to evaluate improvements attained, but also to record the continuing performance of existing systems and indicate the need for maintenance and/or remedial action.

A paper directly pertaining to reliability in the design of airfield lighting systems was presented at the Illuminating Engineering Society Aviation Committee Conference in London in 1991 (reference 76), and addresses the issue admirably.

Deficiencies/Enhancements: Virtually no research has been done in this area, and documented standards on criteria for effectiveness are few. Measurement standards are needed to document continuing effectiveness of the various systems, and to identify the point at which systems become substandard. Criteria may then be developed for measurement and determination of serviceability of the systems.

Sources of Information: Manufacturers, Illuminating Engineering Society.

Future Research: Research efforts should focus on development of improved techniques for monitoring visual system performance and assessing reliability. Present procedures call for maintaining voluminous hand-written records of system inspections, with subjective determination of such essential data as component failure rates, power cable deterioration, and schedules for group replacement of lamps. Additionally, tolerance levels for system outages must be established, so that, once detected, failures causing the system to become unserviceable may be corrected.

In some instances, the techniques adopted already to achieve these objectives may be a case of "over-kill", and create more problems than they solve. Visual Guidance systems are, for the most part, relatively simple, and the techniques for monitoring them and assessing reliability should be less complex as well. Therefore, any development effort should stress simplicity as a prime factor.

6.3.4.10 Flight Simulator Visual Display Enhancement.

Background and Past Studies: Enhancements to flight simulators are necessary to provide a more true-to-life visual presentation of the out-of-cockpit environment. Ground based simulator systems have been used for many years to provide pilots with synthetic emergency and procedural training in lieu of actual aircraft flights and their attendant costs and hazards. Fidelity of visual aids depiction has been a continuing problem with existing simulator hardware/software configurations. Previous research has involved some

elementary modifications to the FAA's Boeing 727 flight simulator at Oklahoma City, and work is underway to modify the Aeronautical Center simulator software for incorporation of a New Denver Demonstration Airport model (reference 77). Enhancements of this sort are needed to provide state-of-the-art visual aid presentations as an aid to pilot training. Additional improvements are also needed, however, to be able to effectively use the simulator as a research device. Many projects that must be conducted under low-visibility conditions are subjected to lengthy delays while awaiting actual instrument weather conditions. These projects may someday be conducted at the Technical Center when a simulator suitable for these purposes is installed at the facility.

The potential value of flight simulator usage for visual guidance R&D work has been recognized by Mr. A.J. Smith, noted visual aids expert of the British research establishment. Mr Smith stated in 1992: "Recent experiences encourage me to believe that modern simulators now have visual scenes that can produce a high fidelity representation of the real world in terms of lighting patterns. When properly calibrated these simulators can become a powerful tool for use in the development of visual aids" (reference 78).

Deficiencies/Enhancements: The visual displays programmed into modern flight simulators are entirely adequate for flight training conducted under simulated good visibility conditions. To suit them to use in visual guidance R&D activities, however, the visual depiction of airfield lighting system in simulated lower visibility situations must be improved dramatically. Light intensities, as viewed by the pilot, are attenuated by airborne particles in bad weather, and this diminution or loss of effectiveness has to be incorporated into the computer program generating the visual display. Additionally, light intensity will vary with viewing angle, due to beam characteristics of the lamps used in the real world, and this effect must also be provided for in the computer generating program. The capability for incorporating these more realistic lighting presentations is presently available with current simulator computer components, and the necessary lighting depiction changes can now be programmed into the system. These will not be minor programming tasks, but they can be accomplished.

Sources of Information: Air Line Pilot Association, FAA Aeronautical Center, Defense Research Agency, Bedford, England

Future Research: The research effort should begin with analysis of actual light intensities of visual aids observed under actual weather conditions. Much of this work has already been accomplished at the FAA Technical Center and at R.A.E. Bedford. The data should then be correlated with current simulator lighting program content, and software changes made subsequently to upgrade the quality of the simulator visual display. The work effort should include modification of simulator programs to include state-of-the-art systems such as PAPI's, Wig-Wag lights, and Stop-bars. Proof of testing should result in fully repeatable characteristics of intensity and beam spreads. The ultimate product will be a research oriented simulator that offers the capability for evaluating effectiveness of new visual aids without the need for actual flight testing.

6.3.4.11 Development of Portable Photometric Device.

Background and Past Studies: Photometric testing of aviation signal lights has been refined over the years to a finite science, with precise measurement of

lighting equipment, but is routinely accomplished only in laboratory and production facilities. Past work in the development of photometric measurement devices has concentrated on such fixed location devices. In the early 1970's efforts were made at the FAA Technical Center in Atlantic City, New Jersey, to develop a device capable of surveying a 10,000 Ft airfield in approximately six hours (reference 79). The device could be carried by one person but the procedure was excessively slow. Development of mobile equipment, suitable for use in the field, has only recently been explored. Carleton University in Canada has recently been examining light measurement devices in the field, employing techniques under development using video photometry. Additional exploratory work is being accomplished in the United States, with a major effort underway at the Marine Physical Laboratory in San Diego, California (reference 80). Significant work has also been accomplished overseas, at a major international airport, under a continuing ten year effort (reference 81). In 1992, field testing of a newly developed mobile airfield lighting photometric testing system was accomplished at Dulles Airport in Virginia (reference 82). This preliminary system offers great promise in improving the time required to measure field performance of light units. Further research is however necessary in attaining the capability to perform rapid and accurate measurement of in-pavement lights. The solution to this problem may now be achieved using newly developed technology.

Deficiencies/Enhancements: The recessed nature of airport in-pavement fixtures allows water and airborne materials to collect on the glass lenses, and frequent visual inspections are necessary to evaluate the unit surfaces for debris and to clean and restore performance (reference 83). A problem exists in establishing the level of deterioration of light performance beyond which active cleaning intervention is required. Visual inspection is imprecise, time consuming, and fails to measure photometric performance. A simpler means of measuring fixture/system performance is needed to evaluate individual in-pavement light units as they are overridden by carrier vehicles. To minimize downtime, vehicle speed should be in the 10-12 mph range to permit testing of a 10,000 runway in approximately 10 minutes.

Sources of Information: IES Aviation Lighting Committee, Lighting Equipment Manufacturers, Airport Operators.

Future Research: The work effort should focus, initially, on obtaining information from sources presently involved with such development. While no device is now available on the open market, it is known that several countries (United States, Japan and Canada) have developed prototype equipments. Subsequently, a working model could be assembled, probably from "off-the-shelf" components, and tested in the field.

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APPENDIX A
RESEARCH ANALYSIS

1. DISCUSSION

Many problem areas, as well as promising technology applications, were identified during the course of this study. From the preceding chapters it is evident that there was a wealth of available information to be sifted and organized. With such a wide diversity of source material, the problem becomes that of distilling the available material to provide a concise summary of results. The following material is organized and presented relative to the source or origin.

2. QUESTIONNAIRE

In April 1992, a questionnaire was distributed by the Air Line Pilots Association to member pilots. The questionnaire was developed to identify significant visual aids issues as viewed from the commercial airline pilot's perspective, and to provide user input into the Visual Guidance Study. A sample questionnaire is included as figure A-1.

Of approximately 400 questionnaires that were distributed, 148 were completed and returned, for a response rate of 37 percent. This must be considered excellent for this type of survey. Some respondents provided more than one answer and thus, in certain cases, answer totals may exceed the total number of questionnaires.

A total of seven questions were asked of the respondents. Questions were tailored so as to identify basic problems and to ultimately reveal research requirements. Following review and analysis, a number of pilot concerns were identified:

2.1 QUESTION 1

Question one dealt with approach and landing operations, and the single specific phase during which pilots experienced the most difficulty due to visual guidance deficiencies. By far the most frequently cited problem area (102 responses) was with identifying the proper runway turnoff/exit point. The second most frequently checked response (41) concerned guidance provided during the approach phase. Only minor concerns were expressed about visual aids used during the rollout (8) and touchdown (9) phases.

2.2 QUESTION 2

Question two solicited more detailed information concerning the specific problem area (approach and landing phase) identified by each pilot in his question one selection. Responses were divided between lighting (42) marking (26) and signs (23) as to those systems most in need of enhancement.

PILOT QUESTIONNAIRE

1. During which one of the following four phases of the Approach and Landing operation do you experience the most difficulty due to visual guidance system deficiencies?

- A. Approach_____
- B. Touchdown_____
- C. Rollout_____
- D. Turnoff/Exit_____

2. With reference to your answer above, what basic problem have you encountered most often, and which visual system (lights, markings, signs, etc.) seems most lacking in effectiveness?

3. During surface movements, which one category of visual devices seem to be least effective in providing taxiing guidance?

- A. Lighting System_____
- B. Sign System_____
- C. Paint Markings_____

4. Considering only the category of visual aids that you selected above, in what manner or way do they seem inadequate?

5. Up until now apron areas have been comparatively neglected in the effort to standardize airport visual aids. Do you feel strongly that more R&D activity should be devoted to this area?

Yes _____ No _____

Why so? _____

6. Finally, and from your own experience, would you mention any other visual guidance problems or deficiencies that appear in need of correction?

FIGURE A-1. PILOT QUESTIONNAIRE

In particular, pilots were most critical of the lack of easily identifiable exit markings and signage. Considering the fact that air traffic control (ATC) frequently issues instructions such as to "exit next available" or to "exit at Foxtrot", it is essential that pilots be provided with bold visual indications of where these exits are in time to make the turnoff. It is most apparent that a significant number of pilots, and perhaps the majority, feel that such critical guidance is lacking at airports.

Of those pilots choosing the approach phase as most lacking in adequate visual guidance (41), most amplified their selection by citing the need for either vortex advisory system (VASI) or precision approach path indicator (PAPI) installations to provide visual approach angle and obstruction clearance guidance.

2.3 QUESTION 3

Question three focused on surface movement (taxi) operations, asking respondents to choose between lighting, marking or sign systems as most in need of improvement for providing taxi guidance. Signs and markings were identified as the least effective systems 75 and 70 times respectively. Lighting systems were considered most in need of enhancement by only 12 respondents.

2.4 QUESTION 4

Question four was an attempt to obtain a more detailed explanation of the surface movement deficiency identified by each pilot in question three. The most frequently recurring problems, for each category of visual devices, were as follows:

- a. Lighting - Lighting issues were mentioned infrequently. Lighting problems identified included; lack of lights (2), the "sea of blue" effect (2), the need for additional taxiway centerline lighting (2), too much taxiway centerline lighting (1), and misleading/confusing patterns (1).
- b. Signs - Problems identified were; lack of standardization (22), incorrect placement (18), legend ambiguity (16), lack of/poor illumination (8), too few (8), and reading difficulty due to size/legend format (7).

It should be noted that the FAA has recently issued a new, drastically revised, advisory circular covering airport taxiway signage. It addresses, and should correct if applied and enforced, many of the signing deficiencies mentioned as critical by the responding pilots.

- c. Markings - Performance of the painted marking system in wet/snow conditions was identified most frequently as inadequate (29). Fading of the markings was cited next most frequently as a deficiency (26). Lack of reflectivity was also considered an issue and mentioned 17 times. Other issues were confusing markings (9), poor pavement marking contrast (4), and failure to remove old markings (2).

2.5 QUESTION 5

Question five dealt with the potential need for research and development activity in the apron visual aids arena. Respondents were asked to give their opinion

as to whether more work should be done in this area. Replies were mixed, with a majority answering yes (85) and a lesser number (53) replying in the negative. Following this question respondents were asked to provide the reason for their answer. Overcrowding, lack of standardization, poor surface and gate markings, extensive unmarked areas, and obstacle clearance were among the most frequently cited problems. Most respondents who said that no research and development (R&D) work was necessary indicated that improvement of other non-apron area visual aids should have priority in the overall scheme of things.

2.6 QUESTION 6

Question six asked for other deficiencies to be identified by the respondent, and a wide variety of answers were recorded. Many respondents indicated that VASI/PAPI's should be placed on all runways used by air carriers. Areas recommended for research included better and brighter paint, additional taxiway edge lighting, and addition of stop bars and improved runway distance remaining markers. Improvements to lighting and markings at SFO, LGA, and JFK airports were also among the items recommended. Sign sizing, paint reflectivity, and airport lead-in lights (LDIN) were also mentioned as worthy of investigation.

Imbedded in the foregoing paragraph is a brief mention of the need for additional taxiway edge lighting, as expressed by several responding pilots. Since the desire for expanded use of taxiway centerline lighting is frequently voiced, this reference to edge lighting may well be overlooked or misunderstood. In fact, a not insignificant number of pilots feel that removal of edge lights on straight sections of taxiways, when centerline lights are retrofitted, may result in a loss of information as to the lateral limits of the weight bearing taxiway surface. Some investigative effort to determine the extent of this seemingly minor problem might be indicated.

2.7 SYSTEM DEFICIENCIES

Numerous deficiencies were identified as a result of the analysis of the questionnaire responses.

Runway Exit Points

Inadequate visual identification of runway turnoff locations was considered a critical problem. Overall, better lighting, signs and markings are needed to expedite exiting the runway area and associated protected zones.

VASI/PAPI Approach Aids

Lack of VASI/PAPI on many air carrier runways was identified as a significant deficiency. While a need for specific research and development effort is not indicated, the problem was considered of importance and reflects a concern among pilots over the lack of these necessary and important visual glide path aids.

Signs/Marking Systems

Surface movement operations are adversely affected by deficiencies in taxiway sign and marking systems. Pilots expressed great concern over the disparities and variations in sign systems encountered at different airports. Hopefully, many of these problems will be remedied with the application of directives

contained in the recently issued, and greatly enhanced, signage advisory circular. With regard to airport markings, however, pilots indicated concerns over problems that can only be resolved through a considerable amount of research and development effort. In particular, they cited the fact that present markings, for the most part painted on the movement area surfaces, are virtually invisible under low visibility conditions and, especially, when standing water is present on the surfaces.

Apron/Gate Marking/Signage

Some research in apron/gate systems may be beneficial, with parking gate markings/signage being the area mentioned most frequently as being deficient. Uniformity of visual presentation is probably the most glaring problem, and some effort to standardize apron aids is certainly indicated. The FAA has not, to date, involved itself in this particular visual aids issue, but perhaps should.

Suggested Research Topics

Several specific recommendations were received concerning potential research topics. Areas mentioned as worthy of further investigation included increasing the size of signs for greater conspicuity, sequentially illuminating taxiway centerline lights to indicate routes, paint reflectivity improvements, enhanced taxiway edge lighting to better define lateral limits of the weight bearing surface, and increased utilization of stop bars for runway protection.

Response Frequency

A summary of responses is included as table A-1. The various responses have been tabulated to provide a numerical perspective.

TABLE A-1. PILOT QUESTIONNAIRE RESULTS

	QUESTION NUMBER						
	1	2	3	4	5	6	OTHER
APPROACH/ LANDING	41						
TOUCHDOWN	9						
ROLLOUT	8						
TURNOFF	102		1				
LIGHTING		42	12			1	
MARKING		26	70			6	
SIGNS		23	75		3		5
YES					88	1	
NO					57		

3. USER ORGANIZATION CONTRIBUTION

Many sources were surveyed during the course of the study to identify areas requiring improvement. These included pilot groups, manufacturers, safety organizations, and representatives of organizations such as the Helicopter Association International. These groups identified various problem areas in need of research solutions. While not all input was specific enough to be useful, even the general comments are included to establish the tone of user organization opinion as to "state-of-the-visual-art" in aviation.

3.1 HELICOPTER ASSOCIATION INTERNATIONAL (HAI)

Helicopter Association International (HAI) identified several problems that helicopter pilots face that may require some research and development effort. From the HAI perspective one of the larger problems is a general inability to differentiate the landing pad area from other nearby, but similarly configured, facilities such as well lighted parking lots, service aprons, etc. It is apparent that the presently used pad perimeter lighting systems are not, in many instances, sufficiently distinctive, and probably should be supplemented with additional visual devices for positive identification. Another area that HAI feels needs some attention is the development of "effective, yet inexpensive" visual aids for the four thousand smaller helipads and heliports throughout the United States.

3.2 AIR LINE PILOTS ASSOCIATION

A meeting was held with the Air Line Pilots Association (ALPA) staff members at their corporate headquarters in Washington DC to discuss visual guidance research study requirements and potential ALPA staff inputs. They provided several recommendations for research efforts, among which were the following:

Commercial Airport Identification Beacon

Develop a unique identification beacon for large air carrier airports. The proliferation of smaller airports, all displaying the common "airport" beacon, makes it difficult for pilots of large, fast moving commercial aircraft to distinguish the air carrier airport at the greater distances required for maneuvering in the terminal area.

Pilot Controlled Lighting Synthesizer Voice Response

Develop an audible response to verify system status and commanded intensity setting for pilot-controlled lighting. Provides confirmation that the desired lighting aids will be available to the pilot once they are within visual acquisition range.

Stop Bar Lighting Control Panel

Automate certain functions of stop bar lighting control panels to facilitate operation by air traffic controllers.

Closed Runway Visual Aid

Develop a new visual aid for the runway safety area to identify runways that are temporarily closed. Possibly a superimposed pattern within the Approach Lighting System array, or laser lights.

Color Specification for PAPI Systems

Variance between systems is a problem. The San Diego installation was more pink than red. ICAO has also changed color specifications for PAPI.

Temporary PAPI System.

Need for a temporary PAPI system. PLASI has a temporary specification, and a similar one is needed for PAPI type systems.

Taxiway Lighting

Selectively switchable lighting for surface movement control. Also work has been done on lights flashing in close proximity to the runway. (Spanish)

Marking Conspicuity Improvement

Conspicuity of markings is an important issue to ALPA. Some of the various ways to improve conspicuity may require further analysis. These include use of new plasticised materials in airport applications, and use of reflective materials and stimsonite-type markers. It also includes improved wide-area markings and the possible development of internally lighted materials for pavement markings. Paint removal technology is also an area of interest for ALPA.

Paint Marking Performance Measurement

Airport maintenance personnel, and certification inspectors as well, presently have no objective means for assessing the serviceability of reflectorized markings and, hence, the need for refurbishment.

Field-encountered Problems

Some portion of the R&D effort should be devoted to solving problems arising in the field, with time and resources scheduled for such work. This is viewed as an on-going necessity.

3.3 NATIONAL BUSINESS AIRCRAFT ASSOCIATION

A meeting was held with staff members of the NBAA at their Headquarters in Washington DC. Several recommendations were forthcoming as a result of this meeting. These included the following:

Small Aircraft Signs and Markings

Concern was expressed on the effects of low cockpit cutoff angles on the ability to acquire and maintain contact with signs and markings. This is generally considered to be a large aircraft problem, although it has also been experienced by smaller aircraft.

Inexpensive PAPI Installations for Small Airports.

Smaller airports cannot afford much of the more expensive equipment specified by the FAA. Affordable yet effective approach aids are needed.

Solar Power Applications for Airports.

Greater application of solar technology to the airport environment deserves attention, particularly for use at remote airport locations and in the small airport environment.

3.4 NATIONAL ASSOCIATION OF STATE AVIATION OFFICIALS

Principal contact was with Mr. Ed Scott, in-coming director of the National Association of State Aviation Officials (NASAO), headquartered in Silver Springs, Maryland. NASAO had several recommendations on visual guidance issues, and solicited member inputs for inclusion in this study. According to NASAO, the Congress included a requirement to study retroreflective signs and markings in the latest budget. Almost all local airports have a need for lower cost, yet effective, visual aids; and might be able to use highway shop facilities and labor pools to construct them if suitable designs were to be made available by FAA.

3.5 AIRCRAFT OWNERS AND PILOTS ASSOCIATION

Meetings were held with representatives of the AOPA at their corporate headquarters in Maryland to discuss the purpose of the visual guidance research and development study, and also to review current technology applications underway at various locations around the world. A number of topics were discussed, to include the composition of AOPA's membership, their needs, and the organization's often expressed concern that the needs of the small General Aviation airport are being ignored. Considerable discussion concerned the recently revised advisory circular on signage, and its effect on General Aviation pilots and airports.

Some specific AOPA interests were suggested as specific areas for research:

- . Laser type visual approach aids for Category 1 operations
- . Turf runway markings
- . Low cost airport identification beacons
- . Enhanced runway turnoff lighting for low profile aircraft
- . Highway reflector applications for small airports
- . Lighted markers for overhead wires

The AOPA displayed minimal interest in applications such as stop bars and computer control systems, but instead focused on improvements needed for the VFR and Category 1 IFR environment.

3.6 GENERAL AVIATION MANUFACTURERS ASSOCIATION

A meeting was held with the Vice President of Operations at GAMA headquarters in Washington DC. During the course of the discussions the purpose of the visual guidance research and development study was reviewed, as well as current technology research underway at various locations around the world. A number of topics were discussed, including the GAMA membership and the organization's composition. The General Aviation Manufacturers are interested in visual guidance improvements for all segments of aviation, although no specific recommendations were forthcoming at the meeting. The organization promised to solicit inputs at subsequent technical committee meetings but, unfortunately, nothing further has been heard from this group.

3.7 FLIGHT SAFETY AGENCY SOURCES

Contacts were made with representatives of several flying safety organizations soliciting inputs to the Visual Guidance study. These included the following organizations:

Flight Safety Foundation

Arlington VA., Mr. Bob Van Del-Airports Specialist.

Aviation Safety Institute

Worthington, Ohio, Mr. John Gallipault, President.

National Transportation Safety Board

Washington DC, Mr. Larry Roman, Airports Safety Investigator.

The purpose of the visual guidance study was described to each of these individuals while soliciting recommendations for the study. Emphasis was placed on the safety aspects of visual guidance. Mr. Larry Roman of the NTSB discussed the relevant aspects of the Detroit Northwest Airlines Accident. The actual report was reviewed by the authors for applicability to research issues. Runway incursions can be prevented by positive surface movement control, and new technology may be of great benefit in providing the visual guidance systems needed to assist pilots. These technologies include software, sensors, light sources, and fiber optics.

3.8 REGULATORY AGENCY SOURCES

The authors met with a number of different regulatory agency sources. As previously noted, the contacts are depicted in table 4.4.

Field Maintenance Technicians

The authors met with airfield maintenance personnel to assess the status of needs from their perspective. Field identified needs focused on hardware such as the following:

- MALSR Aiming Problem

The aiming device frequently does not fit properly on the PAR 38 lamps. Different manufacturers provide slightly different size lamps, causing problems in securing the aiming device. Also, three different aiming devices are required to properly aim a single system, with separate devices required for the PAR 38's, the flashers, and the threshold lights. Of the three devices, only the flasher device is considered satisfactory.

- MALSR Lamp Problems

PAR 38 lamp bases are considered to be insufficiently secured in their mounts. It was stated that: "the lights are wobbly as hell". In addition there appears to be a problem with the connectors burning off at the rear of the lamps.

- ALSF/SALSR

The PAR 56 aiming device is considered satisfactory. However, the retrofitting of rain shields makes it impossible to mount the aiming device.

- VASI Case Damage Problems

Lack of adequate shielding of VASI boxes in snow areas is considered to be a deficiency in the field. As a result the units suffer damage from snow, dirt and rocks being pushed or thrown against them by snowplows, resulting in dents and physical distortion of the equipment.

- REILS Problems

The maintenance technician indicated that the REILS consume an inordinate amount of maintenance time. He also has experienced problems with the flash tubes manufactured by certain companies - problems of intermittent operation and also excessive premature lamp failures.

- Approach Light Settings

The approach light angle settings for MALSR and ALSF2, along with the required light beam coverages, were discussed and the technician was unaware of any rationale for the large difference in individual station aiming angles between the two systems. It would appear that some sort of research effort may be necessary in order to determine optimal aiming angle settings for the MALSR systems to obtain the most efficient system performance.

Regional Certification Inspector

The authors met with a regional certification inspector to assess the Southern region's regulatory perspective on field problems and needs. The representative provided insight on field problems and areas for potential improvement. Some of the problem areas discussed included the need for effective monitoring of taxiway and runway lighting under ultra low visibility conditions. These include runway edge, TDZ, and runway and taxiway centerline lighting systems.

Development of a flashing (pulsing) mode for in-pavement hold-bars may also be necessary for improved performance.

FAA Headquarters

The authors consulted with FAA personnel from the Washington Headquarters frequently and, during the course of the discussions, many of these individuals provided inputs on problems and needs related to the area of visual guidance. Various problem areas that were specifically mentioned included the following:

- . Inadequate and/or confusing signage
- . Ill defined taxiways due to large open areas of concrete
- . Inadequate, faded pavement markings
- . Insufficient apron lighting
- . Inability to selectively control taxiway lighting segmentally

Many of the above indicated problem areas result from a failure of airport designers and consultants to follow existing FAA advisory circular recommendations and requirements. They also reflect, in large part, deficiencies that may be attributed to maintenance shortcomings and the continuing lack of funding for necessary airport improvements. Nevertheless, they do echo the complaints of user organizations mentioned previously.

Potential Solutions that were offered by the group included the following:

- . Develop improved stop bar control techniques
- . Adopt non-visual guidance techniques for taxiing aircraft (Autonomous Aircraft)
- . "Tear Up concrete", or provide synthetic raised surfaces
- . Standardize taxi routings
- . Install addressable signs
- . Automated Visual Control System (Segmented Route Lighting)
- . Use of sensors for selective lighting control
- . Runway Access barriers (physical and movable)
- . Develop improved pavement marking materials

Here again we find that the "solutions" offered were most general in nature, and many related to actions already being taken to remedy deficiencies previously identified by the user groups. The issues mentioned certainly emphasize the need for research, but provide little in the way of specific/detailed guidance.

The following new technology areas were recommended for investigation:

- . Computer control systems
- . Microwave sensors
- . In-pavement sensors
- . Fiber optics
- . Addressable signs
- . Laser applications

No specific applications were suggested, possibly because most of the individuals contacted were in regulatory positions and not intimately familiar with the day-to-day problems of pilots and airport operations personnel.

4. UNIVERSITY TECHNOLOGY RESEARCH

A large amount of the nation's research base is resident within the University structure. While most of this effort is concerned with basic rather than applied research, the following material is useful in identifying individuals and groups engaged in technological development efforts that may find application in airport visual guidance systems of the future.

Discussions were held with Mr. Qiang Huang of the Optics Department at Alabama University/Huntsville regarding projects in Waveguide Holography. Mr Huang is performing Doctoral Research on the potential use of Holograms in various applications. This includes such applications as signs, non destructive inspection, and alignment/docking assistance. Huntsville is the location of the Redstone Arsenal and the Huntsville NASA Space Center, both of which maintain a large research presence in the area. Mr. Huang has authored a number of articles for the Society of Photo-Optical Instrumentation Engineers and the Holography Newsletter, and several of his articles are included as attachments. His laboratory contains a number of holograms, of both the two and three-dimensional variety, that he has personally created. Most of these are of the display hologram type, mounted in four inch square frames. The holograms are created by exposing the special hologram film to the subject, backlighted by a laser light source. Color properties of the hologram are determined by the properties of the laser light. The hologram image may then be mounted on a substrate material which can be illuminated by an incandescent or neon source. This type of hologram may have some application as display and highway signs in the immediate future.

At the present time the display holograms are too small for aviation applications. In order to make a larger size hologram, of a size suitable for airport sign experimentation, it will be necessary to use a much larger laser than the one currently possessed by the university optics department. The cost for such a large laser may be a limiting factor, although use of incandescent lighting sources for the edge-lit holograms would appear to be practical.

Contrast problems are another issue to be resolved, since effective edge-lit holographic signs must be conspicuous and have effective acquisition ranges during both daylight and night operations. Mr. Qiang Huang is researching the costs of creating a sign large enough for airport applications.

Extended discussions were held with Dr. John Gilbert, Director of the University of Alabama Center for Applied Optics. Dr. Gilbert's department is involved in a variety of research activities that include; holography, the use of optical borescopes for medical examinations and non-intrusive inspection purposes, and display imaging to support space docking. One particular technology application that appears to be of potential benefit is the application of fiber optics as sensors for surface movement. Dr. Gilbert's group is developing a system of optical fibers that are monitored by an optical transducer to determine when vehicular movement has occurred. Profiles for individual vehicles are stored in the monitoring computer for specific identification. The potential advantages of this technology include insensitivity to temperature, freedom from corrosion, and the ability to be imbedded in pavement surfaces. This technology should receive further examination for airport applications.

Discussions were held at Georgia Tech University in Atlanta, Georgia. During meetings with Professor Clifford Brogdon, Manager of aviation programs and Associate Vice President at the University, considerable time was spent reviewing the Visual Guidance Study requirements and various programs at the University. Dr. Brogdon provided names and telephone numbers of key Professors in Optics, manufacturing technology, visual communications, and transportation. The University is heavily involved in developmental research on lasers and addressable sign technology. Georgia Tech is also involved with uses of fiber optic technology in communications applications.

Several professors at the Virginia Polytechnic Institute in Blacksburg, VA were contacted to discuss fiber-optic and laser applications in airport lighting. Virginia Tech has been exploring the feasibility of using various light sources (including lasers) in combination with optical fiber networks to light runways. Centralized light sources may thus be used to illuminate lighted fixtures at remote locations. Such a lighting system would be virtually lightning proof and centralized for maintenance purposes. Optical-grade fiber is produced at the university, as well as the other components necessary to complete fiber optic systems.

Other universities around the country are heavily involved in research and development efforts which may be applicable to future visual guidance systems. Rutgers and Princeton Universities in New Jersey are involved in fiber-optics research. The University of California Scripps Oceanographic Institute in San Diego has been developing a technique called "whole sky imaging" that uses a "Horizon Scanning Imager" to determine beam transmittance (reference 1). A calibration scheme is incorporated into the software to provide real-time measurement and results. Similar work is also being done in Ottawa, Canada by Carleton University. These efforts offer potential improvements in automated measurement of airport lighting systems performance as an aid to maintenance.

5. INDUSTRY TECHNOLOGY RESEARCH

Industry research programs constitute the largest areas of research in the country, and Government sponsorship of research is closely intertwined with private sponsorship. Much of the marking materials research, as might be expected, is sponsored by state highway departments. Lighting research is primarily focused on potential market penetration and is profit orientated. Sign technology is fairly stable, although fiber-optic applications are being investigated as a means of increasing effectiveness.

5.1 LIGHTING RESEARCH.

Lighting research is on-going at many of the nations manufacturing facilities, with a large number of projects currently underway. These include such developments as the Airport Smart Power (ASP) control system for stop bar and other lighting systems. Computer control, fiber optics, new lamps and lenses, and low visibility applications all are being researched.

Portable photometric equipment is also being developed, and one such system was demonstrated to the authors during the study effort. Calibration of the device is the most time consuming aspect of system operation since, following setup, test measurements must be correlated with a hand-held photometer. Once preparations are completed, the sequence is fairly rapid and takes only 20-30 seconds per fixture. This should allow measurement of light output along a 10,000 foot runway to be completed in about an hour. For the demonstration the system was set up outside the office and operated with actual hardware. The system was mounted on a pickup truck for the demonstration, and components included the sensor rack, 8086 computer and the control equipment. The test of the system revealed it to be an effective device.

Laser Research

Laser lighting research is underway at individual companies such as Humbug Mountain Laboratories in California. Humbug Mountain Laboratories has been supporting the United States Navy in laser lighting development, with emphasis on visual approach guidance systems for carrier operations.

Control Systems Technology

The application of impressed signals on cables for control purposes has been used in rail transportation for years. Recent use of this technology for aviation lighting control offers potentially great benefits for airports. The use of existing power circuits to carry control signals can avoid expensive retrofits as airports upgrade lighting and sign systems. United States manufacturers have developed this technology for controlling stop bars at the SEATAC International Airport in Washington state, with ADB-ALNACO pioneering the technology application among United States companies.

Fiber-optics Research

The use of fiber-optics for control uses is expanding rapidly since it is chemically inert, reduces signal losses, and is relatively inexpensive to produce. United States companies are leading fiber optic producers, with a

Massachusetts company producing all of the fiber optic materials used in Canadian airport sign applications.

Electro-luminescent Technology Research

Electro-luminescent visual devices have been extant for many years. In 1982 the United States Air Force evaluated electro-luminescent lighting for portable airfield lighting (reference 2), and, recently, the Visual Guidance Section evaluated an electro-luminescent heliport lighting system at the FAA Technical Center. While the evaluation offered mixed results, some significant improvement was noted over previously tested first generation electro-luminescent devices. Insufficient light output has been a continuing problem, with some improvement evident with the newer systems.

Another application for this technology, with significant potential, is its use as a substitute for the standard incandescent lamp, a Sylvania development. The use of phosphors which are stimulated by an electrical current, instead of use of the traditional tungsten filament, has the potential for cost effective savings over the long life of the lamp. Whether the light output level (intensity) will prove satisfactory remains to be determined.

5.2 MARKING RESEARCH.

Various types of marking materials are currently in use in the United States. These are: water-borne paints, solvent-borne paints, thermoplastics, epoxy thermoplastics, thermosets, polyesters, tapes, beads, and raised markers. Solvent-borne paint is by far the most commonly used material because of its durability and ease of application. Water-borne paints are being carefully examined by several states and the FHWA because of recently imposed stringent environmental restrictions. The South Coast Air Quality Management District (Los Angeles) placed limits on the amount of volatile emissions that can be released per day. This impacted the CALTRANS ability to apply traffic striping using solvent-borne paints, and as a result they have transitioned to use of water-borne paints. Water-borne traffic paint is now the only material allowed in most of Southern California. Concern has arisen in other states with regard to the problem of disposing of the containers (55 gallon drums) used to ship solvent-borne paints. Since these are classified as hazardous materials, the disposal of the drums is a problem.

Thermoplastics

Though use of Thermoplastic materials is becoming common in many states, they do have certain limitations. Thermoplastics cost on the order of five to six times more than paint, and some are alkyd based. Thermoplastics generally last three to five years, and can be sprayed on or extruded. Although extrusion methods are slower, the edges of the lines so applied are more distinct than can be achieved by spraying. Other considerations that restrict airport application are problems with surface cracking, color stability, and possible damage (material lifting) during snow removal operations.

Thermoset Materials

Thermoset materials are also being used by the many state DOTs for pavement marking. These contain two different components that are brought together, forming a chemical reaction producing heat to aid in the bonding of the material to the pavement. Both polyester and epoxy systems are being used as highway marking materials. Polyester paint is a two component, thermosetting system and is a proprietary product manufactured by several major paint producers. Drying time varies with the ambient temperature but is usually 10 to 45 minutes. Polyester performs well on Portland cement concrete but not on aged asphaltic surfaces.

Two component thermosetting epoxy systems have been in use since the 1970's. The two components (resin/pigment and catalyst) are mixed together and sprayed on the pavement. The material can be placed on wet or dry pavement and, in some cases, wetting of the pavement ahead of the area to be sprayed is required. Curing time is usually 15 to 30 minutes.

Tapes

Tapes come in two types: regular, for permanent marking, and a special type with removable foil-backing that can be pulled up by hand for temporary use around construction sites. Regular tapes are preformed plastic strips made of polyvinyl chloride resin binders, usually provided with a pre-applied adhesive under a protective paper backing. In some cases, however, epoxy primers are used with those tapes that do not have pre-applied adhesives.

Pavement Markers

Pavement markers come in a numerous shapes and sizes. The most commonly used nonreflective raised markers are made of ceramics with glazed surfaces. Reflective markers use cube-cornered acrylic lenses, tempered glass lenses, or glass beaded lenses and are mounted in plastic, ceramic, or metal bases. Because of the problem of dislodgement by snowplows, the metal housing was developed and the marker is embedded or inset within a groove in the pavement.

6. OVERSEAS RESEARCH.

A number of foreign agencies and companies were contacted during the course of the study.

6.1 CANADA

Transport Canada, the Canadian counterpart of the FAA, was contacted during the study for the purpose of surveying the latest Transport Canada activities in the visual guidance realm. Mr. Ed Alf of the agency provided information on a proposed stop bar and control system installation at Toronto Airport, a project somewhat similar to the SEATAC stop bar evaluation program. Transport Canada is also involved with a medium-intensity approach lighting system with runway alignment indicator lights (MALSR) installation program that has generated several concerns about the aiming angles used for the system as specified by the FAA. Transport Canada also provided information on new sign installations that utilize fiber-optic technology. The signs have been installed at several airports including Edmonton, Halifax, Monckton, Calgary, and Cambridge Bay.

Mr. Ed Alf provided contact points for the various manufacturers of this equipment.

During the course of the study a number of Canadian firms and organizations were contacted regarding new technology applications in visual aids.

Ms. Charlene Davis of Davis Airfield Signs in Edmonton, Alberta, provided information on the company's fiber-optic sign products, which have found widespread acceptance at airports throughout Canada. In addition to the previously mentioned airports, installations are scheduled at Ottawa, Winnipeg, and Vancouver in the near future. Ms. Davis indicated that bifurcated fiber optic technology is used in the signs, with multiple fibers and light sources employed for redundancy. Benefits attributed to the signs include greater conspicuity and enhanced legibility over wide viewing angles. Literature on this technology is included in attachments to the study.

Mr. Regent Tasse is marketing manager for Tassimco Company of Montreal which is retrofitting a fiber optic lighting system to illuminate a large cross on a hill in Montreal. They are investigating possible airport applications for this system.

Mr. Phil Gabriel of the Bendix-Avalex Company provided information on the surface movement control system the company is presently installing at Toronto International Airport. The system is to be used for ramp traffic guidance, and employs a combination of piezzo sensors, stop bar lights, and computer control apparatus to provide segmented lighting control within the ramp area. Much of the technology is derived from systems previously developed by Simon-Parmeko Ltd. of the United Kingdom. The unique nature of the system lies in its software control logic and in the types of sensors and switching combinations employed to sequence aircraft. While the United States has no stated need for ramp control at present, the use of similar technology could assist in maintaining surface movement separation on other areas of the airport surface that are under ATC control.

6.2 UNITED KINGDOM

The Royal Aircraft Establishment of the United Kingdom has a long tradition of research achievement in the area of visual aids. In past years the Bedford Laboratory was responsible for developing new landing aids such as the PAPI visual approach system. An ambitious work program is currently underway at the Bedford facilities and includes work on simplification of airport and heliport lighting systems to achieve reductions in installation and maintenance costs. In response to a letter requesting information, the RAE facility provided a series of current research activities underway at the facility, and also provided a listing of recommended research activities and needs projected for the future. A summary of their recommendations for future work follows:

- . Visual aids for ground movement
- . New sign technologies
- . Simulator visual aid fidelity
- . Rotorcraft visual aids
- . Control system technology

6.3 GERMANY

The application of new technology is a tradition in German scientific and industrial research. Currently German companies are at the forefront of development for surface movement control and guidance systems. The new airport that recently opened at Munich is provided with state-of-the-art control systems for surface movement, featuring loop detectors and computer control of surface lighting for aircraft guidance. Siemens AG has performed significant research into methods for controlling airport surface movement. Literature on the Siemens system is included in the attachments to the study.

6.4 SPAIN

The Spanish government has enthusiastically sponsored visual aids research for the past several years, following serious mishaps arising from runway incursions at Madrid's Barajas Airport. Installation of surface movement control systems and the application of stop bars at the airport are significant efforts currently underway.

6.5 SWEDEN

Sweden is a major developer of new technology applications in airport visual aids. Smart Power control systems were first developed and tested by the Swedes in airport applications. The successful application of power cable signal control has enabled companies such as Airport Technology (AT) to market their products in other countries such as the United States and Italy. The Swedish government is also conducting testing of new signs and markings.

6.6 RUSSIA

The Russian government has conducted extensive testing of visual aids suitable for military operations. While information is somewhat limited, it is known that the Russians have conducted research on visual landing devices such as the "Glacada" visual approach aid, a Laser version of the VASI system.

7. NON-FAA GOVERNMENT RESEARCH

Various agencies conduct research for the Federal Government. As mentioned earlier, the National Bureau of Standards was at the forefront of much of the earlier aviation lighting research conducted at Arcata, California. Considerable other visual guidance research is being done at government laboratories throughout the United States. Study contacts made at these facilities are outlined below.

7.1 NAVAL AIR WARFARE CENTER

The authors met with visual guidance specialists at the Naval Air Warfare Center in Lakehurst, New Jersey, for the purpose of determining the status of visual guidance work at the Center laboratory and to assess the capabilities of the their photometric research laboratory. The following personnel were contacted during the course of the visit:

Mr Greg Dyczco, ICOLS Project Manager
Mr. Don Raman, Airfield Landing Aids Manager

The majority of the day was spent with Mr. Dyczco, who explained the evolution of the Improved Carrier Optical Landing System (ICOLS). The Navy is in the process of developing an upgrade to its current shipboard visual guidance system, the Fresnel Lens Optical Landing System (FLOLS), and the new system will employ laser technology to increase the effective range for acquisition and use. Other enhancements include the provision of azimuth information to supplement the traditional glide slope cues and a unique new integration of radar information with the visual signal to provide optical rate of descent cues. Thus far the effective range for system use is approximately 10 miles, as compared with 1 to 2 miles for the traditional FLOLS system. Separate lasers are used in the system to provide individual corridors of light. The research effort is supported by Humboldt Mountain laboratories in California as the NAWC contractor. As an aside, various types of lasers are being used in the project, to include argon and helium/neon types. Additionally, other laser applications may soon be explored at the laboratory. One potential application currently under consideration is the use of a yellow laser to provide alignment information to the pilot during landing rollout on a conventional runway. This could be a particularly valuable enhancement at civil aviation airports.

Potential research exploration areas were reviewed, and Mr. Raman's extensive experience in the visual aids realm was most helpful in identifying and highlighting areas for research. These included the following:

- . Need for improved devices for setting ALSF and MALS individual lamp vertical aiming angles.
- . Need for an effects analysis for loss of individual barrettes in the approach light system where terrain also is sloping.
- . Identify acquisition range differences between smaller and larger distance-to-go markers.
- . Test use of fiber optics to separate light sources from impact region of in-pavement lights.
- . Test the scatter effects of laser light sources versus incandescent sources in visible moisture conditions.

7.2 U.S AIR FORCE ENGINEERING AND SERVICES CENTER

The Air Force Engineering Center at Tyndall Air Force Base in Florida is the focal point for marking and lighting research in the United States Air Force. In recent years the principal focus has been on portable lighting systems and on development of visual aids for use in combat areas. Past testing has involved radio-luminescent lighting aids, retro-reflective markings, and tone-down color schemes. At the current time testing is being conducted on improved painted markings for enhanced performance and reflectivity (reference 3).

7.3 VOLPE TRANSPORTATION SYSTEMS CENTER (VTSC)

In December 1991, the Department of Transportation Volpe Transportation Systems Center in Cambridge, Massachusetts, was visited. The purpose was to assess research activities sponsored by the center for possible incorporation into visual guidance testing at the Technical Center. The VTSC is a major

participant in the Airport Surface Traffic Automation (ASTA) project. While the air traffic control aspect is pre-eminent, a portion of the effort is devoted to establishing automated visual aids at runway entrances and to runway status lights on the runway itself. A particularly salient aspect of the VTSC program is the automated interface of surface and airborne traffic radar signals, and the planned use of sensors to identify ground traffic. Visual aids and automated surface movement are very much a part of research activities sponsored by the facility.

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