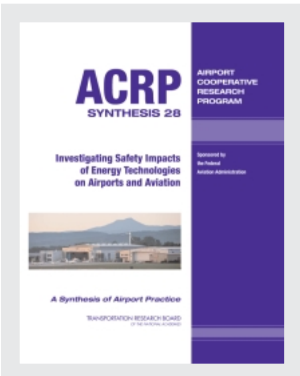

Investigating Safety Impacts of Energy Technologies on Airports and Aviation

DETAILS

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ACRP SYNTHESIS 28

Investigating Safety Impacts of Energy Technologies on Airports and Aviation

A Synthesis of Airport Practice

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TRANSPORTATION RESEARCH BOARD

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

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NOTICE

The project that is the subject of this report was a part of the Airport Cooperative Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

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Cover figure: Wind turbine at Burlington International Airport, Vermont (*credit:* Christopher Hill, Heritage Aviation).

FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer
Transportation Research Board

This synthesis study is intended to inform airport operators, aircraft pilots, planning managers, energy developers, legislators and regulators responsible for aviation safety, land use compatibility, airport planning and development, and airport financial self-sustainability about existing literature, data, and ongoing research on physical, visual, and communications systems interference impacts from energy technologies on airports and aviation safety. The energy technologies that are the focus of this report are:

- Solar Photovoltaic Panels and Farms—Solar photovoltaic (PV) generates electricity from sunlight on light absorbing panels with many panels together representing a solar farm.
- Concentrating Solar Power Plants—Concentrating solar power (CSP) utilizes mirrors to focus and intensify the sun's heat to boil water and drive a traditional steam turbine for the production of electricity.
- Wind Turbine Generators and Farms—Wind turbine generators (WTGs) convert energy from wind to electricity either as single units or multiple units also known as farms.
- Traditional Power Plants—Traditional power plants are fueled by fossil or biofuels and generate base load electricity by boiling water and forcing the steam through a turbine. Cooling systems are necessary to cool the steam for reuse. Peaker power plants are a subset of this category that are being proposed to start up and shut down quickly in response to seasonal fluctuations in energy demand.

Information used in this study was acquired through both published and preliminary sources and interviews with experts in the fields of aviation and energy.

Stephen B. Barrett and Philip M. DeVita, Harris Miller Miller and Hanson Inc., Burlington, Massachusetts, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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INVESTIGATING SAFETY IMPACTS OF ENERGY TECHNOLOGIES ON AIRPORTS AND AVIATION

SUMMARY

Economic, technical, and social factors are leading to a nationwide expansion in energy developments. New technologies and innovations are making renewable energy generation more efficient and cost-effective. Growth in energy demand combined with a shift toward a decentralized energy-generation network is moving energy projects away from population centers to locations where indigenous energy resources can be harnessed. As projects are proposed in new areas, potential conflicts with existing uses including airports and aviation have emerged.

The purpose of this report is to compile existing literature, data, and ongoing research on physical, visual, and communications systems interference impacts from energy technologies on airports and aviation safety. Information has been collected from both published and unpublished sources, and interviews have been conducted with experts in the fields of aviation and energy. The intended audience for the report is airport operators, aircraft pilots, planning managers, energy developers, and legislators and regulators responsible for aviation safety, land use compatibility, airport planning and development, and airport financial self-sustainability. With a comprehensive inventory undertaken of the safety impacts of energy technologies on airports and aviation, gaps in the existing knowledge base are identified along with future research to fill those gaps. These suggestions are summarized at the end of the report.

The energy technologies that are the focus of this report are:

- Solar Photovoltaic Panels and Farms—Solar photovoltaic generates electricity from sunlight on light-absorbing panels, with many panels together representing a solar farm.
- Concentrating Solar Power Plants—Concentrating solar power utilizes mirrors to focus and intensify the sun's heat to boil water and drive a traditional steam turbine for the production of electricity.
- Wind Turbine Generators and Farms—Wind turbine generators convert energy from wind to electricity either as single units or multiple units also known as farms.
- Traditional Power Plants—Traditional power plants are fueled by fossil or biofuels and generate base load electricity by boiling water and forcing the steam through a turbine. Cooling systems are necessary to cool the steam for reuse. Peaker power plants are a subset of this category, which are being proposed to start-up and shut down quickly in response to seasonal fluctuations in energy demand.
- Electrical Transmission Infrastructure—Transmission infrastructure, including towers and electrical lines, are a fundamental component of any energy project that generates electricity and delivers it to the electrical grid.

The potential impacts of energy technologies that have been identified are as follows:

- Physical Penetration of Navigable Airspace (also referred to in this report as "airspace") as defined by FAR (Federal Aviation Regulations) Part 77—Structures rising more than 200 ft above ground level or less when located close to airports intrude on defined airspace.

TABLE 1
SUMMARY OF ENERGY TECHNOLOGIES AND POTENTIAL IMPACTS

Potential Impacts	Energy Technology	Impact Assessment Metric	Mitigation	Examples	References
Physical Penetration of Airspace	Solar photovoltaic Concentrating solar power Wind turbine generators Traditional power plants Electrical transmission	Part 77 review Affect on minimum en route altitude TERPs penetration of 35 ft or more	Appropriate siting Modify structure height Marking and lighting Update air navigation charts Modification to instrument approach procedures	Solar PV, Oakland International, California: design accommodates imaginary surface Ivanpah Solar Plant, California: 3 power towers each 459 ft tall; FAA lighting required Bowers Field, Ellensburg Washington: increased approach minimums after Wild Horse Wind Farm constructed Blythe Solar Plant, California: CEC decision decreased height of transmission towers, lights, and ball markers	FAA (2010f). *Technical Guidance for Evaluating Selected Solar Technologies at Airports* FAA (2008a). *Procedures for Handling Airspace Matters*, Order JO 7400.2G
Communications Interference	Solar photovoltaic Concentrating solar power Wind turbine generators Traditional power plants Electrical transmission	Corona discharges where leaks occur between conductors and insulators	New radar facilities Transponders in aircraft Building set-backs from primary radar Radar-absorbing material Correction to STARS configuration	Solar PV, Oakland International, California: 500-ft set-back from ASR Shepherd Flats Wind Farm, Oregon: FAA approval contingent on upgrade of primary radar facilities Travis Air Force Base, Fairfield California: study concludes impacts avoided with software upgrade via STARS configuration	U.S. Transportation Command (2010). *Assessment of Wind Farm Construction on Radar Performance*, Cooperative Research and Development Agreement, Research Conclusions and Recommendations
Glare Visual Impairment	Solar photovoltaic Concentrating solar power	Ho Method (see Ho et al. 2009)	Anti-reflective coating Modified flight procedures Proper siting and design Notification to aviation community	Blythe Solar Plant, California: CEC decision required update of air nautical charts, operational movements during nighttime, and documentation of complaints Ivanpah Solar Plant, California: CEC decision requires	California Energy Commission (2010). Blythe Solar Power Project Commission Decision Ho, C., et al., (2009). *Hazard Analysis of Glint and Glare from Concentrating Solar Power Plants*, Solar PACES 2009

TABLE 1
(*continued*)

			Positioning mirrors during non-daylight hours Continuous operations and maintenance Specific design requirements Glare avoiding operational planning Procedures for recording and responding to public complaints	development of heliostat monitoring plan, and power tower luminescence monitoring plan, update of air nautical charts	California Energy Commission (2010). Ivanpah Solar Power Project Commission Decision
Thermal Plume Turbulence	Concentrating solar power Traditional power plants	Australian Method (4.3 m/s velocity signifies potential impact)	Notification to aviation community Modified flight procedures Aircraft preserve 1,000-ft buffer from energy facilities Avoid flights directly over the facility	Blythe Solar Plant, California: CEC decision required update of air nautical charts Ivanpah Solar Plant, California: flights over facility no lower than 1,350 ft	FAA (2006). *Safety Risk Analysis of Aircraft Overflight of Industrial Exhaust Plumes* (DOT-FAA-AFS-420-6-1)
Vapor Plume Visual Impact	Concentrating solar power Traditional power plants		Aircraft preserve 1,000-ft buffer from energy facilities Avoid flights directly over the facility	Ivanpah Solar Plant, California: flights over facility no lower than 1,350 ft	
Rotor Turbulence	Wind turbine generators	Trolberg setback (750-ft buffer from wind turbine)			Troldborg, N., et al. (2007). Actuator Line Simulation of Wake of Wind Turbine Operating in Turbulent Inflow," *Journal of Physics: Conference Series 75. The Science of Making Torque from Wind*

TERPS = Terminal Instrument Procedures; PV = photovoltaic; CEC = California Energy Commission; STARS = Standard Terminal Automation Replacement System; ASR = airport surveillance radar.

- Communications Interference—Electromagnetic interference can be caused by any large structure that can reflect radar signals causing loss of radar coverage "downstream" or produce false radar signals referred to as clutter. Physical structures can also obstruct view of navigational aids.
- Visual Impacts from Glare and Glint—Certain materials produce glint (a momentary flash of bright light) and glare (a continuous source of bright light), which can disrupt pilot and air traffic controller vision.
- Visual Impacts from Vapor Plumes—Vapor plumes can be caused by the release of power plant exhaust from wet cooling systems resulting in reduced pilot visibility.
- Turbulence from Thermal Plumes—Thermal plumes are created by power plants using dry cooling systems releasing hot air that rises at a measurable rate and causes air turbulence. Unlike a vapor plume, that turbulence cannot be perceived by a pilot, which increases the potential risk to aviators.
- Turbulence Downwind of Wind Turbine Rotors—Wind turbines disrupt uniform air flow causing unseen turbulence produced downstream of wind turbines.

The information collected for this report is summarized in Table 1. The table presents technologies and potential impacts, metrics identified for assessing impacts, example projects, useful references, and data gaps. It was found that a significant amount of research has been conducted, particularly over the past year, on energy technologies and their safety impacts on airports and aviation. Some of the issues (e.g., wind turbine impacts on radar) have received more study than others (e.g., visual impairment of glare). Current activities of government agencies studying these issues are also summarized. In general, data collection efforts have been reactive in response to new proposals for energy facilities.

Based on this information, additional field studies may be conducted on each technology that can be used to further define thresholds for assessing impacts and establishing a carrying capacity limit for each technology. Further research may include a baseline inventory of energy facilities for implementing planning and conduction cumulative impact assessment; siting and planning guide books to include mitigation and opportunities for aviation adaptation; and glare and thermal plume turbulence assessment tools.

CHAPTER ONE

INTRODUCTION

This report presents the results of ACRP Project S10-06, *Investigating Safety Impacts of Energy Technologies on Airports and Aviation.* This introductory chapter describes the purpose of the report, presents the methodology used to develop the report, and outlines the organization of the report.

PURPOSE OF REPORT

As federal, state, and local governments increase support for energy sources such as solar, wind, and other types of power plants, the impact of these technologies on the operational safety of airports and aviation is coming under increased scrutiny.

Solar energy is a growing alternative energy source. Despite its generally accepted use on or adjacent to airports there are concerns. Two major safety concerns frequently expressed by pilots and airport operators regarding solar collectors are glare and physical location. Glare can cause temporary visual impairment to pilots or controllers. Improper placement can adversely affect the safety of airport operations. Wind energy is another growing alternative energy source. Two major concerns are the height of the turbines/blades and communications systems interference. Other concerns include turbulence, lighting and marking for wind farms, and temporary meteorological test facilities. 14 CFR Part 77 addresses the height, location, and size of obstacles to aviation. However, much of this information is advisory in nature, and limited data exist on the extent of radar interference occurrences between wind turbine farms and various types of air traffic control radar systems. States and local governments are witnessing an increase in the number of applications to locate power plants adjacent to airports. Exhaust plumes from these plants have the potential to create in-flight hazards that affect the control and maneuverability of aircraft. However, the literature that supports efficient siting of newer technology plants near airports is not available in one location in a concise format for use by airport operators, aviation land use planners, and regulators.

The objective of this synthesis project is to compile existing literature, data, and ongoing research on physical, visual, and communications systems interference impacts from energy technologies on airport and aviation safety. It is not an analysis of federal and state energy or aviation policy. The intended audience for the report is airport operators, planning managers, energy developers, and legislators and regulators responsible for aviation safety, land use compatibility, airport planning and development, and airport financial self-sustainability.

METHODOLOGY

This synthesis report follows four steps. First, a review of the existing literature was completed to identify potential hazards from energy technologies on airports and aviation. Second, experts in the area of energy and aviation were contacted and interviewed to augment the existing information base. Third, the information has been organized in a systematic format by energy technology and impact type that includes a concise understanding of the potential impact, methods available for defining and measuring potential impacts, laws and policies that have been enacted to codify impact definition and required analyses, and mitigation practices available to minimize impacts to an acceptable level. The literature review provides examples from existing projects to support the impact definition and analysis. As a final step, gaps in the existing literature have been identified and suggestions for future research provided.

REPORT STRUCTURE

The remainder of this document is as follows:

Chapter Two—Energy Technologies and Types of Impacts	An introduction to the developing energy technologies (and associated infrastructure) identified by the Topic Panel as presenting a potential hazard to airport and aviation is provided. As a basis for assessing impacts on airports and aviation the regulatory definition of navigable airspace is presented. Then the potential types of impacts that might occur from the energy technologies on airports and aviation operating in airspace are described. A section on the sources of information available for understanding the current state of practice that have been used in this report is also provided.
Chapter Three—Solar Energy and Potential Impacts	An introduction to the different types of solar technologies and the potential impacts associated with each is provided. The technologies described are photovoltaics and concentrating solar power. Potential impacts focus on physical penetration of airspace, communications systems interference, visual impacts from glare and vapor plumes, and turbulence from thermal plumes. Technology-specific mitigation measures are provided.
Chapter Four—Wind Energy and Potential Impacts	Wind energy facilities and potential impacts on airports and aviation are described. A brief overview of the modern wind turbine generator is provided and typical configurations for facilities described. Potential impacts of wind energy facilities are defined as physical penetration of airspace, communications systems interference, and rotor-induced turbulence. Technology-specific mitigation measures are provided.
Chapter Five—Traditional Power Plants and Potential Impacts	New traditional power plants and their potential impacts on airports and aviation are described. A summary of power plant technology, siting objectives, and electricity generation drivers is provided. Potential impacts from traditional power plants are identified as turbulence from thermal plumes and visual impacts from vapor plumes produced by cooling towers. Technology-specific mitigation measures are provided.
Chapter Six—Electrical Transmission Infrastructure	All of the energy-generation technologies described previously require electrical transmission infrastructure to deliver electricity along high-voltage lines to areas where the electricity will be consumed (oftentimes referred to as "load centers"). Potential impacts of new transmission infrastructure on airports and aviation include physical penetration of airspace and communications interference.
Chapter Seven—Summary of Data Gaps and Agency Programs	An assessment of potential data gaps is presented along with a description of the benefits of filling those gaps to understanding potential impacts and protecting safe air navigation. In addition, ongoing agency efforts for investigating conflicts between energy and aviation are described.
Chapter Eight—Conclusions	The final chapter summarizes the findings of the report. These findings will provide a technical assessment of current practices, describe barriers to further understanding of the issues and solutions, and identify existing knowledge gaps.
Glossary of Terms, Abbreviations, and Acronyms	A brief glossary of terminology, including abbreviations and acronyms commonly used in energy and aviation, used in the synthesis report is provided.
References	A listing of the reports, websites, and data sources used in preparing the synthesis report is provided.

CHAPTER TWO

ENERGY TECHNOLOGIES AND TYPES OF IMPACTS

This section of the report describes the energy technologies of interest and the types of impacts that they may produce. This chapter also summarizes the types of information available for assessing existing impacts of energy technologies on airports and aviation, including reviewing the regulatory definition of airspace that is used to evaluate potential impacts.

ENERGY TECHNOLOGIES

The energy technologies that are analyzed in this report are solar power [both photovoltaic (PV) and concentrating solar power (CSP)], wind turbine generators (WTGs), and traditional power plants. The report also considers issues associated with the new electric transmission infrastructure necessary for delivering the electricity from these new facilities to high energy consumption load centers.

Solar Photovoltaics and Concentrating Solar Power

A *solar PV system* is made up of various components that collect the sun's radiated energy, convert it to electricity, and transmit the electricity in a usable form. The main component is the solar panel, which is typically comprised of 40 individual solar cells made from silicon that convert sunlight into electricity (see Figure 1). The panels are held in place by a frame that is either fastened to an existing structure or placed atop a stand that is mounted on the ground. Panels are covered by a thin layer of protective glass and the panel is attached to a substrate of thermally conductive cement that traps waste heat produced by the panel and prevents it from overheating. Several panels connected together in series are identified as a "string" and often operate as a single generating unit. Multiple strings assembled into one solar facility are referred to as an "array." Other types of PV technologies include thin film and multi-junction versions. Solar PV systems may consist of just a few panels providing electricity to a single building or cover tens to hundreds of acres and transmit electricity to the power grid. Utility-scale solar plants are connected to the electricity grid by networks of transmission towers and high-voltage electrical lines (NREL 2010a).

CSP systems use reflective mirrors in large arrays to focus the sun's energy on a fixed point producing intense heat, which is then converted to electricity. The most common means for producing electricity in these systems is to heat water and produce steam, which drives a turbine, usually for the purpose of supplying commercial power to the grid. Three CSP designs are parabolic troughs, power towers, and dish engines (NREL 2010a).

Parabolic troughs continually track the sun and concentrate the sun's heat onto receiver tubes filled with a heat transfer fluid (see Figure 2). The fluid is heated up to 750°F then pumped to heat exchangers that transfer the heat to boil water and run a conventional steam turbine producing electricity. Parabolic troughs have been producing 350 MW of utility-scale electricity at a site in the Mojave Desert for more than 15 years (NREL 2009).

Whereas parabolic troughs focus sunlight to receivers located on each individual unit, power towers focus all the facility's sunlight to a single receiver (see Figure 3). The power tower facility is comprised of individual heliostats (mirrors) that track with the sun. Each heliostat reflects sunlight onto the central receiver at the top of a tower. As with the parabolic trough, a heating fluid transfers heat to create steam to drive a turbine and produce electricity. A 10 MW power tower pilot project is operating in Barstow, California (DOE 2008).

A dish engine, also referred to as a dish stirling (Figure 4), is a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point. The collected heat is utilized by an engine located at the focal point. They typically use two axes tracking to maximize potential solar radiation as its position in the sky changes (NREL 2010a). There are no commercial scale dish engine facilities in operation. However, there is a 150 kW demonstration project at DOE's Sandia National Laboratories (NREL 2011).

As with traditional fossil and biofuel-fired power plants, CSP facilities boil water and drive a steam turbine. Therefore, they are equipped with either an evaporative wet or dry cooling system.

Wind Turbine Generators

WTGs convert air blowing across the earth's surface into electricity. The WTG's rotor is comprised of the rotor hub and typically three blades (see Figure 5). Behind the rotor is attached a box called the nacelle, which encloses the turbine

FIGURE 1 Solar PV on roof [*courtesy:* Harris Miller Miller & Hanson Inc. (*courtesy:* HMMH)].

and other equipment necessary for generating electricity. The nacelle sits on top of a tower. The WTG is secured to the ground using concrete and/or bolt anchors depending on the composition of the substrate. WTGs may be sited as single units providing local power or in expansive wind farms comprised of hundreds of units that contribute electricity to the electrical grid. Utility-scale wind turbines constructed on land can be as high as 500 ft above ground level to the blade tip height. Large wind farms are connected to the grid through traditional electric transmission infrastructure comprised of transmission towers and high-voltage lines (NREL 2010b). Utility-scale wind turbines are operating in 37 states, with Texas, Iowa, and California the top three states in generating capacity (AWEA 2011).

Traditional Power Plants

Traditional power plants utilize conventional fossil fuels and biofuels to make steam and drive a turbine to produce elec-

FIGURE 2 Parabolic solar collector (*courtesy:* HMMH).

FIGURE 3 Power Tower at Sandia National Laboratories (*courtesy:* Dr. Clifford Ho, U.S. DOE, Sandia National Laboratories).

FIGURE 4 Dish stirling at Sandia National Laboratories (*courtesy:* Dr. Clifford Ho, U.S. DOE, Sandia National Laboratories).

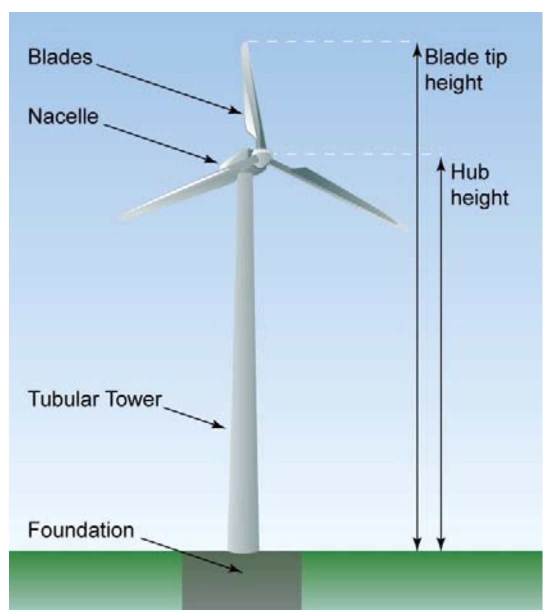

FIGURE 5 Wind turbine schematic (*courtesy:* HMMH).

FIGURE 6 Power plant (*courtesy:* U.S. EPA website).

tricity (see Figure 6). Because the fuel they run on is always available (unlike renewable sources), these plants provide base load electricity to the grid. Older plants operate with coal and oil, whereas newer plants typically utilize natural gas or biofuels, which comply with modern environmental regulations.

Some smaller capacity plants, known as peakers, are being developed that can start up quickly during periods of peak energy consumption. Peakers typically fire up during the summer months when air conditioners are operating or in the winter during periods of extreme cold when heaters are operating. Peaker plants are less efficient than base load plants and typically have higher exhaust velocities and temperatures because they lack a heat recovery steam generator. This type of generator extracts heat in the flue gas producing cooler exhaust temperatures and lower exit velocities. Because peaker plants can be designed with shorter stacks, they may not trigger an airspace review. In addition, the shorter stack produces a greater dispersion of the plume lower to the ground. When located near an airport, these high temperatures and exhaust velocities can create turbulence for aircraft passing through the plume.

Traditional power plants require a cooling system to cool the exhaust steam for reuse. Cooling towers release heat produced in the steam generation process and transfer it back to the environment, either to the water or air. There are two types of cooling towers: evaporative wet cooling and dry cooling. The mechanics of the systems vary; however, the end process is the same, to remove heat and cool water for reuse. They can use either evaporation to remove the excess heat and cool the liquid (wet cooled) or rely on air to cool the liquid to the ambient temperature (i.e., air cooled). Evaporative wet cooling systems release moisture into the air to transfer heat. Air-cooled condensers transfer heat to the ambient air not unlike an automobile radiator. The air-cooled condenser maximizes surface area for transfer of the heated steam exhaust to the surrounding air and fans blow the heated air skyward. Because water is denser than air its heat carrying capacity is greater,

FIGURE 7 Transmission lines at sunset (*courtesy:* HMMH).

making wet cooling a more efficient heat transfer mechanism. However, owing to concerns about water scarcity, new power plants are often required to assess the feasibility of dry cooling.

Electrical Transmission Infrastructure

Transmission lines consist of towers and high-voltage lines necessary for carrying power produced at energy-generation facilities across distances to areas where the electricity is consumed (see Figure 7). Typically, new transmission lines are built to deliver electricity to locations where the lines can be integrated into the existing regional and local electrical network. The height of the towers can vary; however, taller towers generally mean that they are fewer in number, which tends to be more economical. Tower height and distance follow industry-published design guidelines (ASCE 1997; IEC 2003). Conventional towers are approximately 150 ft high. Because many new energy-generation technologies are located in remote areas, transmission lines are an important component of the energy project.

ASSESSING IMPACTS

This section describes information available for assessing impact. First, the definition of navigable airspace is provided to establish the geographic area where impacts can be produced. Second, the forum for reviewing potential impacts (i.e., the regulatory process) is summarized to provide an understanding of what processes are requiring the impact studies. Third, the community that is impacted by proposed energy projects is described. And fourth, the types of information that have been generated directly and indirectly as the result of regulatory reviews are summarized providing a snapshot of the current knowledge base.

Defining Airspace

One of the FAA prime objectives authorized by statute is to ensure the safety of air navigation and the efficient utilization of navigable airspace by aircraft (FAA 2008a). Under Title

49 of the United States Code, Section 40103(a)(1), "the United States Government has exclusive sovereignty over airspace of the United States." The National Airspace System is a limited resource. New structures and activities that infringe on airspace are continuously proposed. It is the FAA's responsibility to evaluate the significance of each proposal. When conflicts arise concerning a structure being studied, the FAA may advocate the need for conserving the airspace for aircraft; preserving the integrity of the National Airspace System; and protecting air navigation facilities from encroachments such as physical penetrations, electromagnetic interference, and visual impairments that would preclude normal operation. ACRP recently funded a principal reference for understanding airspace review (LeighFisher 2010).

14 CFR Part 77 provides the following regulatory guidance for FAA's authority relative to airspace protection:

(1) establishes standards for determining obstructions to navigable airspace
(2) sets forth the requirements for notice of certain proposed construction or alteration
(3) provides for aeronautical studies of obstructions to air navigation to determine their effect on the safe and efficient use of airspace
(4) provides for public hearings on the hazardous effect of proposed construction or alteration on air navigation.

Furthermore, "[t]he standards established in determining obstructions to air navigation are used by the Administrator to impose requirements for public notice of the construction or alteration of any structure where notice will promote air safety. Notices are used to provide the basis for determinations of possible hazardous effect of the proposed construction or alteration on air navigation."

Airspace, as defined by federal regulation, begins at a height of 200 ft above ground level and extends upward. In closer proximity to airports and military installations, where aircraft approach and descend, the height of airspace is less than 200 ft. The FAA regulations refer to the invisible boundaries that demarcate airspace as imaginary surfaces. These imaginary surfaces extend out from the runway in a manner that reflects where aircraft are likely to fly while also accommodating unforeseen aircraft maneuvers. The height above the ground of the imaginary surface is lowest near the runway and increases at distance from the runway. State and local authorities have attempted to regulate areas below 200 ft as airspace as a result of localized concerns about the impact of shorter structures on aviation.

The FAA is responsible for conducting obstruction evaluations to determine potential impacts on airspace. Specifically, the evaluation may consider the effects on public use and military airports and aeronautical facilities; visual flight rule and instrument flight rule aeronautical departures, arrivals, and en route operations, procedures, and minimum flight altitudes; physical, electromagnetic, and line-of-sight interference on navigation, communications, radar, and control system facilities; and airport traffic and service capacity (FAA 2008a).

The FAA has established clear thresholds for defining airspace and created a notification process for requiring project proponents to notify the FAA of projects that may impact airspace. The definition of airspace is described in the section Physical Penetration of Airspace in this chapter. The process for evaluating potential hazards is described in Order JO 7400.2G, *Procedures for Handling Airspace Matters* (FAA 2008a). For off-airport projects, proponents file a Form 7460 with the FAA Office of Obstruction Evaluation/Airport Airspace Analysis (OE/AAA). The OE/AAA is a particular office under FAA's Air Traffic Organization whose responsibility it is to coordinate the FAA's review of potential hazards to air navigation.

Regulatory Review Processes

The energy technologies discussed in this report typically trigger federal, state, regional, and local permitting processes before being constructed. Under conventional project permitting, applications are filed, hearings are convened, presentations are made, public input provided, and permit decisions rendered based on existing laws and regulations. Through this process, impact analyses are generated. In some cases, independent government studies may be initiated where the permitting process has not adequately resolved the issue. The primary regulatory processes associated with energy technologies and impacts on aviation are described here.

OE/AAA

The FAA's OE/AAA Division undertakes aeronautical studies to assess the potential impacts of a project on air navigation. It distributes the notice to representatives of the various FAA lines of business, including airports, technical operations, services, frequency management, flight standards, flight procedures office, and military representatives. Each division has the responsibility of providing comments on the potential impacts of a proposal on its area of authority and expertise. As an example, air traffic personnel is responsible for identifying whether the structure impinges on airspace; assessing effect on existing and proposed aeronautic operations, traffic control procedures, and traffic patterns; providing comment on mitigation opportunities including marking and lighting; identifying when negotiations with sponsors are necessary; determining when circulation is necessary and coordinating that process; collecting all comments; and issuing the determination. Technical operations staff identifies electromagnetic and/or physical effects including the effect of sunlight and reflections on air navigation and communication facilities.

Upon completing the aeronautical study and obtaining input from the various divisions and organizations involved in the review, the OE/AAA issues a hazard determination on the proposed structure or activity. If the project will not impact aviation, the OE/AAA will issue a Determination of No Hazard. If an impact is identified, the OE/AAA will issue a Determination of Presumed Hazard, the reason for the hazard, and changes that could be made to avoid the hazard. Unless the applicant agrees to the changes in writing, the Notice of Presumed Hazard will be reissued as a Determination of Hazard as the FAA's final determination on the matter. The determination, however, is not a permit enforceable by law but is instead part of a notification process to identify potential hazards to aviation, require marking and lighting of potential hazards to minimize potential risk to aviation, and update aeronautical charts and flight procedures for pilots to avoid the hazard. In reality, however, a hazard determination is sufficient enough to deter project financing and underwriting owing to the potential liability associated with the determination. As an example, most utility-scale wind turbines are greater than 200 ft in height and are subject to airspace review by the OE/AAA. The receipt of a hazard determination from the FAA for a proposed wind turbine is considered by project developers to be a fatal flaw, thereby negating the project.

National Environmental Policy Act

Projects conducted by federal agencies, hosted on federal lands, financed with federal funds, or requiring a federal permit are subject to review under the National Environmental Policy Act (NEPA). Under NEPA, the lead federal agency responsible for the federal action facilitates a broad public review of the project that includes a variety of environmental analyses such as potential impacts on transportation systems. Applicants file reports and analyses that form the basis of a decision (known as an Environmental Impact Statement or EIS) by the lead agency regarding the project's compliance with NEPA. Because the NEPA review is broad, it typically catches all the possible environmental issues that a project might affect. EISs are rich with analyses of potential impacts of projects on airports and aviation.

As noted earlier, the FAA Hazard Determination is not a permit and therefore is not considered a federal action for the purposes of NEPA. It alone cannot trigger a NEPA review. As a result, projects with potential aviation impacts will not be subject to a NEPA review unless there is another issue that triggers NEPA.

Furthermore, project developers may not consider preparing a Form 7460 for an airspace review until the latter stages of the regulatory process unless their project is located close to an airport and aviation issues are raised in the broader permitting context. This has been a common occurrence that has put the FAA in the challenging position of issuing a hazard determination for a project that has otherwise substantially progressed and achieved regulatory approvals (Globa, personal communication, 2010). This is much in contrast to projects subject to NEPA review that provide a forum for early comment from all agencies including the FAA.

Recognizing the importance of the NEPA review for aviation impact issues, the Department of Defense (DoD) and Bureau of Land Management (BLM) have executed a memorandum of agreement (MOA) to evaluate and resolve conflicts associated with projects proposed on BLM land. This is of consequence because the BLM has been issuing leases for energy projects on federal lands. Although the BLM is already obligated under NEPA to solicit input from other federal agencies, the MOA provides the aviation community and the military with an early notification process. Therefore, when the BLM initiates a process to lease land to an energy development company, the DoD is one of the parties notified about the project and can provide comment on facilities and activities and potential adverse impacts. Although the FAA is not party to the MOA, the BLM is obligated to notify the FAA under NEPA.

In April and May of 2010 a military planning group comprised of representatives from the Army, Navy, and Air Force, commented to the BLM that six wind farm projects in the Mojave Desert near Barstow, California, could negatively impact military activities in the area. The DoD reported that the projects will constrain flight operations, interfere with radar, and increase the chance of collisions. Those comments prompted one of the developers who had proposed three of the six projects to withdraw its applications for approval.

State and Regional Regulatory Review

State and regional regulatory authorities may facilitate broad environmental reviews of projects similar to those completed under NEPA. These reviews authorized under state legislation (sometimes referred to as "little NEPAs") are coordinated by state environmental agencies and/or state energy commissions. Some state and regional regulatory reviews require that FAA notification be secured as part of a land use permit. This was the case with the Shepherd Flats Wind Farm in the Columbia River Region of Washington State.

Some friction between the different levels of government that are considering the potential impacts of energy projects on aviation has been reported. Local authorities see local issues and are concerned that state and federal authorities do not recognize them. Meanwhile, decisions by state energy authorities may override local laws, regulations, ordinances, and standards owing to the overall public good in developing energy projects (CEC 2010a). Projects proposed on federal land may be exempt from local and county land use regulations further leaving the local voice unheard (Riverside County 2010). Finally, the FAA has made it clear that airspace cannot be disparately defined and regulated across the country, making Part 77 the basis for all airspace regulation decisions (Whitlow 2009).

The Impacted Community

Regulations have been developed to protect a resource (defined in chapter two as airspace) and to protect a user group of the airspace (i.e., pilots and the customers they serve). It is logical to ask about the community that is impacted by energy projects and what types of users exist.

The affected community starts with the commercial aviation industry that operates from large and medium-sized airports across the country. Airlines provide a passenger transportation service for business and leisure that enhances businesses from each departure and arrival destination. Aircraft also transport commodities, particularly perishables and express packages that require short delivery times.

Smaller general aviation (GA) airports across the country provide essential transportation between remote areas that are otherwise difficult to access by other means. GA airports are also home base for a large community of aviation enthusiasts who fly their own planes for recreational purposes. In addition, many GA airports operate flight training schools for teaching new pilots, while also supporting local airplane services from essential business activities such as crop dusting to entertainment activities such as sky diving and gliding.

Finally, heliports are used by helicopters serving a variety of functions from medical flights to remote land surveying to metropolitan traffic reporting. Each project that is proposed that impinges on and degrades airspace has the potential to affect one or more of these user groups.

The Current Knowledge Base

Because many of the energy technologies assessed in this report are being deployed primarily by private developers at a larger scale in new geographic areas and at a more rapid pace, much of the existing information on potential impacts is found in federal and state environmental permit applications submitted as part of regulatory approvals. Applicants file EISs for projects subject to NEPA, which describe a variety of potential project impacts. As these reviews are distributed for broad public comment, interest groups and organizations across the social spectrum submit written comments about how the proposed project may cause negative impacts, prompting the administering agency (under NEPA it is the lead federal agency) to require the applicant to study the impact and report the findings.

In some cases, federal authorities have recognized a potentially systemic problem associated with a certain technology and has commissioned an independent analysis to define the potential impacts and assess the level of impact and potential ameliorating circumstances. An example of this described later was when the U.S. Air Force expressed concern about the impacts of large wind farms on the ability of the Air Force to train pilots, thereby affecting “military readiness.”

In other cases, the DOE has collaborated with other federal agencies to conduct studies to assess potential impacts of new energy technology. One example of this collaboration is the research being undertaken by the Sandia National Laboratories to assess the effects of glare from CSP projects.

To supplement the various permitting documents and government reports, experts in the field of assessing emerging energy technologies and their potential impacts on airports and aviation were interviewed for this report, and their contributions are discussed throughout.

As a result of a large volume of new energy proposals, a significant amount of analysis has been conducted on the types of impacts identified in this study. Some of these are summarized in the following sections. To assess impacts, these analyses could be compared with regulatory performance standards. However, in most cases, a clear threshold of impact has not been promulgated.

TYPES OF IMPACTS

The types of impacts identified during the preparation of this report included: (1) physical penetration of airspace, (2) communications systems interference, (3) visual impacts from glare, (4) wind turbine turbulence, (5) thermal plume turbulence, and (6) visual impacts of vapor plumes.

Physical Penetration of Airspace

Some objects exceed heights that penetrate aviation imaginary surfaces and thereby impact airspace. Any object that is 200 ft above ground level is determined to penetrate into airspace. Objects that are less than 200 ft in height but within 20,000 ft of an airport runway longer than 3,200 ft (or 10,000 ft for a runway less than 3,200 ft) may still penetrate airspace depending on relative distance to the airport. In addition, some structures less than 200 ft above ground level, such as meteorological test towers, have been identified by local authorities as being a potential hazard.

Airports are required to maintain vegetation, site new airport development, and manage any temporary construction activity to ensure that airspace around runways is clear of objects. Any proposed structure off-airport that is 200 ft in height and/or within 20,000 ft from an airport runway has the potential to penetrate airspace. Applicants conduct a Section 14 CFR 77 (Objects Affecting Navigable Airspace) analysis to determine which structures are subject to airspace review. Such projects are required to notify the FAA by filing Form 7460, Notice of Proposed Construction or Alteration. Typical structures that impede 200 ft include large skyscrapers, communication towers, and wind turbines (see Figure 8). Solar power towers and power plant exhaust stacks may also exceed 200 ft in height or may penetrate airspace with smaller structures if located closer to an airport.

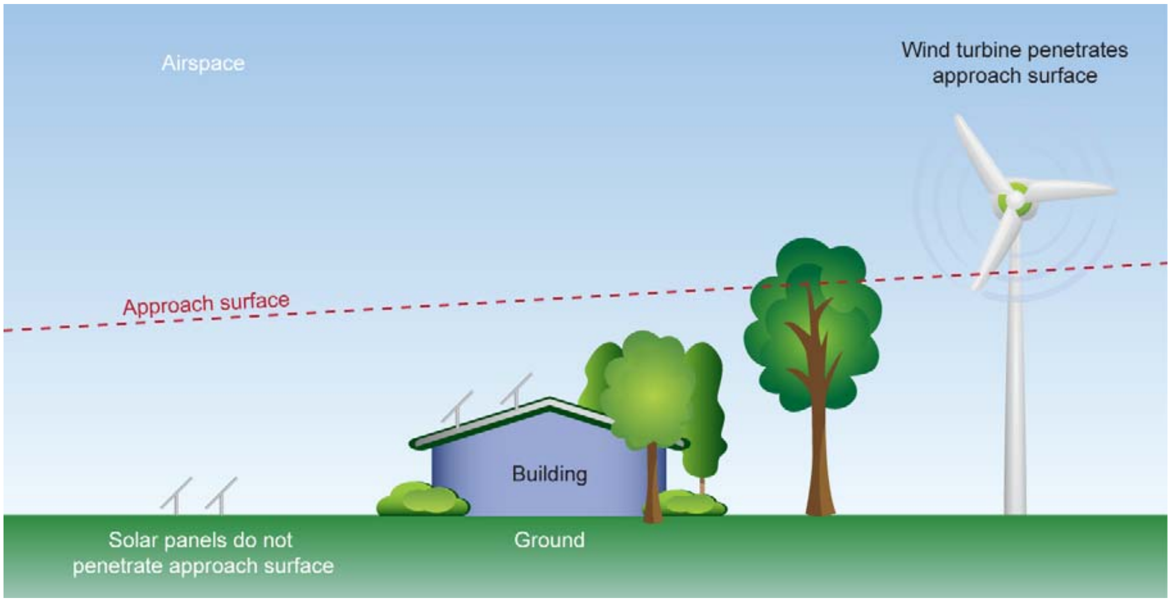

FIGURE 8 Physical penetration of airspace schematic (*courtesy:* HMMH).

Communication Systems Interference

Communication systems interference includes negative impacts on radar, navigational aids (NAVAIDS), and infrared instruments. Although Global Positioning Systems that communicate with satellites and limit the need for traditional surveillance radar are being employed more widely and are expected to be the fundamental component of future navigational systems, the integrity of traditional radar facilities remains central to the current operational environment.

Radar interference occurs when objects are placed too close to a radar sail (or antenna) and reflect or block the transmission of signals between the radar antenna and the receiver (either a plane or a remote location). Although it is possible for interference to be caused by other communication signals, more commonly it is caused by a physical structure placed between the transmitter and receiver. NAVAIDS can be impacted similarly to radar, but they include passive systems with no transmitting signals. Impacts on infrared communications can occur because the solar collectors and receivers can retain and emit heat, and the heat they release can be picked up by infrared communications in aircraft causing an unexpected signal.

Communications interference can result from any of the energy technologies discussed in this report. Potential impacts increase with larger structure size (and cross section) and shorter distance to radar facilities. Large wind farms have generated the most problems and as a result have been studied the most. Transmission lines can also cause interference resulting from electrical signals irradiating from the lines. Impacts from other technologies are primarily from the structure's mass and physical location blocking radar signals. Studies conducted during project siting may identify the location of radar transmission and receiving facilities and other NAVAIDS and determine locations that would not be suitable for structures based on their potential to either block, reflect, or disrupt radar signals.

Off-airport solar projects are unlikely to cause radar interference compared with those proposed on-airport unless located close to airport property and within the vicinity of radar equipment and transmission pathways. However, when located near a radar installation, CSP projects can reflect radar transmissions because of their metallic components.

Visual Impacts of Glare

Glare occurs when sunlight causes a temporary visual impairment to an observer. Glare can be produced when looking directly at the sun, such as when driving in its direction after sunrise or sunset, or at any time of day when sunlight is returned to the observer from a reflective surface. Surfaces that produce glare include mirrors, metal roofs, still waters, and glass. Smooth polished surfaces, such as glass, can cause a specular reflection that is more direct and intense (see Figure 9). Reflections from rough surfaces become diffuse and result in less of an impact. Solar PV, although designed to be absorptive of sunlight, can produce glare in certain instances because of its glass surface. CSP projects that use mirrors have a greater propensity to produce glare. The concern here is that, depending on the location of the solar project, glare could cause a momentary visual impairment to air traffic controllers or pilots.

Wind Turbine Turbulence

Turbulence occurs when air flow becomes chaotic and irregular. Although turbulence is typically caused by changing

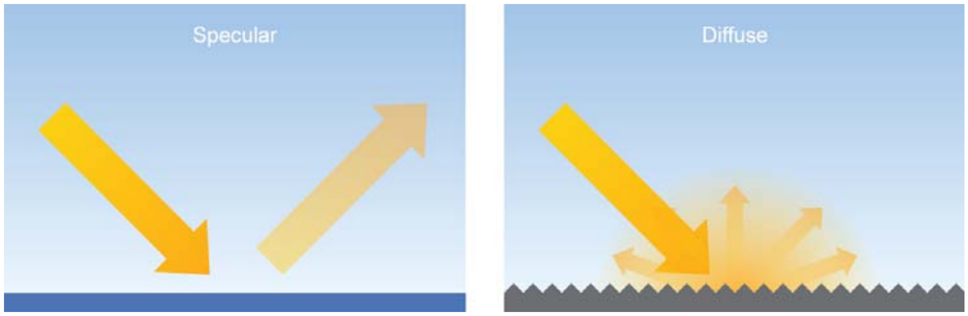

FIGURE 9 Specular and diffuse reflection schematic (*courtesy:* HMMH).

weather patterns or by dramatic topographic variations, turbulence can also be caused by man-made activities. The potential effects of turbulence are of greatest concern when there is a sudden and unforeseen turbulence on a small aircraft caused by some great force.

Turbulence associated with wind turbines is less an issue of predictability, as the turbulence potential can be visualized by the presence of the wind turbines and whether or not they are spinning. The issue is more about understanding the distance that rotor-induced turbulence may occur from a wind turbine and what the degree of turbulence might be compared with other sources of existing natural and man-made turbulence. What is a safe distance for aircraft to travel downwind of a wind turbine?

Thermal Plume Turbulence

Thermal plume turbulence is caused by the release of hot air from a power plant equipped with a dry cooling system. The thermal plume rises causing upward moving turbulence. An aircraft might pass well above the structure of an air-cooled condenser and become subject to the invisible turbulence without warning.

Visual Impacts of a Vapor Plume

Vapor plumes produce a vapor cloud that can result in localized visual impairment. Plumes are produced by large-scale emissions of heated water vapor typically from an evaporative wet cooling system associated with a power plant. Wet cooling towers reject heat into the atmosphere by releasing water vapor. The air leaving the tower is saturated with moisture and warmer than ambient air producing a wet exhaust plume. The saturated exhaust plume may or may not be visible. During cool mornings in the fall or spring when the ambient air is moist cooling towers can add more water to the air, thereby saturating the air and adding water droplets resulting in fog. If the ambient temperatures are below freezing, the resulting water droplets could cause icing on nearby roadways and bridges surfaces.

CHAPTER THREE

SOLAR ENERGY AND POTENTIAL IMPACTS

This section describes the existing body of information on the potential impacts of solar energy technologies on airports and aviation. The technologies described are solar PV and CSP. Potential impacts associated with solar energy facilities include physical penetration of airspace, communication systems interference, visual impacts from glare, turbulence from thermal plumes, and visual impacts from vapor plumes. Note that potential impacts vary significantly between PV and CSP.

PHYSICAL PENETRATION OF AIRSPACE

Solar energy facilities, including PV and CSP, can penetrate airspace. However, because PV utilizes low profile equipment, it is less likely to affect airspace unless it is located very close to an airport runway. CSP, particularly those designed with power towers, can reach into airspace.

Steam boilers are located high up on power towers. Increased height allows for more mirrors to focus their reflected sun energy on the boiler. For the proposed Ivanpah Solar Electric Generating System in southeastern California, the design includes three power towers, each rising to 459 ft above ground level (Bright Source Energy 2010).

In addition, concentrating solar power projects that heat steam to drive a turbine require cooling systems to cool water for reuse. Those that employ air-cooled condensers may also penetrate airspace. Four air-cooled condensers proposed as part of the Blythe Solar Power Project will each rise to 120 ft above ground level.

COMMUNICATIONS SYSTEMS INTERFERENCE

Communications systems interference can be produced by either an electrical interference or as a physical obstacle between the communicator and receiver. However, electrical interference has not been a concern during airspace reviews (J. Decastro, FAA Western-Pacific Region, personal communication, 2010). In its approval of Palmdale, the California Energy Commission (CEC) did not identify electromagnetic interference concerns for the operating frequencies proposed (CEC 2010b: Solar Millennium 2010). CSPs at both Palmdale and Blythe have submitted information to the CEC on electromagnetic frequencies that will be emitted by electrical equipment associated with their projects. Both projects are located close to aviation facilities (Blythe is within one mile). The base frequency from Blythe is 60 hertz (Hz). Frequencies employed at the Air Force Base in Palmdale are 108–135 MHz for very high frequency (VHF) and 225–400 MHz for ultra high frequency (UHF) (CEC 2010b,c).

Potential physical obstructions are correlated with the size of the structure and its proximity to a radar facility. For on-airport solar PV projects, systems have been required to be set back from major on-airport radar equipment as a protected buffer. The solar fields at Oakland (OAK) and Bakersfield (BFL) (see Figure 10) were required to meet setbacks from transmitters of 500 ft (A. Kekakeuwela, Oakland Port Authority, personal communication, 2010) and 250 ft (J. Gotcher, Airport Manager, Meadows Field, personal communication, 2010), respectively.

Some reflections can be mitigated with RAM (radar absorbing material) coatings but these can be cost-prohibitive. One project located just outside the fence at the Phoenix Airport (PHX) was reviewed by the FAA and conditions were placed on the airspace review approval to address potential concerns with radar interference (J. Decastro, FAA Western-Pacific Region, personal communication, 2010). In many cases, communication and coordination with the proper FAA officials can mitigate the issues and concerns regarding solar power installations in and around airports. CSP projects with large structures can also obstruct or reflect radar signals.

GLARE VISUAL IMPACT

The potential impacts of reflectivity are glint and glare (referred to henceforth just as glare) (glint is a momentary flash of bright light, whereas glare is a continuous source of bright light), which can cause a brief visual impairment (also known as afterimage or temporary flash blindness) (FAA 2008a) (FAA Order 7400.2f defines flash blindness as “Generally, a temporary visual interference effect that persists after the source of illumination has ceased”). The potential impact of glare can be measured using the magnitude of reflection (referred to as retinal irradiance) and the subtended angle of the reflection (derived from the size of the reflected area and its distance from the sensitive receptor). [See Ho et al. (2009) for more information on how to calculate reflectivity from solar power projects.]

The reflectivity of a surface is influenced by two primary factors: the color of the surface and its physical composition.

FIGURE 10 Solar PV at Meadows Field, Bakersfield, California (*courtesy:* HMMH).

* Sunlight is measured as watts per squared meter (W/m2). The amount of incoming sunlight is generally considered to be 1,000 W/m2. The percentage of sunlight reflected from each surface can be calculated from this baseline.

FIGURE 11 Reflectivity scale graphic (*courtesy:* HMMH).

Color is important because some colors absorb light and its energy, whereas others reflect it. Light colors are most reflective (white being the most), whereas dark colors are least reflective. Figure 11 shows the percentage of sunlight that is reflected from a variety of common surfaces. The values provided are primarily influenced by color and include two different types of solar technologies: PV and CSP.

The color of the surface and the percentage of sunlight it reflects is only one-half of the equation; the other factor is the physical characteristics of the material's surface. Flat, smooth surfaces will reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces will reflect light in a diffuse or scattered manner and therefore will not be received by the viewer as brightly.

Reflections from natural surfaces have always occurred and people's perception of exposure impacts must accommodate for the glare. New construction may need to consider the impacts of reflectivity from its surfaces. The most common type of project where the impacts of reflectivity have been evaluated is building facades constructed of glass, metal, or other highly reflective materials. Some building rooftops are being designed with white roofs with a high albedo value to purposefully reflect light and heat, and thereby minimize local trapping of heat referred to as "heat island effect."

PV solar panels use silicon to convert sunlight to electricity and silicon is naturally reflective. As a result, all solar panels are designed with a layer of anti-reflective material that allows the sunlight to pass through to the silicon but minimizes reflection. This design results in the dark appearance of the solar panel. Recent generations of panels have included an anti-reflective material on the outer surface of the glass to further limit sunlight reflection. The area of the aluminum frame is very thin and therefore reflection from the aluminum is not a concern. Another recent design feature to limit reflection is to roughen the protective glass surface (C. Ho, Sandia National Laboratories, 2011). A roughened surface will prevent specular reflection, which can produce a sharper and more concentrated ray of light, and instead produce a diffuse reflection. Current solar panels reflect as little as 2% of the incoming sunlight depending on the angle of the sun and assuming use of anti-reflective coatings (Evergreen Solar 2010). However, because the surface of the solar panels is very flat and uniform, it is capable of reflecting a focused ray of sunlight (see Figure 12).

CSP systems are designed to maximize reflection and focus the reflected sunlight and associated heat on a design point (heat collecting element or HCE) to produce steam that generates electricity. Approximately 90% of incoming sunlight is reflected from a CSP mirror. However, because the reflected sunlight is controlled and focused on the HCE, it generally does not reflect back to other sensitive receptors. A small fraction of the sunlight may not be absorbed by the HCE so the potential for that reflection can be assessed. Another source of reflection is the light that contacts the back of the HCE and never reaches the mirror. Parts of the metal frame can also

FIGURE 12 Example of glare at Sandia National Laboratories (*courtesy:* Dr. Clifford Ho, U.S. DOE, Sandia National Laboratories).

reflect sunlight. In central receiver (or power tower) applications, the receiver can receive concentrated sunlight that is up to a thousand times the sun's normal irradiance. Therefore, reflections from a central receiver, although approximately 90% absorptive, can still reflect a great deal of sunlight. Therefore, different analyses are necessary to understand the potential for glare impacts for each of these systems. Models have been developed and analyses have been performed to determine when glint or glare from different sources can cause retinal burn or temporary after-image as a function of retinal irradiance and subtended source angle (Ho et al. 2009).

Anecdotal observance of glare emitted from operating parabolic-style CSP projects has been described. These flights occurred over the Victorville 2 Hybrid Solar Project. Observations from staff from the CEC and the Southern California Logistics Airport stated that no intense "specular" glare was observed (AECOM 2010). Subsequently, Solar Millennium commissioned a systematic aircraft fly-by of the Kramer Junction solar facility in the Mojave Desert, which uses parabolic trough solar technology similar to the proposed Blythe Project to provide an assessment of glint and glare impacts on pilots. The pilot and passenger concluded in separate statements that the Kramer Junction Project does not reflect glint or glare that could significantly impact pilots. Based on their observations and the orientation of the Blythe Airport (BLH) runways to the McCoy Mountains, they determined that the Blythe Project would operate in a similar fashion without significant impacts (CEC 2010b). Analysis by the CEC concluded that a potential for glint and glare could occur close to sunrise and sunset. The CEC specifically indicated four distinct runway procedures that might be affected by glint or glare. Its decision imposed specific mitigation that would help minimize but not eliminate the potential for glint and glare. Because the Riverside County Land Use Compatibility Plan specifically prohibits development that can result in glint and glare, the CEC's decision was a formal override of the county regulation.

FAA tower personnel and airport managers from several airports were interviewed for anecdotal information about reflectivity from operating solar PV farms at airports. Two notable sites are Meadows Field (BFL) in Bakersfield, California, which hosts an 800 kW solar facility, located approximately 250 ft from the runway taxiway, and Fresno Yosemite International Airport (FAT) in Fresno, California, where there is a 2 MW facility in the Runway Protection Zone near the end of one of the runways. The Meadows Field solar project has been in operation since January 2009, whereas Fresno's project has been operational since June 2008. In both cases, the air traffic controllers stated that glare has not affected their operations and they had not received complaints from pilots about glare being a problem (R. T. Martin, FAA Air Traffic Control Tower Manager, personal communication, 2010 and K. Powell, FAA Air Traffic Control Tower Manager, personal communication, 2010).

THERMAL PLUME TURBULENCE

A thermal plume is produced by power plants that employ a dry cooling system often referred to as an air-cooled condenser. For the purposes of this report this could include CSP and peaking power plants. Dry cooling employs fans below the air-cooled condensers that blow hot air up to enhance cooling. The rising hot air can produce air turbulence. The worst case scenario for thermal plume impacts are low wind and large temperature differential, which typically occurs at sunrise for projects proposed in the Southern California desert area between May and October. The most problematic scenario is when the plume contacts only one wing (D. Moss, AeroPacific Consulting, personal communication, 2010).

The CEC uses a 4.3 m/s vertical velocity as a significance criterion for the potential for a thermal plume to produce turbulence that could impact passing aircraft (CEC 2010a). The predicted vertical plume velocity for the air-cooled condensers proposed for the Blythe Solar Power Project is 4.5 m/s at the upper face of the condenser. Flow above the 4.3 m/s threshold used by the CEC was constrained to a few tens of meters above the condenser surface. The results predicted vertical flow velocity to be less than 2 m/s at 250 m above the air-cooled condenser. Velocity flows potentially encountered by aircraft would be similar to those that could be felt under natural occurrences (AECOM 2010). The analysis of potential impact concluded that because of low vertical velocity and minimal air traffic over the condensers based on flight pattern [none of the traffic pattern envelopes (which constitutes 80% of all traffic) intersect with the condensers] impacts will be minimal. The analysis indicated that some air traffic could pass over the condensers but, if following flight procedures, are unlikely to be close enough to the condensers to be affected (Solar Millennium 2010).

The CEC findings for the Blythe Solar Power Project determined that the project has the potential to adversely impact low-flying aircraft in low wind conditions. Further it concludes that aircraft on arrival at Blythe will be flying at altitudes low enough to be impacted particularly when making a particular maneuver to a specific runway. To minimize the risk of this impact, the CEC required a notification to pilots as a condition of its decision.

VAPOR PLUME VISUAL IMPACT

Vapor plume is typically produced by power plants, including CSP and peaking power plants, which utilize an evaporative wet cooling system. Whereas dry cooling transfers heat to the air which rises above the system, evaporative wet cooling produces steam as heat dissipates through evaporation. The mechanics of the two heat transfer systems is similar but the impacts are very different primarily because a vapor plume can be seen whereas a thermal plume cannot. Visible impact from steam is not expected to occur from air-cooled condensers because the heat is cooled by air convection and not water (Solar Millennium 2010).

Wet cooling has been the preferred cooling system owing to enhanced cooling efficiency (compared with dry cooling) and decreased cost. In the past, wet cooling was accomplished with once through cooling, but the impacts of heated discharge to water bodies encouraged the development of evaporative wet cooling. The majority of new fossil fuel plants employ evaporative wet cooling (NREL 2010a). It has been employed at hundreds of power plants across the country, particularly those built in more recent years. For CSP projects that are challenged to compete with traditional sources of electricity on price, use of wet cooling has been the convention with all operating projects as of March 2010 (SEIA 2010). However, as a result of environmental concerns over the scarcity of water, particularly in desert areas where CSP projects are located, newer projects are being forced to examine dry cooling (CEC 2010b).

Steam released from power plants occurs near airports in Pennsylvania. Pilots fly through a vapor plume on approach to Runway 9 at Perkiomen Valley Airport, Pennsylvania (A. Tezla, Mead and Hunt, Inc., personal communication, 2011). The Limerick Nuclear Power Plant is also close to the Pottstown Municipal Airport (PTW). Steam rises from the cooling towers of the Three Mile Island Nuclear Plant into the approach path at Harrisburg International Airport (MDT). It is possible that aircraft are less affected by vapor plumes (than thermal plumes) because they are a recurring feature that can be seen allowing pilots to make adjustments as needed.

MITIGATION OPTIONS

The following mitigation options have been considered in minimizing the impacts of concentrated solar power on aviation:

- For parabolic trough plants, use nonreflective or diffuse materials or coatings (e.g., paint) for bellows shields located every few meters at joints between heat collecting elements.
- The units should be rotated from stow away position to ready position before sunrise to limit potential inadvertent glare.
- Parabolic designs should consider using end caps to reduce glare that "spills" from the ends of the trough.
- Curtailment in facility operations can be prescribed during periods when glare is expected to impact low-flying aircraft.
- Flight procedures can be restricted during certain periods of the day when glare may occur.
- County zoning ordinances may be put into place to limit glare-producing structures in airport influence zones (El Dorado County, California 2009; Clallam County, Washington 2010).

SOLAR ENERGY IMPACT EXAMPLES

The following section describes examples of solar energy impact.

Blythe Solar Power Plant

The Blythe Solar Power Plant is a proposed 1,000 MW CSP facility to be located in California's inland desert on land owned by the BLM. The project will utilize parabolic trough technology that reflects sun from each trough device to a receiver tube. The heat transfer fluid in the tube is raised to 750°F and then piped through heat exchanges used to create steam that drives a traditional steam turbine generator to produce electricity. The Blythe Project provides a current example of the regulatory evaluation for a CSP facility. In September 2010, the CEC issued its Decision on the Application for Certification for the Blythe Solar Power Project. In its review, the CEC assessed many of the potential impacts of CSPs identified in this report. The following is a list of conditions in the CEC's decision to mitigate impacts:

- Proponents have comments or notations inserted in the appropriate Aeronautical Charts, Airport/Facilities Directories, and Notice to Airmen publication to identify potential hazard from glare and thermal turbulence.
- Mirrors are (1) brought out of stowage before sunrise and are aligned to catch the first rays of the morning sun, and (2) returned to stow position after sunset.
- Mirror function is continuously monitored by operators and system controllers.
- The system is designed to automatically turn a malfunctioning mirror east so there is no reflection from the sun as it moves west.
- The owner develops procedures to move mirrors east to avoid glare.
- Mirrors in the southern portion of Units 3 and 4 are not to be rotated off axis during daylight hours when the azimuth angle of the sun is east or north of east.
- Specific procedures for documenting, investigating, evaluating, and resolving (if feasible) public complaints about glare are to be developed.

FIGURE 13 Solar PV at Oakland International Airport, California (*courtesy:* HMMH).

Oakland International Solar PV Project

In 2007, the Port of Oakland entered into a lease agreement with a private solar developer to construct a solar PV project on airport property. Because the project was proposed on airport property, the FAA was responsible for approving the lease and evaluating potential impacts of the project on aviation. The Port selected a lease site close to the runways because the land was otherwise not useable for most aviation activities. To prevent a physical impingement of airspace, the angle of the row of solar panels closest to the runway were pitched close to flat (see Figure 13). To avoid any potential interference with communication facilities, the solar panels were required to preserve a 500-ft setback from the aviation surveillance radar. Glare was determined not to be a hazard from this project, although similar projects at other airports have required in the field studies using solar panels at proposed project locations to assess impacts on the control tower.

Ivanpah Solar Electric Generating Facility

The Ivanpah Solar Electric Generating Facility is a 370 MW CSP facility utilizing power tower technology proposed in the Ivanpah Valley of California on land owned and managed by the BLM three miles west of the Nevada border. The project will consist of three tower facilities, each with heliostat mirrors used to focus the sun's energy to boil steam and drive a steam turbine. Power plant 1 is a 120 MW facility. Power plants 2 and 3 are each 125 MW. The power towers will be 459 ft tall. The facility will be cooled using air-cooled condensers that are approximately 115 ft tall (CEC 2010d). The CEC issued separate decisions on each of the three individual projects in September 2010. The CEC's decisions incorporated the following conditions to avoid impacts on aviation.

1. Preparation of a Heliostat Positioning Plan that would avoid potential for human health and safety hazards from solar radiation exposure.
   - The plan should identify the heliostat movements and positions (including reasonably possible malfunctions) that could result in potential exposure of observers at various locations including in aircraft, motorists, pedestrians, and hikers in the Clark Mountains to reflected solar radiation from heliostats. The plan should describe how programmed heliostat operation would avoid potential for human health and safety hazards at locations of observers as attributable to momentary solar radiation exposure greater than the maximum permissible exposure of 10 kw/m^2 (for a period of 0.25 second or less).
   - Preparation of a monitoring plan that would: (1) obtain field measurements in response to legitimate complaints; (2) verify that the Heliostat Positioning Plan would avoid the potential for human health and safety hazards including temporary or permanent blindness at locations of observers; and (3) provide requirements and procedures to document, investigate, and resolve legitimate complaints regarding glare. The monitoring plan should be coordinated with the FAA, U.S. Department of the Navy, California Department of Transportation, California Highway Patrol, and Clark County Department of Aviation in relation to the proposed Southern Nevada Supplemental Airport and be updated on an annual basis for the first 5 years, and at 2-year intervals thereafter for the life of the project.
2. Preparation of a Power Tower Luminescence Monitoring Plan to provide procedures to conduct periodic monitoring and to document, investigate, and resolve complaints regarding distraction effects to aviation, vehicular, and pedestrian traffic associated with the power towers:
   - Evaluate the effects of the intensity of the luminance of light reflected from the power tower receivers 90 days after commencement of commercial operations, and after 5 years, as well as after any significant design or operational modification, or after a significant complaint.
   - Coordinate monitoring protocol and results with agency stakeholders.
3. Lighting of the power towers as required by FAA under Part 77 Review.
4. Notification of pilots in the area about potential hazards associated with thermal turbulence. Notification should indicate that a hazard could occur up to 1,350 ft above ground level. Request that the FAA prohibit flights over the facility at or below the 1,350 ft altitude.

CHAPTER FOUR

WIND ENERGY AND POTENTIAL IMPACTS

This section describes the existing body of information on the potential impacts of wind energy on airports and aviation. Impacts of wind turbines on aviation include physical penetrations of airspace, communication system interference, and rotor blade-induced turbulence. Although wind turbines like other electricity generation emit electromagnetic fields, owing to the design and size of the generator they do not cause electromagnetic interference (CAA 2010). An additional issue noted in this section is the increased propagation of meteorological test towers (also known as met towers) erected to measure the potential wind energy generating capacity of an area.

PHYSICAL PENETRATION OF AIRSPACE

The FAA undertakes a systematic review of projects that physically penetrate airspace. Project review is coordinated by the Obstruction Evaluation Office and reviews are undertaken by different divisions within the FAA that have specialized expertise, including airports, technical operations, services, frequency management, flight standards, and flight procedures office (see Regulatory Review Processes in chapter two). The FAA also coordinates with the military and local airports, and the review is subject to a 30-day public comment period.

Utility-scale wind turbine generators rise above 200 ft (see Figure 14) and therefore are subject to FAA review under Part 77 regardless of a project's proximity to an airport. The FAA may issue a Notice of Presumed Hazard if a wind turbine is located in an approach area to a runway if the wind turbine exceeds the approach minimums. Wind turbines that are not proposed in airport approach areas are often issued a No Hazard Determination with the conditions that the wind turbine be equipped with FAA-approved marking and/or lighting (FAA 2007). The FAA does not require all wind turbine generators in a wind farm to be marked.

The volume of wind turbine applications to the FAA has increased dramatically in recent years, from 3,030 in 2004 to 25,618 in 2009 (Kaufman 2010). There have been uncommon cases where the Part 77 review overlooked information suggesting that a project will impact procedures and systems. In those cases, the FAA will attempt to modify approvals before construction begins. Where construction has already occurred, the FAA is limited to making adjustments to flight procedures (F. Beard, personal communication, *FAA Airspace Review,* 2010). An example of this latter case is the Wild Horse Wind Farm in Washington State located 13 miles away from Bowers Airport (ELN). After the wind farm was constructed, the FAA flight procedures office assessed the potential impact of the constructed wind farm on instrument approach and missed approach procedures. It determined that the wind farm presented an Adverse Obstacle and raised the height above airport minimums from 421 ft to 801 ft (Rowbothan 2010). Chain of communication breakdown can also occur. For example, in the Shepherd Flats review, the local Air Force base initially signed off on the project, when it required review from other people in the agency (Robyn 2010).

Although utility-scale wind turbines exceed 200 ft above ground triggering an airspace review, met towers often do not. Met towers have even been positioned at heights just under 200 ft, specifically to avoid triggering an airspace review and marking requirements. As a result, state agencies have expressed concern about the potentially undocumented hazard posed by met towers (Bingner 2010; S. Brummond, personal communication, 2010). However, the FAA has informed South Dakota that federal law preempts the states on any matter of regulating airspace (Whitlow 2009).

The FAA issued a notice in the January 5, 2011, *Federal Register* requesting comments on proposed revisions to AC 70/7460-1, Obstruction Marking and Lighting, that provide guidance for voluntary marking of met towers under 200 ft above ground level. The FAA is recommending that met towers include alternate orange and white painting, and also seeks comments on sleeves around the guy wires to make the facilities more visible ("Marking Meteorological Evaluation Towers" 2011). Just two weeks after the FAA's notice, a crop dusting aircraft hit a met tower in the Sacramento–San Joaquin River Delta of California and crashed killing the pilot. The met tower was 197 ft tall and therefore did not require FAA airspace review or obstruction marking ("NTSB: Pilot . . ." 2011).

COMMUNICATIONS SYSTEMS INTERFERENCE

There has been a considerable amount of study on the potential impacts of wind turbines on aviation navigation and communications systems. Initial concern came from the DoD and the potential effect of wind turbines on military training. In a

FIGURE 14 Wind turbines from Klondike Wind Farm, Oregon (*courtesy:* Stephen Barrett).

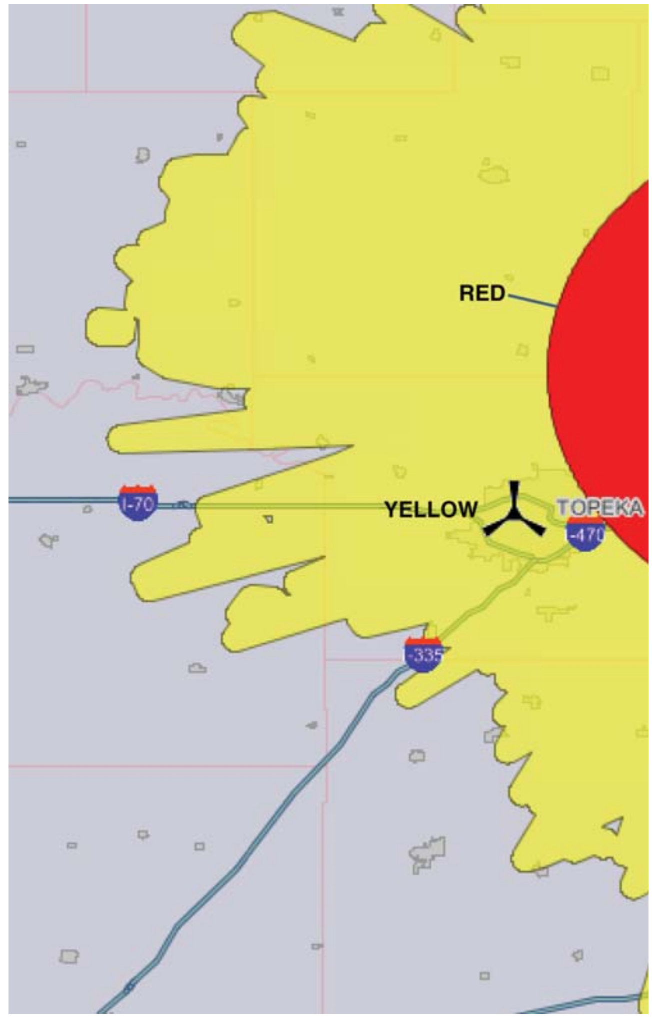

FIGURE 15 Department of Defense screening tool, Topeka, Kansas (*courtesy:* FAA website).

report issued in 2006, the DoD concluded that wind turbines have an effect on primary radar and have the potential to "negatively impact the readiness of U.S. forces to perform the air defense mission" (DoD 2006). Data collection efforts have accelerated since and the DoD and FAA have worked with the wind industry to identify areas sensitive to military training and the nation's radar system. Individual projects continue to require detailed evaluation and consideration of mitigation options. The DoD recently reported in a statement to Congress on the effects of wind turbines on military readiness that "the vast majority of all wind turbines proposed through the OE/AAA process raise no concerns for the Department, and for those that do raise concerns, we can generally find a way to mitigate the problem" (Robyn 2010).

For the purpose of this discussion, communications systems include radar and NAVAIDS. Radar can be divided between primary and secondary systems. The FAA operates two basic radar systems: airport surveillance radar (ASR) and air route surveillance radar (ARSR), both of which include primary and secondary radar capabilities (FAA 2008a). The difference between the two systems is that ASR is focused on near airport activities whereas ARSR is a long-range radar deployed at about 100 locations across the country. There are other supplemental radar systems throughout the air navigation system that provide additional information to pilots.

Two primary areas of impact are blockage and clutter. Two areas of impact analysis from DoD's perspective are (1) impacts on long-range radar used for airspace surveillance and air defense, and (2) impacts on testing and training missions that require electromagnetically pristine environments to collect baseline data and assess weapon performance (DoD 2006; Robyn 2010). The DoD has provided a red-yellow-green map on the FAA's OE/AAA website to alert developers about potential problem areas for wind turbine siting (FAA OE/AAA 2011). Red signifies impact highly likely to Air Defense and Homeland Security radars, aeronautical study required; yellow impact likely to Air Defense and Homeland Security radars, aeronautical study required; and green no anticipated impact to Air Defense and Homeland Security radars, aeronautical study required. Figure 15 shows the output for a fictitious wind turbine proposed in Topeka, Kansas.

Primary Radar Interference

Primary radar transmits a signal that is reflected back to the radar receiver when it contacts an object within the radar line-of-sight. Modern day WTGs present a significant obstacle with a high potential to reflect radar signals and produce images on aircraft and airport radar deemed to be unwanted returns (referred to as clutter) on radar screens. The taller the WTG, the greater is the risk of clutter. Multiple WTGs in wind farms increase the potential for clutter and the closer wind farms are to a radar station the greater potential of false radar returns. Impacts of WTGs on primary radar can be more difficult to predict because the wind turbine rotor position changes with wind direction and as a result its potential to reflect radar signals will also change. The following types of impacts from WTGs on primary radar have been identified (CAA 2010):

- Receiver Saturation—This condition occurs where the wind facility, because of its location, size, and extent, reflects enough energy back to the primary radar to saturate the receiver. This effect can be caused by any large structure and the likelihood of saturation from a wind farm is considered to be low.
- Constant False Alarm Rate—The Constant False Alarm Rate affects radar signal processing whereby the filtering adjustments tuned to receive signals from aircraft are masked by new signals produced by the wind turbines resulting in a masking of the aircraft targets.
- Defeating Moving Target Processing (obscuration)—Filters are used to distinguish between objects based on rate of movement with aircraft radar trained to pick up typical aircraft speeds while effectively filtering out stationary and slow moving objects. Because the speed of the wind blade tip travels at rates within the range of aircraft speed, spinning wind turbines cannot be filtered and removed producing clutter.
- False Radar Returns (clutter)—The clutter produced by the wind blade tips shows up on radar as a “twinkling” that can be distracting to controllers looking for aircraft targets and easily cause confusion. High levels of clutter can obscure tracking of aircraft targets and pathways.
- Plot Extractor/Filter Memory Overload—Some radar systems are equipped with a plot extractor that filters and processes all identified targets. Constant unwanted returns from wind facilities can overload the memory of the plot extractor clutter and cause it to shut down.
- Presenting an Obstruction (shadow)—A WTG, even when stationary, will block and reflect a radar signal such as any solid structure, limiting detection of objects on the opposite side from the radar receiver.

Secondary Radar Interference

Secondary surveillance radar (SSR) identifies and communicates with aircraft that are equipped with transponders. Although clutter is not an issue with secondary radar, two interference issues can occur.

- SSR Reflections—Reflections from secondary radar can occur if the object is in the line-of-sight between the receiver and the transponder. The likelihood of this occurring would be greater the closer the WTG is to the secondary radar receiver. The line-of-sight assessment is more difficult to determine however because aircraft response from the transponder can reflect off of a structure and back to the receiver under certain operating conditions, even if the structure is not directly in the line-of-sight.
- Presenting an Obstruction—As with primary radar, a WTG can present a physical obstruction to locating aircraft on the backside of the structure, thereby blocking the signal and preventing its identification by the secondary radar system.

NAVAIDs Interference

NAVAIDs are systems that support aircraft and pilot navigation and location identification. There are more than 2,000 ground-based NAVAIDs available to pilots across the continental United States (FAA 2008b). They include instrument landing systems and very high frequency omnidirectional radar. Although adoption of SATNAV (satellite-based navigation) has been evolving since the 1980s, some ground-based system may be retained as a back-up for satellite system failure or during periods when satellite signals are interrupted by distortions in the Earth’s atmosphere. NAVAIDs also include visual markings used by pilots operating under visual flight rules. All NAVAIDs have the potential to be impacted by inappropriately sited development including new energy technologies.

Regulatory Review Thresholds

The FAA provides guidance on criteria used for determining if a structure will have an adverse effect. The first trigger is if the structure exceeds the obstruction standards of Part 77 and/or is found to have physical, electromagnetic, or other line-of-sight impact on aviation prompting the FAA obstruction evaluation review (see Figure 16). In its review, the FAA will determine that an obstruction results in an adverse effect if it:

1. Requires a change to an existing or proposed instrument flight rules (IFRs) minimum flight altitude, a published or special flight procedure, or an IFR departure procedure for a public-use airport;
2. Requires a visual flight rule (VFR) operation to change its regular flight course or altitude;

FIGURE 16 Wind Farm at Altamont Pass, California (*courtesy:* U.S. DOE, Lawrence Berkeley National Laboratories).

3. Restricts the clear view of runways, helipads, taxiways, or traffic patterns from the airport control tower cab;
4. Derogates airport capacity and/or efficiency;
5. Affects future proposed IFR and VFR operations; or
6. Affects the usable length of an existing or future runway.

The FAA also considers whether or not the proposal will have an effect on a significant volume of aeronautical activity on an airport, which is a case-by-case determination. Significant volume effects vary for different activities (e.g., effects on departures and arrivals may be a daily impact, whereas instrument procedures and minimum altitudes may be utilized weekly). The FAA will make a substantial adverse effect determination if the structure causes electromagnetic interference on facilities and aircraft or if there is a combination of adverse effects listed previously and an impact on significant volume (FAA 2008a).

Procedures for Handling Airspace Matters provides more specific guidance on whether or not a significant adverse effect will occur. For example, it states that structures that necessitate an alteration to a Minimum En Route Altitude cause an adverse effect. However, flight procedures and air traffic personnel may consider conducting more detailed analysis to determine if the structure will result in a substantial adverse effect depending on the location of the structure relative to flight traffic and extent of use. The loss of altitude for a cardinal direction is generally considered to result in a substantial adverse effect except when the aeronautical study determines that the Minimum En Route Altitude is not normally flown by aircraft nor used for air traffic control purposes.

Another example is provided in Terminal Instrument Procedures (TERPS) guidance (TERPs 2010). A structure that penetrates the 40:1 departure slope for IFR departures is considered to be an obstruction to air navigation. If the obstacle penetrates the departure slope by more than 35 ft, it is presumed to be a hazard and a Notice of Presumed Hazard is issued. Further analysis by flight procedures and air traffic is then necessary to determine if the structure poses a substantial adverse effect.

Guidance from the Civilian Aviation Authority (CAA) of the United Kingdom states that proposed structures large enough to cause a potential impact to radar (including wind turbines) should notify the CAA for an impact assessment if the structure is within 15 miles of a radar facility. However, impacts are not likely for structures beyond 6.2 miles (or 10 km) (CAA 2010).

ROTOR BLADE TURBULENCE

Rotor-induced turbulence can occur downwind of a WTG where the wind flow is disrupted after passing through the rotor producing a chaotic and turbulent airflow (see Figure 17). Analysis of the extent of disruption downwind of the wind turbine suggests that the amount of turbulence is not significantly different from other large structures and, therefore, additional consideration beyond normal minimum separation distances and obstacle avoidance is not necessary (CAA 2010).

FIGURE 17 Gorgonio Wind Farm, California (*courtesy:* NASA Earth Observatory website).

Numerical simulations have shown that natural turbulence in the atmosphere will destabilize the wind turbine creating vortices at a distance of 2–6 rotor-radii (250–750 ft) (Troldborg et al. 2007). Aircraft flying at the same elevation as the wind turbine rotor (200–450 ft above ground) at a distance where turbulence is projected to occur is determined to be operating in an unsafe location. Turbulence downwind of a wind turbine could be a consideration for assessing the suitability of very light sport aviation such as parachuting, hang gliding, paragliding, and microlight operations (CAA 2010).

MITIGATION OPTIONS

The following mitigation options have been considered for minimizing impacts of wind farms on aviation:

- Allow appropriate siting to avoid physical penetration and communication systems impacts.
- Provide developers with the opportunity to fund gap-fill radars or contribute to the cost of replacing long-range radar, thereby providing a dual benefit of allowing renewable energy development and upgrading aging radar systems.
- Re-route air traffic around the wind energy facilities to avoid potential shadow effects and disruptions associated with wind farm radar clutter as part of operational mitigation. Negative effects of an increased noise footprint and CO_2 emissions from longer flight tracks need to be considered.
- Turn off radar that is receiving false returns for the wind farm area and use supplemental radar that is available in

the region but not affected by the clutter fill in the area of the wind farm by a technique called data fusion on in-fill radar. Also referred to as a mosaic radar, this can only be accomplished where the primary radar can selectively turn off specific areas, there is a supplemental radar coverage to provide in-fill, and the two radar systems can be pieced together and displayed.

- Improve radar coverage for areas where low-level radar coverage is not required through physical or terrain masking. This would necessitate moving the radar facility to a higher elevation or constructing a man-made structure to create an artificial radar horizon. Planning this type of mitigation would require detailed study to ensure that the proposed design would resolve the interference issues. Furthermore, this masking technique would only be appropriate if some loss of radar coverage in the area would be acceptable.
- Use radar absorbent materials on WTG towers and nacelles to reduce the radar cross section of the structure that produces clutter. However, materials for use on blades has not been effectively developed, which is particularly problematic because the blades caused the greatest amount of interference.
- Fund research (collaboratively between government and industry) on technical mitigation that collects additional information of existing wind turbine affects, designs parameters for gap-filler radar, characterizes wavelengths used in current radar systems to reduce signatures, and advances software processing.
- Develop new and modified radar facilities. For example, multi-lateration involves establishing a secondary radar system with a number of strategically located receiver stations in the area to provide networked radar coverage. These receiving stations would identify aircraft equipped with transponders and calculate their location through triangulation based on the data collected from multiple locations. This type of system is a more basic and inexpensive form of a SSR system that might be employed today.
- Create non-auto-initiation zones (NAIZs) with some advanced primary radar plots that filter out tracks created by the wind turbines while not filtering out tracks characteristic of aircraft. The problem with a NAIZ is that although the wind turbine tracks are not displayed, the false returns still exist and, depending on frequencies, could affect the display of nearby aircraft tracks producing incorrect information. Furthermore, aircraft gaining elevation from low altitudes and emerging into and above an established NAIZ will not be picked up by radar until above the NAIZ, which is the primary reason why NAIZs are generally discouraged.
- Use advanced tracking algorithms to take advantage of high-speed computer processing capabilities to conduct nontraditional aircraft tracking and data filtering. Although promising, the accuracy of the analytical methods has yet to be fully tested and there may still be a risk of error.
- Create transponder mandatory zones (TMZs) that would allow SSR to provide full augmentation for primary radar. However, TMZs are uncommon at this time.
- Consider a model program where airspace over specified wind farms is restricted to transponder carrying aircraft.

WIND TURBINE IMPACT EXAMPLES

Several examples are provided here to illustrate wind turbine impacts and how they were addressed.

Travis Air Force Base—Fairfield, California

Three wind energy development companies are proposing to construct a combined 142 wind turbines in Solano County, California. The area currently supports 833 turbines, with the closest structure located 4.65 nautical miles southeast of Travis Air Force Base (TAFB). The 60th Air Mobility Wing (AMW) at TAFB expressed concern that the proposed turbines could interfere with the base's ability to provide safe and efficient air traffic services to aircraft operating in the vicinity of the projects. In particular, the AMW focused on the potential impact caused by wind turbines on the terminal surveillance radar used by air traffic controllers to provide radar services to aircraft (Solano County 2010).

The airspace over the project area is complex and includes operations from Buchanan Field, located in Concord, and Rio Vista Municipal Airport (O88), as well as IFR traffic between the Sacramento and Oakland. The airspace is designated as Class E (with the exception of Class D airspace within 5 miles of the AFB), with a floor of 700 ft above ground level. The airspace does not require radar service, although airspace in the area is safer and more efficient as a result of TAFB's enhanced capabilities [Digital Airport Surveillance Radar model-11 (DASR-11), state-of-the-art terminal surveillance radar], which became operational in February 2009.

In moving to resolve potential issues of concern, the U.S. Transportation Command (parent to the 60th AMW) entered into a Cooperative Research and Development Agreement (CRADA) with the three wind energy companies, with the objective of determining the "projected impact of wind turbine development upon air traffic operations near TAFB" (U.S. Transportation Command 2010). Other parties of the CRADA were the U.S. Air Force Flight Standards Agency and the Idaho National Laboratory. Under the CRADA, three specific tasks would be completed: (1) obtain reliable, objective data to assess current air traffic operational radar coverage in the TAFB area; (2) run a simulation to assess the predicted air traffic operational impact potentially caused by proposed wind turbine development; and (3) assess the operational impact on the TAFB air traffic control areas of Shiloh III, Montezuma Wind, and Solano Wind Phase 3 wind projects.

A working group evaluated both baseline (data recorded in October 2009 from TAFB) and simulation data. The overall result of this work indicated that the construction and operation of the three identified projects would not reduce the probability of detection more than the 5 percentage point margin identified by the working group to protect the safety and efficiency of operations in proximity to the area. The following issues were considered when making this determination:

- There would be no impact on aircraft utilizing active transponders or transponder-equipped VFR aircraft because wind turbines do not impact secondary radar signals.
- Because the FAA established a minimum level of safety for Class E airspace that does not require surveillance coverage, degradation of radar coverage caused by wind turbines would not result in a reduction of safety below the minimum standard set by the FAA. However, because radar coverage exists, and that radar coverage increases the safety and efficiency of operations within the airspace, degradation of service caused by the wind turbines could decrease the overall safety and efficiency of operations. Therefore, it was necessary to identify an acceptable level of degradation in radar coverage and, more specifically, the ability to accurately detect nontransponder-equipped aircraft over the area.
- The number of false targets presently observed by the controllers is expected to be reduced, if not eliminated, after a correction to the Standard Terminal Automation Replacement System (STARS) configuration. (The STARS system receives data and flight plan information and presents the information to air traffic controllers on color displays, allowing the controller to monitor and control air traffic.) This correction was temporarily demonstrated by the working group in December 2009, which clearly showed that the use of track eligibility coupled with existing STARS tracking algorithms eliminated false targets even during significant wind activity over the area.
- To further assess the level of impact, the working group considered the number of nonparticipating aircraft likely to be operating at any given time within the lateral limits of the area. Based on the data collection, the number of nonparticipating aircraft was estimated to be minimal. The working group found that approximately 30 primary-only flight tracks occurred in October 2009 over the area.
- Considering all these factors (the airspace classification, operational configuration, air traffic service requirements, and traffic workload), the working group determined that degradation of radar detection resulting from additional wind turbine development in the area could result in a degradation of radar services provided to nonparticipating aircraft; however, given the "see and avoid" requirement, would not constitute a significant degradation of air safety.
- The working group agreed that a minor reduction in probability of detection over the area would not create an unsafe operating environment, but would decrease the safety and efficiency of operations. Because there was no reference point from which to determine the demarcation between acceptable and unacceptable impact, the working group took into consideration the type and frequency of operations over the area to determine a level of degradation of surveillance coverage that would meet the operational needs of the Air Force. Additionally, the working group considered what services would be lost as a result of that degradation and determined that in the best interest of safety and the efficiency of air traffic operations, an average degradation not greater than 5 percentage points below the established baseline values (current performance) of the probability of detection would be acceptable.

Heritage Aviation, Burlington, Vermont

Heritage Aviation of Burlington, Vermont, erected a 130-ft WTG on airport property that it leases from the Burlington International Airport (BTV) to generate electricity for its hangar and facilities (see Figure 18). As part of the project approval, Heritage filed a Form 7460 and provided information on potential impacts of physical penetration of airspace and potential impacts on communication systems.

Westslope Consulting provided an analysis of the potential impact of the wind turbine on existing Airport Surveillance Radar (ASR-11). The physical cross section that might block radar signals and produce false returns was projected to be an additional 52 ft, given that the existing building height of the Heritage hangar is 53 ft and the proposed height of the wind turbine is 98 ft to the top of the tower. The radar impact analysis assumed that the cross section of impact was limited to the tower because the blades and nacelle are made of fiberglass-reinforced polyester and the blades are 120 degrees apart and moving (Westslope 2009). The shadow area is constrained by the close distance of the wind turbine and the ASR and because the terrain rises approximately 2 miles beyond the wind turbine. Using a 6-ft-diameter tower as the obstruction, the shadow modeling predicts a cross range of 12 ft directly behind the tower spreading to 74 ft in width at the hill 2 miles away. The analysis concluded that aircraft would be operating in an environment in this area because of their need to fly at very low altitudes and close to the wind turbine to encounter the radar

FIGURE 18 Wind turbine at Burlington International Airport, Vermont (*courtesy:* Christopher Hill, Heritage Aviation).

shadow cast by the WTG. Furthermore, if an aircraft were to pass through the shadow, the detection level would be below the tolerance level though the modeling report shows the probability of detection percentage decreasing from 100% to 40% in an area approximately one-quarter to one-half of a mile behind the turbine at turbine height and decreasing at distance.

FAA approval included clear conditions that the applicant would be subject to conducting and paying for mitigation necessary to address unforeseen degradation to the ASR-11 system. Specifically, this included ceasing operation of the wind turbine while mitigation is implemented, payment for upgrades to the system, and permanent dismantling of the system at the owner's expense should other mitigation options not succeed (FAA 2009).

Ivanpah Wind Project

A wind energy developer proposed the construction of 83 wind turbine generators on Table Mountain approximately 10 miles west of the proposed Ivanpah Valley International Airport, a new airport proposed near Las Vegas. The FAA issued a No Hazard Determination for the wind project, which was appealed to the U.S. Court of Appeals by Clark County, the sponsor of the new airport.

On April 18, 2008, the FAA was ordered to reconsider its decision to allow the construction of a wind farm near the site of the new Las Vegas Airport. The evidence presented indicated that the turbines would interfere with the airport's radar systems. Specifically, the court agreed with evidence presented by an aerospace consultant for the county that each wind turbine would have a radar signature similar to a jumbo jet and that the wind farm would appear on the radar similar to a fleet of jumbo jets. The report also stated that the signature could appear and disappear rapidly based on changing wind conditions, which would hamper the air traffic controller's ability to control aircraft in the area. The federal district court determined that the FAA's determination was arbitrary and capricious (Clark County 2008).

CHAPTER FIVE

TRADITIONAL POWER PLANTS AND POTENTIAL IMPACTS

This section describes the existing body of information on the potential impacts of traditional power plants on airports and aviation. Potential impacts include physical penetration of airspace, communications systems interference, and visual impacts of vapor plumes. However, the greatest concern has been expressed about the potential impact of thermal plumes from air-cooled condensers and smokestacks.

PHYSICAL PENETRATION OF AIRSPACE

Power plants may file a Form 7460 with the FAA for structures that result in a physical penetration of airspace. Facilities that can rise high enough to penetrate airspace include the emissions stack and the cooling system (see Figure 19). Because power plants are often high-profile projects that are subject to several layers of federal, state, and local regulatory review, the airspace review is typically undertaken early in the review process and a determination of hazard from the FAA is likely to be fatal for any proposed site. However, new peaker plants are constructed with shorter exhaust stacks that often do not result in physical penetration. Critics have expressed concern that impacts into airspace could be produced by nonstructural forces such as smokestack exhaust.

COMMUNICATIONS SYSTEMS INTERFERENCE

Power plants can also present a physical obstruction to radar and other communication signals. As discussed previously, because these projects are subject to a rigorous and open public process it is expected that issues such as proximity to radar facilities would be raised during public review and studies of potential impacts conducted. Many of the new facilities are being constructed in congested urban areas where physical obstructions to radar communications may already exist. Potential impacts from power plants on communications systems have not risen to a level of concern as other impacts described herein.

THERMAL PLUME TURBULENCE

Exhaust plumes from cooling systems have the potential to create in-flight hazards that affect the control and maneuverability of aircraft. Under certain conditions, the plumes generated by the facilities can create turbulent conditions for aircraft that fly over or through the plumes. There are numerous examples, especially in California, of aircraft being affected by power plant plumes during takeoff and/or landing at airports (C. Ford, personal communication, 2010). This can be particularly troublesome for pilots unfamiliar with the airports and a potential hazard from flying through an exhaust plume.

Thermal plume turbulence for traditional power plants is generally the same as that described in the Thermal Plume Turbulence section in chapter three for concentrated solar power projects. The dry-cooling system, typically an air-cooled condenser, is the same structure regardless of how the power plant generates steam that requires cooling. However, as a result of the increase in new fossil fuel-fired power plants constructed over the last 15 years and concern raised about their impacts on aviation the FAA has provided guidance on the matter.

In January 2006, the FAA prepared a risk analysis on exhaust plumes titled *Safety Risk Analysis of Aircraft Overflight of Industrial Exhaust Plumes* (FAA 2006). This was an advisory study that contained recommendations for changes to FAA Order 7400.2E, *Procedures for Handling Airspace Matters,* regarding the effects of industrial plumes that are not included in the Part 77 evaluations. The safety risk analysis study findings indicated that the risk of an accident from a small plane flying through a plume was low (i.e., below acceptable levels). The study recommended that pilots stay more than 1,000 ft above the plume. The analysis was based on statistical averages and not actual flight tests.

In 2010, the FAA updated the *Aeronautical Information Manual* (*AIM*) to include visible and invisible thermal plumes and their affect on aircraft and pilots. *AIM* is the FAA's guide to flight information and air traffic control procedures. It is basically a pilots guide to flying an airplane and incorporates information such as medical considerations, factors affecting flight, emergency procedures, and air traffic control. The new information on thermal plumes is contained in Chapter 7-5-15, "Avoid Flight in the Vicinity of Thermal Plumes" (FAA 2010b). The section has been updated to warn pilots to avoid flight in the vicinity of thermal plumes including smoke stacks and cooling towers.

In addition to the *AIM* update, the FAA has recently undertaken a study to evaluate the impact of vertical plumes and

FIGURE 19 Bay Front Power Station, Wisconsin (*courtesy:* Seth Tisue, Wikipedia Commons).

exhaust effluent on aviation safety by the Airport Obstruction Standards Committee. The purpose of the study is to:

1. Determine the impact of plume-induced turbulence under a variety of atmospheric conditions;
2. Evaluate potential plume impacts and risk resulting from pollutant concentrations within the plume using EPA and Occupational Safety and Health Administration allowed regulations and potential exposure to the aircraft and crew members through repeated exposure of flying through plumes; and
3. Evaluate potential visible affects from plumes on aviation (i.e., ash and soot).

The state of California has a significant number of existing electric energy plants located near airports. There are several groups opposing these facilities based on the potential safety hazards the new plumes could pose on nearby air traffic at the airports. In California, the procedures for the siting of a new power plant are complex and involve a variety of review organizations that evaluate among other criteria environmental impacts. Review agencies include the CEC, EPA, and FAA, along with local permit agencies. One of the problems in addressing the impact of exhaust plumes and aviation is the lack of current information and studies on the effect plumes have on aircraft. The FAA is currently conducting an analysis of the impact of plume-induced turbulence and the potential risk to aircraft and pilots. The only conclusive information available from the FAA and U.S.DOT is after-the-fact incidents of aircraft crashes in the vicinity of exhaust plumes near airports (CEC 2010b).

The Aircraft Owners and Pilots Association (AOPA) has been active in providing comment on proposed energy projects and their potential impacts on pilots (J. Collins, AOPA, personal communication, 2011). For example, AOPA has provided comments on the potential impacts of thermal plumes from the proposed 200 MW Mariposa Natural Gas-Fired

FIGURE 20 Beaver Valley Nuclear Power Station, Pennsylvania (*courtesy:* Nuclear Regulatory Commission).

Power Plant proposed near Byron Municipal Airport (C83) (AOPA 2010).

VAPOR PLUME VISUAL IMPACT

In addition to turbulence created by industrial plumes, visual hazards created by the plumes, especially from cooling towers, also present a potential problem to pilots (see Figure 20). Plumes from cooling towers have relatively low vertical velocities and typically do not cause turbulence within the flight levels. The main hazard from a cooling tower vapor plume therefore is visual impairment to a pilot primarily resulting from the plume length and height along with potential fogging and icing conditions.

Modeling is used to evaluate impacts from cooling towers. The model has the capability of predicting frequency (including lengths and heights) of visible cooling tower moisture plumes along with the potential hours of fogging and icing conditions.

MITIGATION OPTIONS

The following mitigation options may be considered to minimize impacts from thermal plumes:

- Curtail in energy-generation operations during periods when it may be necessary for aircraft to pass over air-cooled condensers because of to weather conditions or other specific circumstances.
- Restrict in-flight procedures during certain periods of the day when thermal plumes may occur.
- Expand pilot training and awareness programs.

TRADITIONAL POWER PLANT IMPACT EXAMPLES

The following are examples of traditional power plants, both baseload and peakers, identified as having a potential impact on aviation.

Towantic Energy, Connecticut

The Towantic Energy Power Plant is a proposed 512 MW combined-cycle natural gas-fired power plant proposed for Middlebury, Connecticut. Two 150-ft stacks are proposed for the project located approximately 280 ft east of the Oxford Airport runway. The location of the stacks lies directly under the “left downwind leg” approach to the airport and the height and location of the stacks could present a potential hazard to aviation. In addition, potential fogging conditions could occur with the increase in water vapor from the plant, along with potential inversion conditions that could obscure the runways. An analysis was completed to evaluate the vapor plumes emitted by the project near the airport (Egan Environmental 2010). Five aeronautical studies were conducted by the FAA, with the latest determination by the FAA of No Hazard from the stacks (FAA 2010c). The Connecticut Siting Council has approved the project; however, construction of the plant has not occurred owing to the current economic situation and the need to secure a long-term power purchase agreement. In February 2010, as a result of continuing concerns of the potential impact of the proposed plant on Oxford Airport, the FAA announced the Airport Obstruction Standards Committee had begun a plume exhaust initiative to evaluate the potential impacts from plume-induced turbulence along with the potential impact to both aircraft and aircrew from repeated exposure resulting from flying through plume effluent (R. Pietrorazio, FAA Air Traffic Control Tower Manager, personal communication, 2010). The findings of the initiative are expected to be released by the end of 2011.

Blythe I and II, California

The CEC authorized the construction of the Blythe I power plant on January 31, 2001. The Blythe I energy facility is a 520 MW baseload natural gas power plant located approximately 1 mile east of the Blythe Airport (BLH). The plant has two large stacks and cooling towers. The project is currently operating and there have been numerous complaints filed to the CEC by pilots because of the visible and thermal plumes emanating from the plant and the hazards presented to pilots (Ford 2010).

Blythe Energy Project Phase II is a proposed 520 MW combined cycle power plant located to the west of the existing Blythe I project. The project is similar in size to Blythe I, with a bank of cooling towers and two 130-ft stacks. The CEC has approved the Blythe II project; however, the FAA has not granted a No Hazard determination and has rejected proposed mitigation from the developers.

Russell Energy Center, California

Calpine Corporation has proposed a 600 MW combined cycle natural gas electric plant in Hayward, California, known as the Russell City Energy Center. The project would be located approximately 1.5 miles from Hayward Executive Airport (HWD) and consist of two 145-ft exhaust stacks. The project received a No Hazard determination from the FAA. The California Pilots Association is appealing to the Bay Area Air Quality District and the EPA to deny the air quality permit for the facility because of the potential hazards the electric plant could pose to aviation activity in the area including, but not limited to, visual and thermal plume hazards the plant could present to pilots flying in the area (Wilson 2010). The project is still being reviewed by EPA/Bay Area Air Quality District, the CEC, and the California Public Utilities Commission.

The FAA completed an aeronautical study for the Russell Energy Center and issued a determination of No Hazard, dated March 26, 2007. The FAA also reviewed comments from the CEC and issued a determination on those comments on July 18, 2007, regarding the potential hazardous impact of the plumes from the facility (Rodriguez 2007). The FAA findings did not change the original determination of No Hazard for either Hayward Airport (HWD) or nearby Oakland International Airport (OAK).

Eastshore Energy, California

Eastshore Energy proposed a 116 MW natural gas-fired peaking facility in the city of Hayward, California. The project would consist of fourteen 70-ft-tall exhaust stacks located approximately 1 mile from the airport. The CEC denied the application to build based on deficiencies in five areas (CEC 2008). Areas specifically pertaining to aviation were:

- The facility would cause a significant cumulative public safety impact on the operations of the nearby Hayward Executive Airport by further reducing already constrained air space and increasing pilot cockpit workload.
- The thermal plumes from the facility would present a significant public safety risk to low-flying aircraft during landing and takeoff maneuvers because of the close proximity of the Hayward Airport.
- The facility would be inconsistent with the city of Hayward’s Airport Approach Zoning Regulations and incompatible with the Alameda County Airport Land Use Policy Plan.

CHAPTER SIX

ELECTRICAL TRANSMISSION INFRASTRUCTURE

This chapter reviews the existing body of information on the potential impacts of electrical transmission infrastructure on airports and aviation. Electrical transmission infrastructure includes transmission towers and the electrical lines that they carry. This infrastructure supports the energy-generation technologies discussed in previous sections allowing the power generated by the facility to be delivered to load centers in populated areas. Potential impacts to airports and aviation from transmission lines include physical penetration of airspace and communication systems interference.

PHYSICAL PENETRATION OF AIRSPACE

Electric transmission lines and the towers that support them can rise high enough to impact airspace. The transmission towers that hold up the electrical lines are the tallest part of the facility (see Figure 21). The towers are typically constructed of a lattice steel frame and range between 50 and 180 ft in height depending on the size of the electrical line being carried, among other factors (IFC 2007), although transmission towers exist that are as tall as 1,100 ft (Alimak HEK 2011).

COMMUNICATION SYSTEMS INTERFERENCE

Electromagnetic interference can be produced by high-voltage transmission lines. The level of potential interference can vary depending on the design voltage capacity of the line and the distance of a sensitive receptor from the line. Leaks occurring between the conductor and the insulators or metal fittings are referred to as a corona discharge. Typically, concern about electromagnetic release is confined to 345 kV or greater lines.

MITIGATION OPTIONS

Mitigation options associated with electrical transmission are limited. The best option is to locate transmission infrastructure so as to avoid physical penetration of airspace and interference with communications systems. A design option is to place corona rings on high-voltage lines at the conductor–hardware interface points at the end of the insulators to reduce the potential effects of electromagnetic interference.

FIGURE 21 Transmission tower schematic (*courtesy:* HMMH).

EXAMPLES

Transmission towers associated with the Blythe Plant's electrical line are proposed to be 145 ft tall. Shorter poles (90 ft tall) will be employed along a 3,900-ft segment that passes through an airport influence area. After consultation with the Riverside County Airport Land Use Commission, the line was moved an additional 1,000 plus feet to the west (CEC 2010b). The CEC required marking and lighting of all transmission poles in the 3,900 ft airport influence area, which was not a condition of the FAA's No Hazard Determination.

CHAPTER SEVEN

SUMMARY OF DATA GAPS AND CURRENT AGENCY PROGRAMS

The following is a summary of data gaps and current agency programs.

DATA GAPS

In reviewing the existing knowledge base for investigating safety impacts of energy technologies on aviation, the following data gaps have been identified. Filling these gaps will increase the knowledge base and improve the understanding of the issue. These data are not necessarily exclusive nor are they listed in any area of priority.

Comprehensive Inventory of Facilities

Prepare a comprehensive inventory of energy facilities. If the inventory was stored in a geographic information system database it could include information on each facility from technology type to aviation hazards identified. The database would form a baseline knowledge tool useful for supporting planning and cumulative impact assessment.

Survey of Pilots

Conduct a survey of pilots focused on airports where energy facilities are located. Collect experiential information about their knowledge of energy facilities, how they are impacted, and details of specific incidences that could contribute to the current knowledge base.

Assessment of Aircraft Accidents and Potential Energy Connection

Conduct a thorough study of accident reports filed with the NTSB to identify conditions associated with accidents and if there was an energy issue. Follow up the document search with phone inquiries to identify information beyond that reported in the formal report.

Identification of Siting and Planning Guidance

Based in part on information presented in this report, as well as follow-up review and discussion with stakeholders, develop siting and planning guidance for various energy technologies. The guidance could represent a useful tool in directing projects to locations where aviation safety risks can be minimized. The DoD's screening tool is a good example of siting guidance that could be applied to other technologies.

Assessment of Risk and Development of Adaptation

Using the information provided in this report as well as the additional data needs identified, produce a risk assessment of energy technologies on airports and aviation. Provide a systematic analysis of how each energy technology is altering aviation activities and describe the potential consequences of the alteration on the aviation community. In addition, identify how aviation can adapt to the changing energy landscape.

Assessment of Cumulative Impacts

Existing information on the potential cumulative impacts of new energy projects is inadequate. There was some reference to cumulative impacts assessment in relation to the number of wind turbine generators proposed in specific geographic areas of the country (e.g., Columbia River Watershed). However, no metrics for measuring cumulative impacts were identified. This would be a useful tool for future research.

Development of Glare Assessment Tools

The Sandia National Laboratories has undertaken some studies to assess the impact from concentrating solar power (see Figure 22). However, practical tools for modeling and predicting glare still need to be developed. The glare assessment tools may be able to quantify what a glare event is, when it will occur, and the consequences of exposure. This would provide an analytical tool for future projects that is consistent with existing experiences.

Field Data Collection on Thermal Plume Turbulence

The current knowledge provides some suggestions on how far above an energy facility an aircraft should stay to avoid thermal plume turbulence. The height is based on modeling that predicts the velocity of the thermal updraft maintaining a rate of 4.3 m/s or more. However, the impact metric is based on a value used in Australia. Field data on the velocity of a

FIGURE 22 Power Tower Abengoa Energy, Spain (*courtesy:* Dr. Clifford Ho, U.S. DOE, Sandia National Laboratories).

thermal plume that may produce an impact are limited. Therefore, it is suggested that specific field trials be conducted to measure impacts of thermal plume velocity on aircraft to more specifically measure the risk.

CURRENT AGENCY PROGRAMS

The development of indigenous, clean energy supplies is an important, and relatively new, national policy initiative. Preservation of the National Airspace System is an established, long-term objective. Where these two important objectives intersect new issues are raised and conflicts require assessment and resolution. Federal and state agencies have been working together on a number of fronts to increase new clean energy projects without negatively impacting airspace, a finite resource.

The DoD worked closely with the FAA, Travis Air Force Base, the American Wind Energy Association, and individual wind energy companies to study potential impacts of proposed wind farms in Solano County, California, on military readiness. One product of this work was the DoD's Wind Farm Screening Tool, found on the OE/AAA website, which enables wind developers to identify military conflicts early in the process.

Presently, the FAA's Aircraft Flight Standards group is working with the DOE, the DOE's Sandia National Laboratories, the Solar Energy Industries Association, and solar company representatives to discuss issues of potential impacts associated with concentrated solar power facilities.

The FAA is also preparing an internal report on the potential impacts of thermal plumes from air-cooled condensers associated with steam turbine generation.

CHAPTER EIGHT

CONCLUSIONS

As described in this report, energy developments are expanding nationwide as a result of increasing energy demand and development of new and innovative technologies. Although many of these projects result in a decrease in air and water emissions and support national policies including energy security and climate change, many are introducing potential conflicts with existing uses including airports and aviation. This report has reviewed new energy technologies and their potential impacts with the purpose of defining the current state of knowledge and suggesting future research.

The following impacts have been identified and the existing base of knowledge presented.

- Physical Penetration of Airspace—All of the energy technologies discussed in this report have the potential to penetrate airspace depending on their proximity to airports. However, wind turbines are the most common energy technology with a potential impact because utility-scale wind turbines can exist more than 300 ft above ground level. Power towers from particularly concentrated solar power facilities are being proposed at more than 450 ft in height.
- Communication Interference—Again, it is possible that any of the energy technologies assessed could interfere with aviation radar. However, wind farms have been identified as producing the most significant impact owing to the amount of clutter or false radar signals that are picked up by navigation and weather radar.
- Visual Impact from Glare—This impact is specific to solar technologies that have the potential to reflect sunlight from its surfaces. Concentrating solar power facilities, which use mirrors to actively reflect sunlight to concentrate it and boil water, pose the greatest risk of visual impairment from glare.
- Thermal Plume Turbulence—This impact is specific to power generation that boils water to run a steam turbine, which is accomplished either by firing fossil fuels or biofuels or with a concentrated solar power facility. The thermal plume is produced by those facilities that use dry cooling (e.g., an air-cooled condenser) to cool the steam for reuse.
- Vapor Plume Visual Impact—As with the thermal plume, the vapor plume is a product of steam turbine electricity generation. However, the vapor plume is produced by units that utilize evaporative wet cooling to cool the steam for reuse.
- Wind Turbine Rotor Turbulence—Downwind of a wind turbine the air can be destabilized, producing turbulence that can impact aircraft.

This study found that a significant amount of research has been conducted, particularly over the past year, on energy technologies and their safety impacts on airports and aviation. In 2010, the FAA completed *Technical Guidance for Evaluating Selected Solar Technologies on Airports,* which generated new information associated with solar photovoltaic panels and farms. The California Energy Commission has conducted a review and issued decisions for the Blythe Solar Power Plant and the Ivanpah Solar Electric Facility that provide updated guidance on impact assessment of concentrated solar power projects. The DOE's Sandia National Laboratories has produced information on potential glint and glare from concentrating solar power technologies. The U.S. Transportation Command has issued a report in association with Travis Air Force Base and three private wind energy development companies on the effect of farm construction on radar performance.

Furthermore, the FAA is actively administering airspace reviews to assess the potential impact of new energy projects. Where most effective, these reviews are being completed under a systematic and coordinated federal–state environmental review process such as those completed by the Bureau of Land Management and California Energy Commission for concentrated solar projects in Southern California. Wind turbine projects have been more difficult to coordinate as a result of the sheer volume of applications. Although each wind turbine receives an independent review, a cumulative assessment becomes more difficult given the volume of applications and time constraints on reviews. Cooperation between federal agencies and in concert with state agencies have helped identify gaps in the knowledge base and reach consensus on high-profile projects as well as a more coordinated review strategy.

Mitigation measures have been developed by regulatory agencies to minimize the impacts of energy technologies. The mitigation measures identified included the following:

- Marking and lighting of wind turbines, power towers, transmission towers, and other tall structures.

- Operations and maintenance procedures for concentrating solar power facilities to avoid inadvertent glare.
- Use of anti-reflective coatings and roughened surfaces to minimize glare from solar photovoltaic sources. Formal notices to airmen and updates to nautical charts alerting pilots to potential hazards of thermal uplift and glare posed by concentrating solar power and air-cooled condensers.
- Monitoring plans to assess the potential impact of glare on sensitive receptors.
- Upgrading of radar infrastructure and software to filter out radar clutter.
- Preservation of a flight buffer of 1,000 ft above energy facilities.

Based on this information, we suggest the following data collections be conducted to enhance the existing knowledge base:

- Develop a comprehensive inventory of energy facilities to establish a baseline for implementing planning and conducting cumulative impact assessments.
- Conduct a survey of pilots to collect more experiential information about their understanding of potential energy impact issues and document their experiences.
- Conduct a detailed review of aircraft accidents to quantify energy technology components.
- Prepare siting and planning guidance for each energy technology.
- Conduct a risk assessment for each energy technology and opportunities for aviation adaptation.
- Assess cumulative impacts for each technology.
- Develop predictive glare assessment tools that more actively and consistently quantify glare impacts experienced at existing facilities.
- Collect field data on thermal plume turbulence to support an impact assessment threshold.

GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS

Aeronautical Information Manual (*AIM*)—A primary FAA publication whose purpose is to instruct airmen about operating in the National Airspace System of the United States. It provides basic flight information, air traffic control procedures, and general instructional information concerning health, medical facts, factors affecting flight safety, accident and hazard reporting, and types of aeronautical charts and their use.

Air-cooled condenser—also referred to generically as dry cooling, an air-cooled condenser condenses exhaust steam from the steam turbine and returns condensate to the boiler without using cooling water. Two typical designs are mechanical draft and natural draft. In either case, air cools the exhaust steam causing hot air and condensate (which is reused in the plant).

Air route surveillance radar (ARSR)—radar used primarily to detect and display an aircraft's position while en route between terminal areas. The ARSR enables controllers to provide radar air traffic control service when aircraft are within the ARSR coverage. In some instances, ARSR may enable an air traffic control center to provide terminal radar services similar to but usually more limited than those provided by a radar approach control.

Airport Cooperative Research Program (ACRP)—An industry-driven, applied research program that develops near-term, practical solutions to problems faced by airport operators. ACRP is managed by TRB for the FAA. The research is conducted by contractors who are selected on the basis of competitive proposals.

Airport surveillance radar (ASR)—approach control radar used to detect and display an aircraft's position in the terminal area. ASR provides range and azimuth information but does not provide elevation data. Coverage of the ASR can extend up to 60 miles.

Bureau of Land Management (BLM)—Division of the U.S. Department of the Interior whose mission is to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.

Civilian Aviation Authority (CAA) of the United Kingdom—agency responsible for safety regulation of civil aviation in the United Kingdom under the Civil Aviation Act 1982.

California Energy Commission (CEC)—state's primary energy policy and planning agency established in 1974.

Clutter—unwanted (false) returns picked up by the radar.

Concentrating solar power plants—solar generation technology that utilizes mirrors to focus and intensify the sun's heat to boil water and drive a traditional steam turbine for the production of electricity.

Cooling tower—see air-cooled condenser.

Cooperative Research and Development Agreement (CRADA)—A written agreement between a private company and a government agency to work together on a project. Created as a result of the Stevenson–Wydler Technology Innovation Act of 1980, as amended by the Federal Technology Transfer Act of 1986, a CRADA allows the federal government and non-federal partners to optimize their resources, share technical expertise in a protected environment, share intellectual property emerging from the effort, and speed the commercialization of federally developed technology.

Digital Airport Surveillance Radar (DASR)—a new terminal air traffic control radar system that replaces current analog systems with new digital technology. The U.S. Air Force Electronics Systems Center, the FAA, and the U.S. Navy are in the process of procuring DASR systems to upgrade existing radar facilities for the DoD and civilian airfields. The DASR system detects aircraft position and weather conditions in the vicinity of civilian and military airfields. The civilian nomenclature for this radar is the ASR-11. ASR-11 will replace existing ASR-7, ASR-8, and ASR-9 models. The military nomenclature for the radar is AN/GPN-30. The older radars, some up to 20 years old, are being replaced to improve reliability, provide additional weather data, reduce maintenance cost, improve performance, and provide digital data to new digital automation systems for presentation on air traffic controller displays.

Dish engine—also referred to as a dish stirling, this is a type of concentrating solar power system that is a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point.

Distributed energy—Distributed energy refers to a variety of small, modular power-generating technologies that can be combined with load management and energy storage systems to improve the quality and/or reliability of the electricity supply.

Department of Defense (DoD)—cabinet department of the U.S. federal government responsible for the country's defense policy with authority over the military and civilian forces.

Department of Energy (DOE)—cabinet department of the U.S. federal government responsible for the country's energy policy.

Department of Transportation (DOT)—cabinet department of the U.S. federal government responsible for the country's transportation policy and infrastructure.

Diffuse reflection—produces a less concentrated light and occurs from rough surfaces such as pavement, vegetation, and choppy water.

Environmental Impact Statement (EIS)—a document prepared by a federal agency to demonstrate that its actions are in compliance with the National Environmental Policy Act.

Environmental Protection Agency (EPA)—the federal agency whose mission is to protect human health and the environment through the enforcement of laws enacted by the federal government.

Farm (as in wind farm or solar farm)—a group of generator units that together produce significantly more electricity than any one unit alone.

Federal Aviation Administration (FAA)—the federal agency whose mission is to provide the safest and most efficient aerospace system in the world.

Form 7460—Notice submitted to the FAA for structures that impinge on airspace as defined by 14 CFR Part 77.

Glare—a continuous source of bright light.

Glint—a momentary flash of bright light.

Heat recovery system generator (HRSG)—extracts heat in the flue gas producing cooler exhaust temperatures and lower exit velocities

Instrument flight rules (IFR)—A set of rules governing the conduct of flight under instrument meteorological conditions.

Instrument landing system (ILS)—A precision instrument approach system that normally consists of the following electronic components and visual aids: localizer, glideslope, outer marker, middle marker, and approach lights.

Nacelle—A box that sits on top of the wind tower and encloses the turbine generator and other equipment necessary for generating electricity.

National Airspace System—The common network of U.S. airspace; air navigation facilities, equipment and services, airports or landing areas, aeronautical charts, information and services, rules, regulations and procedures, technical information, and manpower and material. Included are system components shared jointly with the military.

Navigable airspace—Airspace at and above the minimum flight altitudes prescribed in the CFRs including airspace needed for safe takeoff and landing.

Navigational Aids (NAVAIDS)—Any visual or electronic device airborne or on the surface that provides point-to-point guidance information or position data to aircraft in flight.

National Environmental Policy Act (NEPA)—A U.S. environmental law that established a U.S. national policy promoting the enhancement of the environment and also established the President's Council on Environmental Quality.

Office of Obstruction Evaluation/Airport Airspace Analysis (OE/AAA)—A particular office under FAA's Air Traffic Organization whose responsibility is to coordinate FAA's review of potential hazards to air navigation.

Parabolic trough—continually track the sun and concentrate the sun's heat onto receiver tubes filled with a heat transfer fluid.

Peaker power plants—typically traditional fossil fuel-fired stations modified to start up and shut down quickly to respond to seasonal fluctuations in energy demand.

Power tower—facility is comprised of individual heliostats (mirrors) arranged in a circular array that track with the sun. Each heliostat reflects sunlight onto the central receiver at the top of a tower.

Primary surveillance radar (PSR)—uses a continually rotating antenna mounted on a tower to transmit electromagnetic waves that reflect, or backscatter, from the surface of aircraft up to 60 miles from the radar. The radar system measures the time required for a radar echo to return and the direction of the signal. From this, the system can then measure the distance of the aircraft from the radar antenna and the azimuth, or direction, of the aircraft in relation to the antenna. The primary radar also provides data on six levels of rainfall intensity. The primary radar operates in the range of 2700 to 2900 MHz. The transmitter generates a peak effective power of 25 kW and an average power of 2.1 kW. The average power density of the ASR-11 signal decreases with distance from the antenna. At distances of more than 43 ft from the antenna, the power density of the ASR-11 signal falls below the maximum permissible exposure levels established by the Federal Communications Commission.

Probability of detection (Pd)—measures the likelihood of detecting an event or object when the event does occur.

Secondary surveillance radar (SSR)—uses a second radar antenna attached to the top of the primary radar antenna to transmit and receive area aircraft data for barometric altitude, identification code, and emergency conditions. Military, commercial, and some general aviation aircraft have transponders that automatically respond to a signal from the secondary radar by reporting an identification code and altitude. The air traffic control uses this system to verify the location of aircraft within a 60-mile radius of the radar site. The beacon radar also provides rapid identification of aircraft in distress. The secondary radar operates in the range of 1030 to 1090 MHz. Transmitting power ranges from 160 to 1,500 watts.

Solar photovoltaic panels and farms—Solar photovoltaic (PV) generates electricity from sunlight on light-absorbing panels with many panels together representing a solar farm.

Specular reflection—reflects a more concentrated type of light and occurs when the surface in question is smooth and polished

Standard Terminal Automation Replacement System (STARS)—a system jointly procured by the FAA and DoD to replace capacity-constrained, older technology systems at FAA and DOD terminal radar approach control facilities and associated towers.

Terminal Instrument Procedures (TERPS)—procedures for instrument approach and departure of aircraft to and from civil and military airports.

Thermal plume—vapor clouds produced by large-scale emissions of heated water vapor either through a direct emission or from an air-cooling structure.

Transmission infrastructure—Transmission infrastructure including towers and electrical lines are a fundamental component of any energy project that generates electricity and delivers it to the electrical grid.

Ultra-high frequency (UHF)—The frequency band between 300 and 3,000 MHz. The bank of radio frequencies used for military air/ground voice communications. In some instances this may go as low as 225 MHz and still be referred to as UHF.

Very high frequency (VHF)—The frequency band between 30 and 300 MHz. Portions of this band, 108 to 118 MHz, are used for certain NAVAIDs; 118 to 136 MHz are used for civil air/ground voice communications. Other frequencies in this band are used for purposes not related to air traffic control.

Visual flight rules (VFR)—Rules that govern the procedures for conducting flight under visual conditions. The term "VFR" is also used in the United States to indicate weather conditions that are equal to or greater than minimum VFR requirements. In addition, it is used by pilots and controllers to indicate type of flight plan.

Wind turbine generator (WTG)—A machine that converts wind energy into electricity.

Utility-scale—refers to larger electricity generation units that typically transmit most if not all of the electricity generated to the electric grid.

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Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation