Appendix A
Patuxent River Complex Activity and Asset Descriptions

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Abbreviations and Acronyms

Acronym	*Definition*
ALMDS	airborne laser mine detection system
AMNS	airborne mine neutralization system
ASW	anti-submarine warfare
ATMO	Atlantic Targets and Marine Operations
DICASS	Directional Command-Activated Sonobuoy
E^3	electromagnetic environmental effects
EA	electronic attack
COBRA	coastal battlefield reconnaissance and analysis
EIS	Environmental Impact Statement
EP	electronic protection
ES	electronic warfare support
EW	electronic warfare
IED	improvised explosive devices
IPOE	intelligence preparation of the operational environment
IR	infrared
ISR	Intelligence, Surveillance, and Reconnaissance
JDAM	Joint Direct Attack Munition
LOS	line of sight
MCM	mine countermeasure
MEM	military expended materials
MIW	mine warfare
MOP	magnetic orange pipe
N/A	not applicable
NAS	Naval Air Station
NAWCAD	Naval Air Warfare Center Aircraft Division
NTWL	Naval Test Wing Atlantic
OASIS	organic airborne and surface influence sweep
OPAREA	Operating Area
PRC	Patuxent River Complex
R-	restricted area
RCS	radar cross section
RDT&E	research, development, test and evaluation
RF	radio frequency
ROV	remotely operated vehicles
SAR	search and rescue
SEPTAR	Seaborne Powered Target
TUMS	towed unmanned submersible
UAS	unmanned aerial systems
UGS	unmanned ground systems
UMS	unmanned maritime systems
USNTPS	United States Naval Test Pilot School
USV	unmanned surface vehicles
UUV	unmanned underwater vehicles

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A.1 Patuxent River Complex Users

Primary users of the Patuxent River Complex (PRC) include Naval Test Wing Atlantic (NTWL) and other tenant squadrons home-based at Naval Air Station (NAS) Patuxent River. NTWL accounts for over 80 percent of the annual flight hours within the PRC. Transient aircraft, not stationed at NAS Patuxent River, also perform training and testing within the complex. These primary PRC users are responsible for generating the flight hours being analyzed in this Environmental Impact Statement (EIS). Each squadron is briefly described in Table A-1.

Table A-1: Primary Patuxent River Complex Users

Squadron Name		***Description***
Naval Test Wing Atlantic Squadrons		
Air Test and Evaluation Squadron	Two Zero (VX-20)	Supports RDT&E of fixed-wing battleforce support, strategic, and training aircraft. Current platforms include E-2C/D, C-12M, C-2A, C/KC-130J/T, E-6B, MQ-4C, P-8A, C-38, and T-6A.
	Two One (HX-21)	Supports RDT&E of rotary-wing and tilt-rotor aircraft and maintains NAS Patuxent River SAR assets. Current platforms include AH-1, UH-1, CH-53K, MH-53E, MH-60R/S, V-22, and Executive Transport Helicopters.
	Two Three (VX-23)	Supports RDT&E of fixed-wing tactical aircraft and is the largest flight test organization within Naval Air Systems Command. Current platforms include F/A-18A-F, EA-18G, and T-45A/C, as well as on-going contractor demonstration efforts for the F-35B/C and MQ-25A.
	Two Four (UX-24)	Supports RDT&E of UAS headquartered at Outlying Field Webster. Current platforms include RQ-12 Wasp, RQ-11 Raven, RQ-20 Puma, RQ-21 Blackjack, and MQ-8 Fire Scout. Aerostar UAS provide customers range clearance support and a platform to test payloads.
U.S. Naval Test Pilot School		Trains test pilots, flight officers, engineers, industry, and foreign partners in test and evaluation of aircraft and aircraft systems. Only U.S. test pilot school with a formal rotary-wing syllabus and only in the world offering an airborne systems curriculum. Navy's most diverse aircraft fleet (currently 46 aircraft of 14 different platforms) exposes students to a broad spectrum of performance, flying qualities, and weapon system capabilities.
Other NAS Patuxent River Squadrons		
Air Operations SAR		Provides SAR helicopter services in support of testing, training, and non-military events. Primary platform is the MH-60S.
Fleet Air Reconnaissance Squadron Four (VQ-4)		Maintains NAS Patuxent River Take Charge and Move Out Atlantic alert site. Provides launch and maintenance of E-6B aircraft in support of the squadron's strategic communications mission. Flight operations typically occur outside of the PRC.
Air Test and Evaluation Squadron One (VX-1)		Serves as the Navy's evaluator of airborne anti-submarine warfare and maritime anti-surface warfare weapon systems in an operational environment. Current platforms include P-8A, E-2D, and MH-60R/S and provides support for E-6B, KC-130J, MQ-8B, and MQ-4C.

Table A-1: Primary Patuxent River Complex Users, Continued

Squadron Name	***Description***
Scientific Development Squadron One (VXS-1)	Provides airborne research platforms for the Naval Research Laboratory, U.S. Navy, U.S. Government and its contracting agencies. Current platforms include two uniquely configured NP-3C, a RC-12, a UV-18, and numerous small UAS.
Maryland Army National Guard	Serves as the RQ-7 Shadow Tactical UAS Platoon operating out of Outlying Field Webster. Occasionally hosts similar National Guard units from other states such as Virginia and Pennsylvania.
Non-NAS Patuxent River Transients	
Transients	Transient aircraft, not stationed at NAS Patuxent River, that use range complex airspace for training or testing or the airfield as an airport. Primarily F-16 from Andrews Air Force Base, Maryland and Atlantic City International Airport, New Jersey; F-22 and T-38 from 1st Fighter Wing Langley, Virginia; and A-10 Reservists from Maryland and Pennsylvania. Also includes: federal and state agency small propeller research and/or surveying aircraft; commercial customer aircraft; and aircraft from Navy deployed Virginia Capes carriers.

Key: NAS = Naval Air Station; RDT&E = research, development, test and evaluation; SAR = search and rescue; UAS = unmanned aerial systems; U.S. = United States

A.2 Patuxent River Complex Activities

Testing and training activities analyzed in the 1998 PRC EIS included aircraft flight activities, ground-based activities, and surface vessel activities. These, as well as several activities assessed in various Environmental Assessments since 1998, are discussed within this appendix. They include surface and subsurface testing and training and a variety of mine countermeasure (MCM) systems, anti-submarine warfare (ASW) systems, and unmanned air, ground, and maritime systems activities. The definitions of laser classes are also provided.

A.2.1 Aircraft Flight Activities

Aircraft flight activities include test flights, training flights, and other flights.

A.2.1.1 Test Flights

Test flights are categorized into four main areas that encapsulate the unique Naval Air Warfare Center Aircraft Division (NAWCAD) research, development, test and evaluation (RDT&E) mission. They include air vehicle, carrier and shipboard suitability, mission systems, and electronic warfare (EW) tests. Each area is divided into subareas that further define specific test types. A small amount of test flights are also conducted by VX-1 in carrying out its operational test (versus developmental test) mission. Table A-2 provides a description of PRC test flight activities.

Table A-2: Test Flights

Activity Name	***Activity Description***
1.0 Air Vehicle	The air vehicle mission area includes four subcategories of tests that are conducted throughout the flight envelope to expose the airframe and aircrew to the full operational limits of altitude, speed, load factor, gross weight, environmental conditions, and operational situations experienced during Fleet operations. They include aeromechanics, air vehicle subsystems, structural tests, and crew systems. These tests may contain both flight and ground elements although the majority are conducted in flight. Tests are performed on manned and unmanned fixed- and rotary-wing aircraft and may involve the release of non-explosive munitions or other expendables.
1.1 Aeromechanics	Aeromechanics tests include aircraft aero propulsion, flying qualities/stability and control, performance, weapons compatibility, and weapons separation and jettison.
1.1.1 Aero Propulsion	Aero propulsion tests evaluate the in-flight operating characteristics and performance of the aircraft propulsion system. These tests include in-flight thrust measurement, engine stall and recovery characteristics, air starts, water and steam ingestion, gun and missile gas ingestion, engine control system response, engine/inlet compatibility, propeller and gearbox performance, engine monitor system functionality, and other similar types of tests. Aero propulsion tests may occasionally require the firing of guns, rockets, or missiles to conduct gun/missile gas ingestion tests.
1.1.2 Flying Qualities/Stability and Control	Flying qualities/stability control tests evaluate aircraft handling characteristics, stall characteristics, pilot-induced oscillations, spin and spin recovery controllability, and similar tests to determine compliance with detailed specifications. On rare occasions, tests may include intentional fuel dumping to achieve test weight objectives.
1.1.3 Performance	Performance tests evaluate aircraft performance characteristics such as take-off distance, climb rate, turn rate, sustained g-force, level acceleration, specific fuel consumption, and similar tests to determine compliance with detailed specifications. On rare occasions, tests may include intentional fuel dumping to achieve test weight objectives.
1.1.4 Weapons Compatibility	Weapons compatibility tests evaluate the compatibility between aircraft and expendable weapons. Ground tests evaluate form, fit, and function of the weapons stations and weapons management system. Flight tests include captive-carry of various weapons loadings to verify airframe compatibility, in-flight load and vibration measurement, and specification compliance.
1.1.5 Weapons Separation and Jettison	Weapons separation and jettison tests evaluate weapon separation characteristics and establish safe release envelopes for all expendable weapons. Tests involve the intentional release of weapons or any other expendables released during normal operations or jettisoned for emergencies. Tests include in-flight separation (drop) of non-explosive munitions, firing of gun ammunition with non-explosive rounds, or firing of missiles or rockets with live motors and non-explosive warheads. This category also includes weapons delivery accuracy testing.
1.2 Air Vehicle Subsystems	The air vehicle subsystems category involves the testing of aircraft cargo handling, environmental controls, fire detection/protection, hydraulics and fuel systems, landing systems, and reliability and maintainability.
1.2.1 Cargo Handling	Cargo handling tests evaluate the utility, functionality, durability, and specification compliance of cargo handling systems such as slings, hoists, and air drop stabilization and deceleration devices. These tests typically involve rotary-wing aircraft, but may occasionally be conducted for fixed-wing. Cargo handling tests may also include the intentional release of cargo (or mass equivalents) to test jettison and emergency release characteristics.
1.2.2 Environmental Controls	Environmental controls tests evaluate the functionality, control, operational suitability, and specification compliance of environmental control systems that are designed to cool the cockpit, passenger/cargo area, avionics and equipment bays, and other temperature sensitive areas of an aircraft.
1.2.3 Fire Detection / Protection	Fire detection/protection tests evaluate the functionality, durability, and specification compliance of fire protection, detection, and suppression systems of an aircraft. These tests may include the intentional release of fire suppression chemicals that have the potential to mix with air and water.

Table A-2: Test Flights, Continued

Activity Name	Activity Description
1.2.4 Hydraulics and Fuel Systems	Hydraulics and fuel systems tests evaluate the functionality, durability, and specification compliance of hydraulic pumps, lines, control valves, connectors, fuel management systems, internal and external fuel tanks, refueling devices, and related equipment. These tests include aerial refueling and may also include the intentional release of fuel to evaluate emergency fuel-dumping capabilities.
1.2.5 Landing Systems	Landing systems tests evaluate the functionality, durability, and specification compliance of landing gear systems including controls, tires, brakes, struts, wheels, anti-skid under wet and dry runway conditions, and other associated tests.
1.2.6 Reliability and Maintainability	Reliability and maintainability tests evaluate the reliability and maintainability of an aircraft and its related support systems. These tests may involve the intentional release of non-explosive munitions or other expendables onto a padded surface.
1.3 Structural Tests	The structural tests category involves the testing of dynamic and static airframe loads, flutter, launch and recover loads, and rotor dynamic loads.
1.3.1 Dynamic and Static Airframe Loads	Dynamic and static airframe load tests are conducted to measure static and dynamic loads under a broad range of flight conditions and to determine specification compliance.
1.3.2 Flutter	Flutter tests determine which airspeed and flight conditions may lead to potentially undesirable flutter conditions on aircraft surfaces. These tests primarily involve fixed-wing aircraft, but may occasionally be conducted for rotary-wing.
1.3.3 Launch and Recover Loads	Launch and recover load tests measure flight loads at various parts of the aircraft during catapult launch and recovery and shipboard operations. These tests primarily involve fixed-wing aircraft and may be conducted at shore-based facilities or on various ship platforms.
1.3.4 Rotor Dynamic Loads	Rotor dynamic load tests are conducted to measure loads of rotor system dynamic components under a broad range of flight conditions and to determine specification compliance.
1.4 Crew Systems	The crew systems category involves the testing of aircraft emergency egress, life support and personnel protection, and night combat equipment.
1.4.1 Emergency Egress	Emergency egress tests evaluate the operational characteristics and levels of protection for aircraft emergency egress and escape systems. These ground tests are accomplished in special facilities such as the Vertical and Horizontal Accelerators at the Atlantic Test Ranges.
1.4.2 Life Support and Personnel Protection	Life support and personnel protection tests evaluate the suitability and functional utility of aircrew life support systems and personnel protection equipment and how these items interface with the diverse technologies found in modern aircraft. Preliminary tests are performed in laboratory environments, followed by flight testing.
1.4.3 Night Combat Equipment	Night combat equipment tests evaluate the suitability of night vision systems and their compatibility with various cockpit configurations. Ground tests are accomplished in the Night Combat Test Laboratory. Flight tests are conducted during late night or near sunrise hours to emulate realistic test environments.
2.0 Carrier and Shipboard Suitability	The carrier and shipboard suitability mission area includes three subcategories of tests that are conducted in a shipboard environment or special ground-based facilities designed to simulate a shipboard environment (e.g., TC-7 steam catapult, MK-7 arresting gear, and short takeoff vertical landing facility). They include fixed-wing tests, rotary-wing tests, and ships air traffic control and landing systems certification tests. These tests are performed on manned and unmanned conventional and vertical takeoff and landing/short takeoff vertical landing aircraft and aircraft systems for all classes of aircraft carriers, amphibious ships, and from expeditionary airfields. Tests focus on the major aircraft design considerations driven by the requirement to operate on a ship and the unique adverse operating environments associated with a ship such as ship motion, air wake, confined operating areas, corrosive hazards, acoustic and electromagnetic hazards, ground crew safety, and other naval aviation challenges. Land based catapults and arrested landings are usually combined into a single test block. Carrier and shipboard suitability tests do not involve the release of non-explosive munitions or other expendables.
2.1 Fixed-Wing	Fixed-wing tests conducted at NAS Patuxent River include catapult and arrested landing structural demonstrations and minimum approach speed tests. Shipboard catapult launch, arrested landing, and ground handling tests are typically conducted offshore.

Table A-2: Test Flights, Continued

Activity Name	*Activity Description*
2.1.1 Catapult and Arrested Landing Structural Demonstrations	Catapult and arrested landing structural demonstrations include a series of structural demonstrations conducted at a shore-based facility prior to flying a new or modified aircraft off a carrier. These tests are designed to expose the aircraft and all of its subsystems to the extreme g-loads and impact shock loads associated with Naval aviation. High sink rate landings, off-center arrestments, in-flight engagement of the arresting wire, maximum catapult acceleration, max gross weight catapult and arrested landings, and tail hook dynamic load measurements are typical of this type of test. Steam ingestion catapult tests are also conducted to demonstrate the ability of the engine to operate stall free while ingesting steam leaked by the catapult piston.
2.1.2 Minimum Approach Speeds and Associated Flying Qualities	Minimum approach speeds and associated flying qualities tests involve shore-based testing to define the minimum acceptable approach airspeed and the associated flying qualities.
3.1.3 Shipboard Catapult Launch Tests	Shipboard catapult launch tests involve carrier-based testing to determine aircraft performance under various catapult speeds, crosswind and wind-over-deck conditions, low energy launches, and trim requirements for symmetric and asymmetric store configurations. Minimum catapult end airspeed tests define the slowest safe speed for catapult flyaway.
3.1.4 Shipboard Arrested Landing Tests	Shipboard arrested landing tests involve carrier-based testing to determine aircraft crosswind limits, bolter and wave-off performance, and handling qualities at high wind-over-deck conditions.
3.1.5 Shipboard Ground Handling Tests	Shipboard ground handling tests involve carrier deck-based testing to evaluate aircraft compatibility with shipboard facilities and support equipment such as heavy weather tie-down, canopy opening under high wind conditions, dynamic tip back following arrested landing, and hangar bay spotting and towing.
2.2 Rotary-Wing	Rotary-wing tests conducted at NAS Patuxent River include structural and functional integrity tests and aircraft handling and performance characteristics. Shipboard interface and ground tests are typically conducted offshore.
2.2.1 Structural and Functional Integrity Tests	Structural and functional integrity tests define the structural and functional integrity of an aircraft and its subsystems. Tests may involve water, sand, or ice ingestion; high sink rate landing; high wind conditions; cargo hoist handling; high gross weight take offs; and similar tests that stress an aircraft to its operational limits.
2.2.2 Aircraft Handling and Performance Characteristics	Aircraft handling and performance characteristics tests evaluate aircraft handling and performance during takeoff, approach, and recovery operations. These tests are sometimes referred to as dynamic interface testing.
3.2.3 Shipboard Interface Tests	Shipboard interface tests are conducted on many different types and classes of Navy and Coast Guard ships. These tests establish wind-over-deck limits under normal and emergency conditions, evaluate deck lighting and marking under day and night conditions, and determine compatibility with visual landing aids and mechanical aids such as the Recovery Assist, Securing, and Traversing system.
3.2.4 Shipboard Ground Tests	Shipboard ground tests evaluate aircraft deck handling, servicing, storage, and support operations. Test results are used to define operating envelopes, limits, and interoperability recommendations.
2.3 Ships Air Traffic Control and Landing Systems Certification	Ships air traffic control and landing systems certification includes the testing of Precision Approach Landing Systems for nuclear aircraft carrier landings and of precision approach radar for general purpose amphibious assault ship landings or helicopter dock amphibious assault ship landings.
2.3.1 Precision Approach Landing Systems Tests	Precision approach landing systems tests are conducted on fixed-wing aircraft both ashore and in carrier-based environments offshore. These tests evaluate and certify the electronic, electro-optical, satellite, and visual air traffic control and landing systems for carrier-based aviation. Primary landing systems include the AN/SPN-46 Automatic Carrier Landing System and the AN/SPN-41 Instrument Carrier Landing System.

Table A-2: Test Flights, Continued

Activity Name	*Activity Description*
2.3.2 Precision Approach Radar Systems Tests	Precision approach radar systems tests are conducted on rotary-wing aircraft both ashore and onboard Navy ships that are capable of supporting rotary-wing operations. These tests evaluate and certify the electronic, electro-optical, satellite, and visual air traffic control and landing systems. Primary systems include the AN/SPN-35 Precision Approach Radar and the AN/SPN-41 Instrument Carrier Landing System.
3.0 Mission Systems	Mission systems tests evaluate the performance and operability of subsystems that are integrated into the cockpit displays and fire control systems of modern military aircraft (and ships). These subsystems are commonly referred to as black boxes, avionics, or aircraft electronics. Both the operational functionality of the system (or subsystem) and interoperability with the aircraft and its systems are verified. Tests include communication (including laser), navigation, information warfare systems, central computer/mission computer systems, armament control systems, sensor integration, sensors, electromagnetic environmental effects (E^3), laser rangefinders and designators, and ship-based and shore-based systems. Mission systems tests may include both flight and ground elements and do not typically but may involve the release of non-explosive munitions or other expendables.
3.1 Communication	Communication tests evaluate the clear/secure internal and external voice communications and components that provide the transmission and receipt of digital data required by information warfare systems. System components include radios, data links, intercoms, anti-jam/low probability of intercept appliqués, antennas, data modems, and communications security equipment. This category also includes antennae pattern testing.
3.2 Navigation	Navigation tests evaluate the navigation systems and components that enable safe aircraft transit and provide position and course data to mission systems. This category also includes testing of tactical communications.
3.3 Information Warfare Systems	Information warfare systems tests evaluate the systems and devices for tactical information management, mission planning, data transfer/retrieval and recording, tactical decision-making, intelligence analysis, mission data recording systems, and Identification Friend or Foe systems.
3.4 Central Computer / Mission Computer Systems	Central computer/mission computer systems tests develop, document, integrate, and support the airborne central computer/mission computer systems and their respective operational flight programs.
3.5 Armament Control System	Armament control system tests develop, document, integrate, and support the airborne armament control systems and their respective operational flight programs.
3.6 Sensor Integration	Sensor integration tests develop, document, integrate, and support the integration of avionics and weapons into the aircraft weapons system.
3.7 Sensors	Sensors tests design, develop, and integrate the broad range of sensors used in aircraft and other weapons systems. Types of sensors include acoustic, radio frequency (RF), electro-optical, chemical, and other sensors under development.
3.8 Electromagnetic Environmental Effects (E^3)	E^3 tests are conducted using specialized ground-based equipment/facilities to determine the electromagnetic vulnerability of electronic systems embedded in aircraft and other weapons systems. These tests are performed to identify and correct safety hazards, equipment failures, operability limitations, and specification compliance related to E^3.
3.9 Ship- and Shore-Based Systems	Ship- and shore-based systems tests analyze a wide spectrum of ship- and shore-based electronics such as air traffic controls, surface-based aircraft identification systems, shipboard exterior communications, special communication systems for special and joint operations, shipboard data links, and emerging information technology systems.

Table A-2: Test Flights, Continued

Activity Name	*Activity Description*
4.0 Electronic Warfare (EW)	The EW mission area involves the test and evaluation of U.S. military electronic combat systems against a wide variety of threat simulations, surrogates, and actual systems that represent real-world threat scenarios. Types of tests include electronic attack (EA), tactics development and foreign materials exploitation that would support electronic protection (EP), electronic warfare support (ES) measures, and radar cross section (RCS) and infrared (IR) signature measurement. Systems under test may involve software and/or hardware that range from experimental, pre-production equipment, to fully developed systems that are installed in Fleet aircraft. EW tests may include both flight and ground elements and may involve the release of non-explosive munitions or other expendables related to electronic countermeasures.
4.1 Electronic Attack (EA)	EA involves the use of electromagnetic energy, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability. Examples include anti-radiation missiles, flares, active decoys, and directed energy. EA testing is the verification, or measurement of performance of EA software, hardware, or systems by providing simulated or actual threat signatures to stimulate EA systems and quantifying the received response of a jamming system, anti-radiation missile, or other attack system. This area also includes cyberwarfare testing.
4.1.1 Jammer Testing	Jammer testing includes frequency accuracy, effective radiated power, pointing accuracy, jammer response time and jamming-to-signal ratio, and testing of techniques, such as Range Gate Pull-Off, Velocity Gate Pull-Off, and others. These tests may involve the transmission of high power RF energy.
4.1.2 Expendables (Chaff & Flares)	Expendables are used by aircraft to create a false radar target (chaff) or false IR target (flares). These tests may involve the transmission of high power RF energy and/or the release of chaff, IR decoy flares, RF decoys, or similar non-explosive expendables.
4.1.3 Anti-Radiation and Directed-Energy Weapons	Anti-radiation missile seeker/avionics tests evaluate the seekers and avionics that control and guide anti-radiation missiles. Directed-energy weapons testing involves a high-energy laser or high-power microwave system. High-energy laser weapons are intended to damage or destroy enemy systems. High-power microwave systems are designed to produce effects on electronic systems and can also provide non-lethal anti-personnel capabilities.
4.2 Electronic Protect (EP)	EP involves actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability. These tests are conducted in a simulated threat environment to evaluate the effectiveness of EP software, hardware, and integrated systems.
4.3 Electronic Warfare Support (ES) Measures	ES measures involve actions taken to search for, intercept, identify, and locate sources of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition, targeting, planning, conduct of future operations, and other tactical actions such as threat avoidance and homing. ES testing is the verification of software, hardware, and integrated systems used to passively detect, record, identify, and catalog enemy threat signatures. This is accomplished by providing realistic threat scenarios in order to stimulate sensors and systems under test. These tests involve transmissions of high power RF in all frequency ranges of interest (High Frequency to Ka band).
4.3.1 Electronic Warfare Tactics Developments	EW tactics developments tests develop defensive and offensive tactics against enemy weapon systems. These tests require an extensive array of realistic threat replication or simulation devices to ensure realistic results and may involve the transmission of high power RF energy and/or the release of chaff, IR decoy flares, RF decoys, or similar non-explosive expendables.
4.3.2 Foreign Materials Exploitation	Foreign materials exploitation tests evaluate foreign electronic weapons systems with the intent of identifying vulnerabilities and developing techniques to exploit them. These tests may involve the transmission of high power RF energy, and/or the release of chaff, IR decoy flares, RF decoys, or similar non-explosive expendables.
4.3.3 Intelligence Surveillance, and Reconnaissance (ISR)	ISR involves actions taken to collect/intercept, identify, locate, and analyze electromagnetic transmissions to inform the EW community of current and future threats for purposes of targeting, planning, conduct of future operations, and other tactical actions such as threat avoidance and homing. Information gathered through ISR is also used for EW reprogramming efforts.

Table A-2: Test Flights, Continued

Activity Name	Activity Description
4.3.4 Radar Warning Receivers	Radar warning receiver tests evaluate the effectiveness of warning receivers that are designed to detect threats such as incoming missiles, targeting radar, jamming, and other offensive threats. These tests may involve the transmission of high power RF energy.
4.4 Radar Cross Section and Infrared Signature Measurement	RCS and IR measurement tests involve flight and static ground tests to measure aircraft RCS and IR signatures. These tests are designed to document the vulnerability of an aircraft to detection and targeting by enemy weapon systems. Test articles may include full-scale aircraft, aircraft models, or various subsystems that are installed on aircraft. RCS measurement is a typical test associated with EP. The RCS measurement facility conducts ground-to-air RCS, jamming-to-signal ratio, and chaff measurements relative to aircraft, towed targets, and decoys. The Patuxent River IR Signature Measurement facility conducts surface-to-air and surface-to-surface IR signature measurement of aircraft, missiles, engines, and boats. Both RCS and IR signature tests may involve the transmission of high power RF energy.
5.0 Operational Tests	VX-1 operational aircraft test and evaluate airborne anti-submarine warfare and maritime anti-surface warfare weapon systems, airborne strategic weapons systems, as well as support systems, equipment, and materials.

Key: E^3 = electromagnetic environmental effects; EA = electronic attack; EP = electronic protection; ES = electronic warfare support; EW = electronic warfare; NAS = Naval Air Station; IR = infrared; ISR = intelligence, surveillance, and reconnaissance; RCS = radar cross section

A.2.1.2 Training Flights

Training flights primarily support tenant squadron training (including United States Navy Test Pilot School [USNTPS] test pilot training) as well as unit level training by transient aircraft. These activities are described in Table A-3. Intermediate and advance level training events conducted offshore are also supported by NAWCAD; however, only a small amount of these activities actually occur within the PRC. This support may include target presentation, instrumentations, range surveillance and clearance, telemetry relay, BQM aerial target launch, transient flight authorization, refueling services, and aircraft parking.

Table A-3: Training Flights

Activity Name	Activity Description
	Tenant Training
Aircrew Proficiency Flights*	Aircrew proficiency flights are performed by pilots and aircrew to: familiarize aircrew with new aircraft; complete Naval Aviation Training and Operating Procedures Standardization check flights; demonstrate ability to navigate; conduct instrumented approaches; fly with night vision and other devices; refresh test techniques; practice air combat maneuvering; train enlisted aircrew; maintain search and rescue helicopter skills; rehearse low-level flying; practice helicopter landings in sloped areas or confined landing zones; perform formation flying and tanker practice; and maintain aircrew proficiency in other critical areas.
Field Carrier Landing Practice*	Field Carrier Landing Practice flights are performed on a runway equipped to simulate an aircraft carrier flight deck to familiarize pilots with carrier landings. Flights must be conducted under both daytime and nighttime conditions and may support testing or training events. These flights are performed in close proximity to the airfield and below 3,000 feet.
	Tenant Training
USNTPS Flights	USNTPS flights train experienced U.S. and foreign military pilots, flight test engineers, and flight officers in the processes and techniques of aircraft and systems test and evaluation. The school graduates two classes annually (11 months each) with a syllabus divided into three parts including fixed-wing, rotary-wing, and airborne systems. The syllabus requires students to become familiar with flying a wide variety of aircraft, with a fleet of approximately 46 aircraft of 14 different platform types within the squadron. The school also offers condensed two-week short courses for the developmental flight test community. Flights include: all those for the technical training syllabus; practice of flight test techniques; demonstration of flight characteristics; student familiarization and qualification; USNTPS short courses; developmental test training; and all other USNTPS training flights.

Table A-3: Training Flights, Continued

Activity Name	Activity Description
Transient Training	
Transient Training flights	Transient aircrew train in unit level skills such as aircrew proficiency, field carrier landing practice, EW, weapons integration and separation (e.g., bomb drops or missile/gun/rocket firings), simulated air-to-air combat, and other tactical training tasks. May involve the release of non-explosive munitions or other military expended materials.

Key: * = May also be performed by transients; USNTPS = United States Naval Test Pilot School

A.2.1.3 Other Flights

Other flights are described in Table A-4 and include those conducted by tenant squadrons that have a support or operational function. A large portion of cross-country, mission of state, and strategic communications flights are flown outside of the PRC. However, the portions of flight hours within the PRC are included to capture all tenant squadron activity and ensure comprehensive analysis.

Table A-4: Other Flights

Activity Name	Activity Description
Support Flights	NTWL aircraft provide support needed to successfully accomplish a testing or training event. Flights include in-flight refueling, safety/photo chase, logistics, cooperative target and threat simulation, range surveillance, or other unique services.
Cross-Country Flights	Flown to transport equipment, material, and/or personnel to and from NAS Patuxent River in support of testing, training, or basekeeping operations. Enable pilots to achieve flight hours required to maintain qualifications. Examples include aircraft repositioning; detachment support flights; logistics flights; cross-country training flights; personnel shuttle flights; and aircraft ferry flights.
Functional Check Flights	Conducted to determine whether the airframe, propulsion, accessories, and equipment are functioning in accordance with predetermined standards when subjected to the intended operating environment. Performed after certain phase inspections; engine system installation or reinstallation; flight control surface component replacement; altitude system component adjustment/replacement; and any time the aircraft has not flown for 30 days or more regardless of the reason.
Mission of State Flights	Unmanned aerial systems (e.g., MQ-4C Triton) perform post hurricane surveillance involving high-altitude and meteorological surveys in support of post-disaster relief efforts.
Search and Rescue Flights	Search and rescue helicopters (MH-60) locate and recover military or civilian personnel injured or lost during a testing, training, or non-military event. May involve the release of marine markers as surface reference points to locate/mark survivors.
Strategic Communications Flights	VQ-4 aircraft (E-6B) conduct operational patrols to provide airborne command posts and strategic communications relays.
Scientific Development Flights	VXS-1 aircraft execute airborne science and technology projects such as bathymetry, electronic countermeasures, gravity mapping, and radar development.

A.2.2 Ground-Based Activities

Ground-based activities include those related to aircraft flights or conducted in ground test facilities and laboratories. Ground-based activities related to aircraft flights are described in Chapter 2 (Proposed Action and Alternatives). Ground test facility and laboratory tests include non-flight research and development, aircraft and weapons systems component testing, and modeling and simulation activities. Primary research and development and product areas include: materials, fuels, and lubricants; aircraft weapons certification; electromagnetic effects; EW systems; static engine runs; human-aircraft interface (i.e., human factors); communications systems; and computer-based simulations (U.S. Department of the Navy, 1998). Although most tests occur indoors, some ground test facilities and laboratories have outdoor test environments. These include the representative types (organized by test function) described in Table A-5. Although non-flight or laboratory-based testing can serve as a major supplement to a flight test program, it cannot replace actual flight testing (U.S. Department of the Navy, 1998).

Table A-5: Ground Test Facility and Laboratory Testing

Ground Test Facility/ Laboratory Name	***Description***
Propulsion Facilities	
Open-Air Engine Test Cell Facility*	Primarily developed for testing jet engine test cell instrumentation and control systems. Contains nine test cells including one T-26, one Turboprop Test Instrument, two shaft engine test instrumentation, two T-36 jet engine test instrumentation, and three T-24 test cells. Tests evaluate the functionality and suitability of portable engine test cells, sound suppression devices, or other related engine maintenance hardware, and determine if engines meet the standards for issue and installation into aircraft. Jet engine maintenance runs are limited to mission-critical situations when the primary enclosed maintenance test cell facility (T-10) at NAS Patuxent River is unavailable for extended periods of time.
Aircraft Subsystem and Weapons Certification Facilities	
Armament Test Area*	An operational range area where weapons systems ground testing has been conducted since 1943. Consists of 30 acres of restricted land and 75 yards of prohibited waters extending from the NAS Patuxent River shoreline. Facilities include a gun-firing tunnel, rocket test stand, two munition drop test pits, helicopter missile launch pad, and an aerial target launch area. Test activities include aircraft gun-firing; munition drop tests; aerial target launching; weapons compatibility and certification testing (bombs, missiles, rockets, chaff, flare, and cartridge and propellant actuated devices); and occasional use of a cockpit escape system test rig. Gun ammunitions are fired into the gun-firing tunnel from a test stand or fastened aircraft. Aerial targets, rockets, and missiles are launched into the Chesapeake Bay Water Range. An example weapons compatibility test may evaluate the release or launch mechanisms of new bomb racks or rocket launchers to be integrated with aircraft.
Aircraft Systems Integration Facilities	
Air Combat Environmental Test and Evaluation Facility**	A complex with a variety of facilities and laboratories that, when networked, can simulate virtually all aspects of aircraft operations and actual combat conditions through use of state-of-the-art simulation and stimulation techniques. Facilities and laboratories include: Manned Flight Simulator; Shielded Hanger; Warfare Simulation Laboratory; Threat Air Defense Laboratory; EW Integration Systems Test Laboratory; Communication, Navigation, and Identification Laboratory; Modern Communications Lab; Radar Lab; Advanced Systems Integration Laboratory; Aircraft Anechoic Test Facility; Electro Optical/Infrared Lab; Unmanned Air Systems Integration Lab; Warfare Simulation Lab; and Electromagnetic Effects Environmental Facilities.
Communications and Navigation Systems Facilities	
Communications Test and Evaluation Facility**	Performs fixed- and rotary-wing aircraft evaluation of high frequency, electronic counter-countermeasures communications and antenna systems. Also supports joint interoperability tests with U.S. Air Force and Army electronic counter-countermeasures communication systems. Has an unobstructed, over-the-water test environment that is only limited by line-of-sight propagation conditions.
Radar Facilities	
Facilities for Antenna and Radar Cross Section Measurement**	Consists of two anechoic chambers, three outdoor test ranges, and a rain erosion/impact measurement laboratory. Provides research and development engineering support for antenna technology from the concept phase through system integration. Exploratory and advanced research programs and antenna design, fabrication, and measurements are also conducted.

Table A-5: Ground Test Facility and Laboratory Testing, Continued

Ground Test Facility/ Laboratory Name	*Description*
Electromagnetic Radiation Facilities	
Electromagnetic Pulse Test Facilities**	Simulates the effects of nuclear electromagnetic pulse to conduct active and passive tests on avionics equipment and weapon systems electronics. Tests determine the survivability and electromagnetic pulse vulnerability of aircraft systems and subsystems.
Naval Electromagnetic Radiation Facility**	Simulates worldwide and Fleet operational electromagnetic environments to evaluate their effects on aircraft vehicle systems, critical functions, and mission systems. Supports military and commercial aircraft, ground support equipment, and air-launched munition systems testing.
Electromagnetic Interference Laboratory**	An outdoor, mobile, radiated susceptibility site that identifies potential electromagnetic environmental effect problems at the platform level. Provides Fleet support in areas of electromagnetic compatibility engineering analysis, component troubleshooting and correction, electromagnetic interference consultation, and correlation of specifications and limits to changing electromagnetic environmental effect environments.
Electromagnetic Effects Environmental Facilities**	Part of the Air Combat Environmental Test and Evaluation Facility. Performs electromagnetic compatibility and P-static testing on aircraft, weapons systems, and components. Uses high voltage and high amperage generators to test the effects of and protection from lightning strikes. Capabilities include: Military Standard 461/464 testing; electromagnetic interference detection; mobile electromagnetic compatibility; electromagnetic vulnerability; electromagnetic pulse; hazards of electromagnetic radiation to ordnance; directed energy weapons testing; and safety-of-flight testing.

Key: * = Conducts Open-Air Testing; ** = Emits Electromagnetic Radiation

A.2.3 Surface and Subsurface Activities

Surface and subsurface activities include support activities performed by NAWCAD Atlantic Targets and Marine Operations (ATMO) range support boats, as well as surface and subsurface testing and training conducted by non-NAWCAD combatant and patrol craft and unmanned maritime systems (UMS). Range support boat activities are described in Chapter 2 (Proposed Action and Alternatives). Table A-6 further describes surface and subsurface testing and training.

Table A-6: Surface and Subsurface Testing and Training

Activity Name	*Activity Description*
Testing Activities	
Surface Vessel Tests	Evaluate the performance and handling characteristics of prototype boats (e.g., hovercraft), combatant craft, amphibious vehicles, or scale models with advanced hull designs. May also include high-speed vessel test demonstrations.
Subsurface Vehicle Tests	Evaluate the performance and handling characteristics of unmanned underwater vehicles, their ability to operate autonomously, or their integration and interoperability with other manned or unmanned systems. Tests do not normally focus on the subsurface vehicle itself, but rather on various sonar and sensor packages integrated into the platform for a specific function.
Watercraft Detection and Disabling Tests	Assess methods for detecting and disabling small watercraft that could be used by hostile forces. Tests evaluate maritime technologies and products (e.g., electronics, radio and communication devices, personal safety equipment, and surveillance tools), signature measurements, watercraft identification and disabling devices, warning shot effectiveness, and weapon systems firing. Tests may involve the release of non-explosive munitions (e.g., gun ammunitions and missiles) or other military expended materials.
Training Activities	
Small Boat Training	Provides opportunities for crewmembers to test combat weapon systems, maintain proficiency, and train in realistic environments. Small boat crews train in unit level skills such as surface navigation, evasive tactics, or surface-to-surface gunfire; and therefore, may involve the release of gun ammunitions.

A.2.4 Mine Countermeasure Systems Testing

MCM systems testing demonstrates the capability and effectiveness of integrating and deploying mine detection and neutralization systems into and from manned and unmanned air, surface, and subsurface platforms. MCM systems fall into two broad categories including mine detection and mine neutralization.

A.2.4.1 Mine Detection Systems

Mine detection systems are used to locate, classify, and map mine shape targets on the surface, in the water column, or on the seafloor. Systems may be airborne, towed, or hull-mounted devices, or an unmanned underwater vehicles (UUV) or remotely operated vehicles (ROV) with acoustic, optical, laser and/or radar sensors. Representative mine detection systems include the airborne laser mine detection system (ALMDS), coastal battlefield reconnaissance and analysis (COBRA) system, and towed unmanned submersible (TUMS) system. Dipping sonar systems and sonobuoys may also be used for mine detection.

Airborne Laser Mine Detection System. The AN/AES-1 ALMDS is a mine hunting system designed to detect, classify, and localize floating and near-surface, moored sea mines using a low energy laser (i.e., streak tube imaging light detection and ranging). The system is integrated with a helicopter, such as the MH-60, to provide rapid, wide-area reconnaissance and assessment of mine threats. ALMDS also provides mine geo-location to follow-on neutralization systems. Figure A-1 illustrates an ALMDS testing scenario.

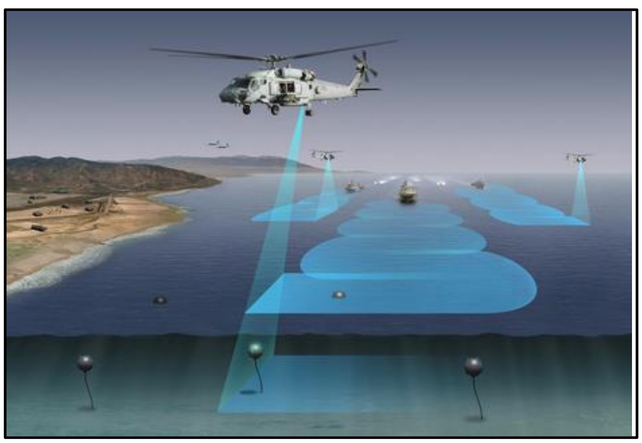

Figure A-1: Airborne Laser Mine Detection System

Coastal Battlefield Reconnaissance and Analysis System. The AN/DVS-1 COBRA system conducts unmanned aerial tactical reconnaissance in the littoral environment using optical sensors to detect and localize mines and obstacles in the surf zone and beach zone. The system is typically carried on the MQ-8 Fire Scout. Figure A-2 illustrates a COBRA testing scenario.

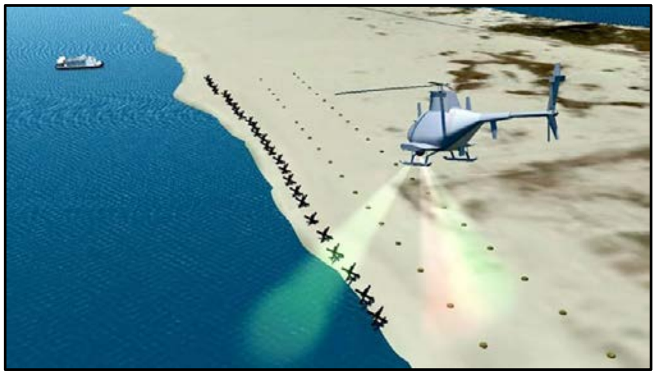

Figure A-2: Coastal Battlefield Reconnaissance and Analysis System

Towed Unmanned Submersible System. The TUMS system is a unique unmanned deep-sea submersible vehicle capable of operating in depths beyond the reach of conventional diving systems or ship sensors. The system performs a wide range of search, identification, classification, and recovery operations at full ocean depths using optic, acoustic, and magnetic sensors as well as a manipulator arm.

A.2.4.2 Mine Neutralization Systems

Mine neutralization systems are used to disrupt or disable mine targets. Systems include towed devices or UUV that may: deploy neutralizing vehicles with armor-piercing munitions to neutralize targets; generate acoustic or magnetic ship signatures to trigger or disable targets; or employ mechanical systems (e.g., cable cutters) to detach moored mine targets so they float to the surface for dispatch. Representative mine neutralization systems include the airborne mine neutralization system (AMNS) and in-water electromagnetic systems including the organic airborne and surface influence sweep (OASIS) system and magnetic orange pipe (MOP).

Airborne Mine Neutralization System. The AN/ASQ-235 AMNS deploys up to four UUV from a launch and handling system supported from the MH-60S helicopter. UUV are equipped with sonar, video camera, light, and non-explosive neutralizers to locate and neutralize moored and bottom mines. The fiber optic cables connecting the UUV to the handling system are typically expended during testing. Figure A-3 illustrates an AMNS testing scenario.

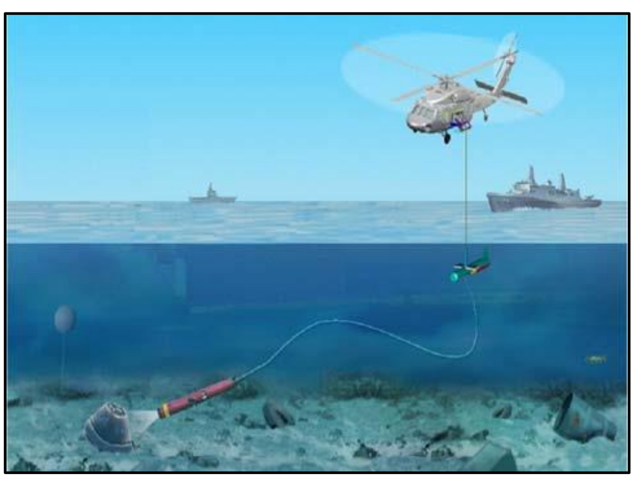

Figure A-3: Airborne Mine Neutralization System

Organic Airborne and Surface Influence Sweep. The OASIS system (Figure A-4) is a high-speed, magnetic and acoustic influence sweep system that is towed by a surface vessel or UUV to neutralize sea mine threats in areas where mine hunting is not possible due to mine burial or high bottom clutter. Sweeps are conducted over test areas containing tethered and/or totally buried mine-shapes to demonstrate the system's effectiveness to influence or trigger the magnetic mine targets.

OASIS emits an electromagnetic field equivalent to 2,300 microteslas (a measure of magnetic intensity). Forward and aft electrodes generate the magnetic signature, which is engaged after deployment and disengaged prior to recovery and captive carriage. A water-driven acoustic generator creates the acoustic energy that mimics a ship's signature. Historically, all MCM systems tests in the PRC Study Area have been non-magnetized events.

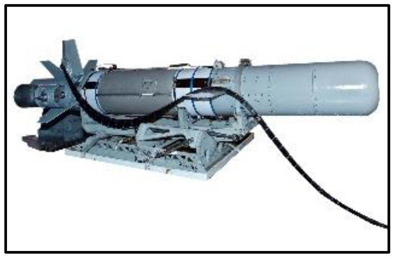

Figure A-4: Organic Airborne and Surface Influence System

Magnetic Orange Pipe. The MOP (Figure A-5) is a 30-foot, 1,000 pound, 10 3/4-inch diameter orange pipe filled with polystyrene foam. The pipe is given a magnetic charge before each sweep mission and if desired can be coupled with a mechanical acoustic generating device (i.e., MK-2(g) Rattle Bars) capable of actuating acoustic mines.

Figure A-5: Magnetic Orange Pipe

A.2.5 Anti-Submarine Warfare Systems Testing and Training

ASW warfare testing within the PRC evaluates the integration, deployment, and operation of helicopter dipping sonar systems. Tests assess sonar system software and hardware upgrades as well as weapons that operate in concert with the system (e.g., sonobuoys). Aircrew also conduct proficiency training on the sonar operation and practice helicopter hovering while the sonar transducer is deployed, maintained at depth, and recovered. A photograph of helicopter dipping sonar is shown in Figure A-6.

Figure A-6: Helicopter Dipping Sonar

Dipping sonar and sonobuoys may be active (sound emitting) or passive (listening only) to allow for short- and long-range target detection during an event. All sounds, including sonar, are categorized by frequency. When active, sonars emit a ping and then rapidly scan or listen to the sound waves in the surrounding area. This provides both distance to the targets as well as directional information. Sonar pings occur at intervals, referred to as duty cycles; the signals themselves are very short. For example, a sonar emitting a 1 second ping every 10 seconds has a 10 percent duty cycle. Consequently, active sonar is rarely used continuously throughout a testing or training event.

Representative types of ASW systems include the AN/AQS-22 dipping sonar and Directional Command-Activated Sonobuoy (DICASS). When active, both systems operate in the mid-frequency range of 1–10 kilohertz.

The AN/AQS-22 sonar is the Navy's latest mid-frequency active dipping sonar and one of the primary systems needed to perform the ASW mission. The AN/AQS-22 sonar has improved detection capabilities over previous dipping sonar systems and more readily counters the current and emerging ASW threat posed by submarines in the littoral (shallow water) environment.

The DICASS operates under direct command from a helicopter or ASW fixed-wing aircraft and can be deployed to various depths within the water column. Once deployed, DICASS determines the range and bearing of a subsurface target relative to the sonobuoy's position. After water entry, the sonobuoy transmits sonar pulses (continuous waveform or linear frequency modulation) upon command from the aircraft. The echoes from the active sonar signal are processed in the buoy and transmitted to the receiving station onboard the launching aircraft.

A.2.6 Unmanned Systems Testing and Training

Tests unique to unmanned systems are described in Table A-7. Types of unmanned air, maritime, and ground systems are discussed in Sections A.3.1.1, A.3.2.2, and A.3.3.1 respectively.

Table A-7: Unique Unmanned Systems Tests

Activity Name	*Activity Description*
Integration and Interoperability Tests	Ensure different types of unmanned systems, when deployed together, can collaborate and operate in synergy to execute tasks and achieve a common mission. Tests focus on the interoperability between system controls, automation, communications, data products, and data links. Demonstrate interoperability among platforms built by different manufacturers and operated by United States military services, foreign allies, and other United States agencies.

Table A-7: Unique Unmanned Systems Tests, Continued

Activity Name	*Activity Description*
Teaming Tests	Develop and demonstrate the ability of manned and unmanned systems to cooperatively execute and achieve common mission objectives such as anti-submarine warfare, strike, and intelligence, surveillance, and reconnaissance. Manned-unmanned systems teams work together to collect, process, exploit, and disseminate data.
Autonomy Tests	Asses the ability of an unmanned system to operate effectively with limited or no human intervention. Tests range from human delegated, to human supervised, to fully autonomous levels. Fully autonomous systems do not require outside control, but rather are governed by embedded logic that directs their behavior. Tests evaluate the full range of behaviors that might emerge in simulated and real world environments.
Counter-UAS	Determine the effectiveness of counter-UAS technologies designed to detect, track, identify, and mitigate potential UAS threats. Threats are detected by employing sensors (electro-optical, IR, acoustic, or radio frequency) or radar systems individually or in combination. Once detected, UAS may be engaged or disabled using EW jamming devices to interfere with the communications link to its operator. Other electronic strikes are intended to seize operational control of the UAS. UAS can also be destroyed or neutralized using traditional air defense systems, gun ammunitions, physical deterrents or barriers, or directed energy weapons.

Key: IR = Infrared; UAS = unmanned aerial systems

A.2.7 Lasers Systems

Laser classes 1-4 are used within the PRC. Definitions for each class are provided in Table A-8.

Table A-8: Laser Classes

Laser Class	*Class Description*	*Energy Emitted*	*Safety Issues*	*Examples*
Class 1*	Low powered devices considered safe from all potential hazards	N/A	No injury, regardless of exposure time, to eyes or skin. No safety measures necessary.	Laser printers, toys, compact disc players, compact disc read-only memory devices, laboratory analytical equipment
Class 2*	Low power, visible light lasers that could possibly cause damage to a person’s eyes	< 1 milliwatt (mW)	Usually safe. Eye protection normally afforded by the aversion response (turning away from a bright light source or closing or blinking eyes). If directly viewed for long periods of time with no blinking, damage to eyes could result.	Pointers used in presentations, toys, range finding equipment, aiming devices
Class 3**	Medium Power	< 500 mW	May be hazardous to eyes under direct and specular reflection (almost perfect reflection such as a mirror) viewing conditions, but is normally not hazardous.	Laser scanners, military hand-held laser rangefinders, entertainment light shows, target illuminators

Table A-8: Laser Classes, Continued

Laser Class	*Class Description*	*Energy Emitted*	*Safety Issues*	*Examples*
Class 4	High Power	> 500 mW	Direct beam or specular reflection is hazardous to eyes and skin. May pose a diffuse reflection hazard (reflected off an imperfect reflective surface) or fire hazard. May produce air pollutants.	Medical surgery, research, drilling, cutting, welding, aircraft target designator used for guided weapons, military laser weapons

Source: American National Standards Institute (2007)
KEY: mW = milliwatt; N/A = not applicable.
* Class 1M and 2M categories also exist, which have the same parameters as above, except that direct viewing with an optical instrument such as a telescope could be potentially hazardous.
**Two subcategories exist under Class 3: Class 3R lasers are potentially hazardous if the eye is appropriately focused and stable, but probability of injury is low; energy emitted is < 5 mW. Class 3B may be hazardous under direct and specular reflection viewing conditions; energy emitted is < 500 mW.

A.3 Testing and Training Assets

Testing and training activities conducted within the PRC may use a variety of air-, water-, and land-based assets as well as non-explosive munitions and other expendables.

A.3.1 Air-Based Assets

Air-based assets include types of aircraft and aerial targets.

A.3.1.1 Aircraft

Aircraft are categorized according to their design and operational characteristics as fixed-wing jet, fixed-wing propeller, rotary-wing (including tiltrotor), or unmanned aerial systems (UAS). Example platforms for each category are shown in Table A-9. This table is not all-inclusive but represents the primary platforms flown by tenant squadrons and transients that generated the majority of flight hours being analyzed in this EIS. Future platforms projected to be tested within the PRC are also indicated. Although aircraft models, series, and variants may change, the four broad category types remain the same. Therefore, for the purpose of analysis, the F/A-18E/F, C-12, UH-60A, and T-34 (UAS surrogate) have been chosen as representative platforms for each aircraft category respectively.

Table A-9: Example Aircraft Types and Platforms

Aircraft Type	*Aircraft Platform*	
Manned Systems		
Fixed-Wing Jet	A-10 Thunderbolt⁺ BAC-111 Jet Airliner⁺ C-21 Learjet C-38 Courier CRJ-700 Bombardier⁺ E-6 Mercury E/A-18 Growler F/A-18 Hornet/Super Hornet	F-16 Fighting Falcon⁺ F-22 Raptor⁺ F-35 Lightning II Joint Strike Fighter F/A-XX* P-8 Poseidon Sabreliner⁺ T-38 Talon T-45 Goshawk

Table A-9: Example Aircraft Types and Platforms, Continued

<table>
<tr><th>Aircraft Type</th><th colspan="5">Aircraft Platform</th></tr>
<tr><td>Fixed-Wing Propeller</td><td colspan="2">C-12 Huron
C-26 Metroliner
C-130 Hercules
Cessna+
E-2 Hawkeye/Advanced Hawkeye</td><td colspan="3">KC-130 Super Hercules
NP-3C Modified Orion
RC-12 Guardrail
T-6 Texan
U-6 Beaver</td></tr>
<tr><td>Rotary-Wing</td><td colspan="2">Future Vertical Lift*
H-1 Super Cobra/Iroquois
H-53 King Stallion/Sea Dragon
H-58 Kiowa
H-60 Seahawk/Blackhawk</td><td colspan="3">H-72 Lakota
TH-57 Sea Ranger
VH-92 Presidential Helicopter
V-22 Osprey (Tiltrotor)</td></tr>
<tr><td colspan="6">Unmanned Systems</td></tr>
<tr><td>Unmanned Aerial Systems</td><td><u>Group 1</u>
RQ-11 Raven
RQ-12 Wasp
RQ-20 Puma
XM-8 Quadcopter</td><td><u>Group 2</u>
Scan Eagle</td><td><u>Group 3</u>
RQ-7 Shadow
RQ-21 Blackjack
RQ-26 Aerostar</td><td><u>Group 4</u>
MQ-1 Grey Eagle
MQ-8 Fire Scout</td><td><u>Group 5</u>
MQ-4Triton
MQ-25 Stingray*</td></tr>
</table>

Key: + =Transient Aircraft Only; * = Future Projected Aircraft

UAS are categorized into five groups based on weight, operating altitude, and speed (Table A-10). These attributes allow categorization without respect to UAS mission, propulsion type, or payload. Example UAS types for each group size are provided in Table A-11.

UAS may be air- or ground-launched using conventional (i.e., launched under their own power) or unconventional means (i.e., requires assisted take off). UAS Groups 1 and 2 are typically launched on-range or use unconventional take-off systems such as catapults, slingshots, or by hand. In addition, these UAS may be launched from platforms such as aircraft, surface and subsurface vessels and platforms, vehicles, or tethering towers. Recovery methods may include conventional landing, vertical/short takeoff and landing, net, wire, arresting gear, dirt strip, or intentional crash. UAS Groups 3 through 5 typically use established airfields and runways for take-off and landing; some Group 4 and 5 UAS flights may require chase aircraft.

In addition, lighter-than-air systems, such as airships and aerostats, are a subset of UAS that have been historically used for military surveillance and anti-submarine warfare. Unlike fixed- or rotary-wing aircraft, aerostats and airships typically use helium to stay aloft and therefore, the classifications provided in Table A-10 do not apply. Airships use engines to fly whereas aerostats are tethered to the ground by a cable that also provides power.

Table A-10: UAS Groups

<table>
<tr><th>UAS Group</th><th>Maximum Gross Takeoff Weight (lbs.)</th><th>Normal Operating Altitude (feet)</th><th>Speed</th></tr>
<tr><td>Group 1</td><td>0-20</td><td>< 1,200 AGL</td><td>< 100 knots</td></tr>
<tr><td>Group 2</td><td>21-55</td><td>< 3,500 AGL</td><td rowspan="2">< 250 knots</td></tr>
<tr><td>Group 3</td><td>< 1,320</td><td rowspan="2">< 18,000 MSL</td></tr>
<tr><td>Group 4</td><td rowspan="2">> 1,320</td><td rowspan="2">Any Airspeed</td></tr>
<tr><td>Group 5</td><td>> 18,000 MSL</td></tr>
</table>

Source: Joint Unmanned Aircraft Systems Center of Excellence (JUAS COE) CONOPS, Joint Concept of Operations for Unmanned Aircraft Systems, Version 1.5.

Key: *AGL = Above Ground Level *MSL = Mean Sea Level

Table A-11: Example UAS Types

UAS Group	***Example Platform***	
UAS Group 1	 **RQ-20 Puma**	 **RQ-11 Raven**
Group 2	 **Scan Eagle**	 **Silver Fox**
Group 3	 **RQ-21A Blackjack**	 **RQ-7B Shadow**
Group 4	 **RQ-1 Predator**	 **MQ-8B Fire Scout**

Table A-11: Example UAS Types, Continued

UAS Group	*Example Platform*	
Graoup 5	 **MQ-4C Triton**	 **MQ-25 Stingray**

A.3.1.2 Aerial Targets

Aerial targets include towed banners and unmanned air platforms ranging from small hand-launched UAS, to aerial target drones, to full-scale aircraft. Targets may be augmented with various components (e.g., radio frequency, IR, or other electromagnetic or visual features) to meet testing or training requirements. Larger aerial targets, such as full-scale aircraft, serve as visual and radar targets only. Representative types of aerial targets are depicted in Table A-12. The BQM-74E is being replaced by the BQM-177A as the Navy's next generation subsonic aerial target drone. BQM targets require jet-assisted takeoff bottles for launch.

Table A-12: Example Aerial Target Types

Aerial Target	*Description*	*Photo*
BQM-74E	– A subscale, subsonic aerial target designed to simulate tactical threats by enemy aircraft and missiles – 13 feet long, 6 feet wingspan – Speed of 240-540 knots – 240 pounds, 749 pounds at launch – Williams J400-WR-404 Jet Engine	
BQM-177A	– A high-subsonic, sea-skimming anti-ship cruise missile threat target – 20 feet long, 10.5 feet wingspan – Capable of speeds in excess of 0.95 Mach – Sea-skimming altitude as low as 10 feet – Carries a suite of payloads to meet mission requirements	

Table A-12: Example Aerial Target Types, Continued

Aerial Target	*Description*	*Photo*
Potensic T25 Quadcopter	– A small remotely operated aerial system used as a target – Body measures 10.6 x 10.6 x 4.7 inches across the 3 axes – 4 pounds (including the attached camera) – 4 spinning rotors to generate lift – 984 feet signal range for drone control – 394 feet maximum flying height – Maximum speed of 15.5 miles per hour – Flight time up to 10 minutes per battery	

A.3.2 Water-Based Assets

Water-based assets include types of vessels, UMS, and surface and subsurface targets.

A.3.2.1 Vessels

Vessels include range support boats, operated by the NAWCAD ATMO Division, and combatant and patrol craft, operated by non-NAWCAD organizations such as the Naval Sea Systems Command and U.S. Coast Guard. Vessels are categorized by size as small (less than 50 feet), medium (50-100 feet), or large (greater than 100 feet but not usually exceeding 400 feet).

Table A-13 provides the operational characteristics of the current ATMO fleet. ATMO may also periodically contract or procure other boat types of similar size and performance. Representatives are noted for each size category and were chosen for analysis based on highest historical use. Table A-14 provides representative types of combatant and patrol craft for each size category. Types of amphibious vehicles are also included; however, they are not frequently used and do not operate on land within the PRC.

Table A-13: ATMO Range Support Boats

Range Support Boat	*Description*	*Photo*
SMALL (Less than 50 feet)		
Fountain Boat*	– Length: 38 feet – Speed: 57+ knots – Weight: 10,600 pounds – Propulsion: Three Mercury 300 gasoline engines; 300 Horsepower each – Manned only – Used as a range support boat or mobile target	

Table A-13: ATMO Range Support Boats, Continued

Range Support Boat	***Description***	***Photo***
Rigid Hull Inflatable Boat	– Length: 28 feet – Speed: Max of 45 knots – Weight: 4,000 pounds – Propulsion: Two Mercury outboard gasoline engines; 200 Horsepower each – Manned and remote controlled – Used as a range support boat, mobile target, or to tow targets	
	MEDIUM (50 to 100 feet)	
Patrol Boat-777*	– Length: 65 feet – Speed: Max of 30 knots – Weight: 32 tons – Propulsion: Three GM 8V92 diesel engines; 650 Horsepower each – Manned only – Used as a range support boat or mobile target	
Prince	– Length: 53 feet – Speed: Max of 17 knots – Propulsion: Four 496 8.1 liter diesel engines; 370 Horsepower each – Manned only – Used as a range support boat or mobile target	
QST-35A SEPTAR	– Length: 56 feet – Speed: Max of 25 knots – Propulsion: Four Mercruiser gasoline engines; 370 HP each – Fiberglass, reinforced plastic hull – Manned and remote controlled – Used as a range support boat, mobile target, or to tow targets	

Table A-13: ATMO Range Support Boats, Continued

Range Support Boat	*Description*	*Photo*
QST-35B SEPTAR	– Length: 58 feet – Speed: Max of 30 knots – Propulsion: Two Detroit MTU series 60 diesel engines; 750 Horsepower each – Fiberglass, reinforced plastic hull – Manned and remote controlled – Used as a range support boat, mobile target, or to tow targets	
	LARGE (Greater than 100 feet)	
Navy Relentless*	– Length: 145 feet – Speed: 10 knots – Propulsion: Two Caterpillar 3508B diesel engines; 805 Horsepower each – Manned only – Used as a range support boat	

Key: SEPTAR = Seaborne Powered Target
* = Representative for Size Class

Table A-14: Example Combatant and Patrol Craft

Combatant and Patrol Craft	*Description*	*Photo*
	SMALL (Less than 50 feet)	
Rigid Inflatable Boat*	– Length: 35 feet, 11 inches – Speed: 40+ knots – Weight: 17,400 pounds Propulsion: Two Cummings Engines; 400 Horsepower each	

Table A-14: Example Combatant and Patrol Craft, Continued

Combatant and Patrol Craft	*Description*	*Photo*
Amphibious Combat Vehicle	– Length: 29 feet – Speed: 7-25 knots – Weight: 67,500-7,280 pounds (depending on load) – Propulsion: Single engine; 690 Horsepower – Replacing the Advanced Amphibious Assault Vehicles	
MEDIUM (50 to 100 feet)		
Mark V Patrol Boat*	– Length: 82 feet – Speed: 65 knots – Weight: 57+ tons - Propulsion: Two MTU 16V2000M94 Engines; 2,660 Horsepower each	
Landing Craft Air Cushion	– Length: 92 feet – Speed: 40+ knots with full load – Weight:105-195 tons (depending on load) – Propulsion: 4-Allied-Signal TF-40 gas turbines (2 propulsion, 2 lift); 16,000 Horsepower sustained	
LARGE (Greater than 100 feet)		
Cyclone-Class Patrol Ship*	– Length: 179 feet – Speed: 35 knots – Weight: 331 tons Propulsion: Four 2,250 HP Paxman Engines	

*Representative for size class

A.3.2.2 Unmanned Maritime Systems

UMS can be defined as unmanned vehicles that displace water at rest and include unmanned surface vehicles (USV) and UUV. Both may be equipped with various sonar or sensor packages depending on test requirements. When operated remotely, mobile surface and subsurface targets may be considered a USV or UUV respectively.

USV operate with near-continuous contact with the surface of the water and fall within four size-based classes (Table A-15). Examples of USV are shown in Table A-16. UUV operate without necessary contact with the water surface but may need to be near the surface for communication purposes. Descriptions of UUV class are provided in Table A-17 and examples are shown in Table A-18. UUV also include ROV and bottom crawlers, which are boxed-shaped underwater robots versus typical torpedo-shaped UUV. ROV are unmanned but connected to a surface vessel or platform by cables and may include cameras, lights, sonar systems, and/or articulating arms for accomplishing mission tasks. Bottom crawlers are fully autonomous vehicles used in areas, such as shallow waters, where torpedo-shaped UUVs cannot effectively operate.

Table A-15: USV Classes

Vehicle Class	*Size*	*Description*
Class 1	**Very Small** (Length ≤ 7m)	Very Small USV, such as the Greenough Advanced Rescue Craft, focus on ISR, armed escort, and communications relay capabilities.
Class 2	**Small** (Length >7m and ≤12m)	Small USV, such as the Mine Countermeasures USV, focus on mine hunting, mine sweeping, mine neutralization, ISR, ASW, counter piracy, and communications relay capabilities.
Class 3	**Medium** (Length >12m and ≤ 50m)	Medium USV, such as the Sea Hunter, focus on ISR, armed escort, surface warfare, ASW, counter swarm, EW, mine countermeasures, and mining capabilities.
Class 4	**Large** (Length >50m)	Large USV, such as the Overlord, are being developed under the under the Ghost Fleet Program and focus on EW, ISR and targeting, anti-surface warfare, ASW, logistics, and payload carrying capabilities. Large USV will be fully autonomous and capable of conducting coordinated operations.

Source: Briefing by Captain Pete Small, Program Manager, Unmanned Maritime Systems (PMS 406), entitled "Unmanned Maritime Systems Update," January 15, 2019

Key: ASW = anti-submarine warfare; EW = Electronic Warfare; ISR = intelligence, surveillance, and reconnaissance; USV = unmanned surface vehicle

Table A-16: Example USV Types

USV Class (Example Platform)	
 **Class 1 Very Small USV (Greenough Advanced Rescue Craft)**	 **Class 2 Small USV (Mine Countermeasures USV)**

Table A-16: Example USV Types, Continued

USV Class (Example Platform)	
 **Class 3 Medium USV (Sea Hunter)**	 **Class 4 Large USV (Overlord)**

Key: USV = unmanned surface vehicle

Table A-17: UUV Classes

Vehicle Class	*Diameter (inches)*	*Launch Method*	*Description*
Small	>3 and ≤ 10	Surface or Submarine	Small UUV, such as the Sandshark, are man-portable and focus on MIW, IPOE, and battle space awareness capabilities.
Medium	>10 and ≤ 21	Surface or Submarine	Medium UUV, such as the Razorback, focus on MIW, IPOE, battle space awareness, and mine hunting capabilities.
Large	>21 and ≤ 84	Surface or Submarine	Large UUV, such as the Snakehead, focus on IPOE, ISR, extended range IPOE and ISR, EW, anti-surface warfare, anti-submarine warfare, and payload carrying capabilities.
Extra Large	> 84	Pier	Extra Large UUV, such as the Orca, may be autonomous and focus on ISR, EW, anti-surface warfare, anti-submarine warfare, MIW, mine countermeasures, payload carrying, and strike capabilities.

Source: Briefing by Captain Pete Small, Program Manager, Unmanned Maritime Systems (PMS 406), entitled "Unmanned Maritime Systems Update," January 15, 2019

Key: EW = electronic warfare; MIW = mine warfare; IPOE = intelligence preparation of the operational environment; ISR = intelligence, surveillance, and reconnaissance; UUV = unmanned underwater vehicle

Table A-18: Example UUV Types

UUV Class (Example Platform)	
 **Small UUV (Sandshark)**	 **Medium UUV (Razorback)**
 **Large UUV (Snakehead)**	 **Extra Large UUV (Orca)**

Key: UUV = unmanned underwater vehicle

A.3.2.3 Surface Targets

Surface targets are categorized as mobile (manned and unmanned), free floating or towed, or stationary (anchored). Table A-19 depicts example types for each target category and indicates representatives chosen for analysis based on highest historical use.

Mobile surface targets are propeller or impeller driven and range in size from 10 feet to 60 feet in length. When remote controlled, mobile surface targets are essentially types of USV. Mobile surface targets may be used to tow another target or be augmented with a sensor or emitter for detection or threat simulation. Mobile targets that also serve as range support boats are not expendable. Free floating or towed targets can be augmented with billboards or other items for weapons impact but are not used frequently within the PRC. These surface targets may be engaged with sensors, gun ammunitions, rockets, or other weapons systems.

Stationary surface targets are anchored to the seafloor or other objects to be visible at the water's surface. Examples include spar buoy, mine shapes, and moored rafts. Targets, such as the spar buoy, may be augmented with a radar reflector or other sensors. Moored rafts may be used for activities such as weapons delivery accuracy tests. Scenarios showing mine shape targets at the water surface and in the surf zone are depicted in Figures A-1 and A-2 respectively.

Table A-19: Example Surface Targets

Surface Target	***Description***	***Photo***
	Motorized Propeller	
High Speed Maneuverable Surface Target *	– Length: 29 feet – Speed: 40+ knots – Propulsion: Twin gas outboard engines, 200 Horsepower each – Rigid aluminum hull – Manned and remote controlled – Used as a mobile target (to simulate high speed enemy patrol boat) or to tow targets – Also used as a range support boat	
Fast Attack Craft Target	– Length: 50ft – Speed: 50+kts – Manned and remote controlled – Used as a mobile target – Also used as a support boat	
QST-35A (SEPTAR)	– Length: 56 feet – Speed: Max of 25 knots – Propulsion: Four Mercruiser gasoline engines; 370 Horsepower each – Fiberglass, reinforced plastic hull – Manned and remote controlled – Used as a mobile target or to tow targets – Also used as a range support boat	
QST-35B* (SEPTAR)	– Length: 58 feet – Speed: Max of 30 knots – Two Detroit MTU series 60 diesel engines; 750 Horsepower each – Fiberglass, reinforced plastic hull – Manned and remote controlled – Used as a mobile target or to tow targets – Also used as a range support boat	

Table A-19: Example Surface Targets, Continued

Surface Target	***Description***	***Photo***
	Motorized Impeller	
Ship Deployable Surface Target*	– Length: 10ft 10inches – Speed: 40+ knots – Propulsion: 4 stroke, 3 cylinder 155HP engine – Manned and remote controlled – Used as a medium to high speed target or to tow targets	
	Free Floating or Towed	
Catamaran Surface Towed Target (Super Cat)	– Length: 15 feet – Towed or free floating – Used for surface-to-surface and air-to-surface training in support of bombing, gunnery, and laser operations	
Improved Surface Towed Target	– Length: 29 feet – Fiberglass hull; mountable target augmentation systems – Towed or free floating target – Can be used for direct fire scenarios	
Inflatable Banana Target	– Length: 17 feet long, 2 feet diameter – Commercial ocean rider – Towed or free floating	
Low Cost Modular Target*	– Pontoon target – Size can me modified by removing and inserting pontoon sections	

Table A-19: Example Surface Targets, Continued

Surface Target	***Description***	***Photo***
Low Cost Towed Target	– Length: 15 feet – Weight: 750lbs – Fiberglass hull; mountable target augmentation systems – Towed or free floating	
PAX Pontoon Target	– Length: 16 feet – Low cost target – Towed or free floating	
Polyethylene Towed Target	– Length: 15 feet – Weight: 400lbs (base), 800lbs (with ballast) – Towable target at high speeds	
Squid	– Length: 135 inches – Wight: 350lbs (base), 500lbs (with ballast) – Unsinkable towed target – Easy to take apart and repair	
	Stationary/Anchored	
Spar Buoy*	– Bottom anchored static target on which a radar reflector can be placed	

Key: * = Representative for surface target category; SEPTAR = Seaborne Powered Target.

A.3.2.4 Subsurface Targets

Subsurface targets include mine shapes and UUV that are used as targets. Mine shapes may be anchored at various depths below the water's surface or on the seafloor bottom. Example scenarios using subsurface mine shape targets are shown in Figures A-1 and A-3. UUV targets may be stationary, self-propelled, or towed and serve as a visual, radar, or acoustic target. A representative example is shown in Table A-20.

Table A-20: Example Subsurface Target

Subsurface Target	***Description***	***Photo***
	Mobile	
Autonomous Mobile Periscope System	– UUV with target acoustic system and expendable mobile acoustic training target signaling capability – Designed to simulate submarine activity in a littoral environment – Equipped with a periscope that can be raised close to the surface or lowered to allow visual or acoustic detection	

A.3.3 Land-Based Assets

Unmanned ground systems (UGS) and land targets are types of land-based assets. Other land-based assets include ground test facilities and laboratories and other types of ground vehicles described in Section A.2.2 (Ground-Based Activities) and Section 2.1.3.3 (Land-Based Assets), respectively.

A.3.3.1 Unmanned Ground Systems

UGS are robotic platforms that are used as an extension of human capability. These robots are capable of operating indoors or outdoors and over a wide variety of terrain. UGS include both wheeled and tracked vehicles and are commonly used to complete tasks by functioning in place of humans. UGS are generally defined based on size (i.e., transportability) and mode of operation. The four types of UGS based on transportability are shown in Table A-21. These systems can range from a few pounds up to 700 pounds. UGS modes of operation are described in Table A-22.

Table A-21: UGS Types

UGS Type	***Description***
Soldier Transportable	Systems small enough to be transported by a single person.
Vehicle Transportable	Systems too heavy to be transported by a person, or too slow to keep up with formation.
Self-Transportable	Systems too heavy to be transported by a person, but fast enough to keep up with formation.
Appliqué	Systems that are optionally manned due to a "kit" applied to the system allowing it to operate without a driver in the seat.

Sources: Army 2011 and Army 2012

Table A-22: UGS Modes of Operation

UGS Type	*Description*
Tethered	A mode of control wherein the human operator controls the UGS through a direct, wired connection. An example of such connection would be a fiber optic cable. Typically line of sight (LOS) must be maintained under tethered operation; however, under certain circumstances, a LOS is not necessary (i.e., operation in tunnel, around corners, etc.).
Remote Controlled	A mode of control wherein the human operator must dedicate 100 percent of their attention to system operation without benefit of sensory feedback from the vehicle. A LOS must be maintained with the vehicle under remote control operation.
Teleoperated	A mode of control wherein the human operator has control of the UGS through cues provided by video, audio and digital feedback. The human operator controls the UGS through a wireless connection transmitted over radio frequencies. The human operator must dedicate 100 percent of their time to operating the UGS. A LOS does not necessarily need to be maintained under teleoperation.
Autonomous	A mode of control wherein the UGS is self-sufficient. The human operator can program a mission for the UGS, but the UGS would execute the mission without any human interaction. There are varying levels of autonomy in regards to the level of human interaction with the UGS.
Semi-autonomous	A UGS that has multiple modes of control occurring simultaneously to include at least one autonomously controlled function. The level of semi-autonomy can vary greatly between UGS systems.

Key: LOS = line of sight; UGS = unmanned ground system

A.3.3.2 Land Targets

Land targets may be stationary or mobile and consist of fixed target arrays, full-scale three-dimensional targets, and manned or remote-controlled vehicles. These targets are primarily used for visual targeting, laser designating, sensor testing, or tracking. No munitions are released on land targets.

Stationary land targets generally include instrumented target boards, mock tanks and military vehicles, anti-radiation or radar reflecting posts, and other land targets. Examples of stationary land targets are shown in Table A-23. Mobile land targets can be UGS or manned vehicles such as pick-up trucks, vans, Jeeps, and High Mobility Multipurpose Wheeled Vehicles. Land targets may also include natural or man-made land features that can be used as a target or reference point (e.g., Bloodsworth Island Range [BIR], airfields, runways, roads). These are typically used to test sensors with unique detection capabilities. Other land targets are designed to meet specialized test requirements, such as mine shapes placed to simulate a beach zone minefield (as seen in Figure A-2), or practice improvised explosive devices (IED) placed or buried to simulate explosive, biological, or chemical IED threats (Navy, 2019). Practice IEDs would contain no hazardous materials. Unique tests involving these types of targets occur only on occasion (once every several years), such as testing a new MCM system or demonstrating IED sensors at a science and technology event. Some land targets are semi-permanent features (e.g., radar reflecting posts), whereas others are temporarily placed and removed following events.

Table A-23: Example Stationary Land Targets

Land Target Description	*Photo*
– Full-scale, three demensional target – Low-cost, plastic armored vehicle – Can be augmented to include RF and IR systems and camouflage paint themes	
– Radar Reflectors on Posts	

Key: IR = infrared; RF = radio frequency

A.4 Non-Explosive Munitions and Other Military Expended Materials

The typical types of non-explosive munitions and other military expended materials (MEM) expended within the PRC include: bombs, mines, missiles, rockets, torpedoes, and gun ammunitions (small and medium caliber), as well as decoys (chaff and flares). A general description of each is provided below. Other MEM includes: marine markers, signal cartridges/spotting charges, sonobuoys, launchers/dispensers/pods, search and rescue rafts and recovery kits, AMNS munitions, cartridge and propellant actuated devices, and other miscellaneous items such as fuel tanks and mass equivalents (e.g., I-Beams, sleds, or concrete blocks used for heavy lift testing). These materials are less common and intermittently used within the PRC. Accessories, such as parachutes, endcaps, pistons, and wires, associated with munitions and other MEM, are listed in Appendix B (Military Expended Materials and Physical Disturbance and Strike Analysis).

Bombs. Bombs are unpowered munitions dropped from aircraft on Chesapeake Bay Water Range targets. Bombs fall into four categories including cluster bombs, general purpose bombs, guided bombs, and practice bombs.

- **Cluster Bombs:** A cluster bomb is delivered in the same manner as a conventional practice bomb. After release from the aircraft and during free-fall, a strip of small shaped charges (similar to a firecracker) fire and opens the bomb canister releasing about 245 non-explosive bomblets.

- **General Purpose Bombs:** General purpose bombs (MK-80 Series) used in the PRC are composed of a steel case containing concrete. These bombs are available with or without a guidance system. Those with guidance systems, also referred to as “smart bombs,” detect a target illuminated by a laser beam.

  The MK-80 Series general purpose bombs also can be modified by the addition of a Joint Direct Attack Munition (JDAM) guidance kit. Conversion of a general purpose bomb involves replacing the tail section with the JDAM guidance kit. This guidance kit contains a global positioning system/inertial guidance system unit to improve the accuracy of bomb delivery in adverse weather conditions.

Some of the general purpose bombs used in the PRC may be equipped with laser guidance systems and/or JDAM kits and may be equipped with battery-powered telemetry units. The bombs may be instrumented with a telemetry unit if the potential exists for it to exhibit poor separation characteristics and thus be likely to contact the aircraft or another munition.

- **Guided Bombs:** Guided bombs are designed to use electronic systems (laser or television) to improve the accuracy of delivery from an attack aircraft to a surface target. Typical guided bombs tested in the PRC include, but are not limited to GBU-24 and AGM-154 Joint Standoff Weapon. Guided bombs expended in the Chesapeake Bay Water Range have their guidance systems deactivated prior to being expended.

- **Practice Bombs:** Practice bombs are manufactured as either solid cast-metal bodies or thin sheet-metal containers that can be filled with wet sand or water to meet desired weight requirements. Practice bombs used for separation purposes in the PRC include but are not limited to: MK-76, MK-106, BDU-48/B, and the Laser Guided Test Round.

  To assist in visual observation in weapon-target impact, a practice bomb signal cartridge (i.e., spotting charge) that emits smoke or flames for impact marking can be used. A spotting charge is similar in explosive strength to a firecracker. Three different signal cartridges are used with practice bombs (MK-4, CXU-3, and CXU-4). The MK-4 cartridge contains about 65 g (2.3 oz) of red phosphorus. The red phosphorus ignites on impact and produces a bright flash and white smoke. The bright flash is important for night training. The CXU-3 and CXU-4 cartridges contain about 1 fluid oz and 2 fluid oz, respectively, of titanium tetrachloride. When exposed to air or moisture, titanium tetrachloride produces white smoke. While spotting charges are not used in support of testing activities in the PRC, they are commonly used in military training activities.

Mines. Mines are used as a subsurface anti-ship or anti-submarine weapon. The MK-56 mine has been in use since its development in 1966. More advanced mines include the MK-60 Captor (or “encapsulated torpedo”), the MK-62, MK-63, and MK-65 (Quickstrike), and the MK-67 (Submarine Launched Mobile Mine - SLMM). Most mines are delivered to the target by aircraft.

Missiles. Inert missile shapes (some with parachutes and telemetry units) are used for weapons separation testing from aircraft in the PRC. These shapes, mass-ballasted to account for the absence of the warhead and solid fuel rocket motor, are usually jettisoned or dropped in the Chesapeake Bay Water Range. The missile shapes used in weapons separation testing in the complex may represent the following types of missiles:

- **Air-to-Air Missiles:** Sidewinder (AIM-9), Sparrow (AIM-7), and Advanced Medium-Range Air-to-Air Missile, AIM-120). These shapes are not recovered.
- **Air-to-Surface Missiles:** - Shrike (AGM-45), Maverick (AGM-65), Harpoon Block II+ (AGM-84), (Stand-Off Land Attack Missile - AGM-84E), (Stand-Off Land Attack Missile Enhanced Range – AGM-84H/K), (High-Speed Anti-Radiation Missile - AGM-88), (Advanced Anti-Radiation Guided Missile Extended Range – AGM-88E), Joint Standoff Weapon (AGM-154), (Long Range Anti-Ship Missile – AGM-158), Griffin (AGM-176), (Joint Air-to-Ground Missile – AGM-179), Hellfire (AGM 114), and Switchblade. These missile shapes are usually recovered.

Recovery of air-to-surface missiles that have been dropped or jettisoned (including the parachute and telemetry package) occurs at an in-shore sandbar in the vicinity of Hooper target. The use of the parachute allows the jettisoned/dropped missiles to slow down as they enter the water and significantly minimizes the potential for breakup of the missile and/or the telemetry unit.

Rockets. Within the PRC, rockets may be launched from flying aircraft or from the rocket test stand at the Armament Test Area. From aircraft, single firings of rockets are allowed at Hooper Target and rockets can be dropped or fired at Hannibal Target (all rockets contain non-explosive warheads). More accurate than free-falling bombs, rockets are driven forward by the discharge of rapidly expanding gases from the nozzle of a motor. These gases are produced from the burning of a solid propellant that consists of a fuel and an oxidizer. Rocket sizes are most commonly 2.5 inches and 5 inches in diameter. Some rockets may contain flechette warheads that release up to 2,200 pointed steel projectiles, similar to a cluster bomb.

Gun Ammunition.

Gun ammunition is fired from aircraft, surface vessels, and occasionally personnel (from surface vessels or the Armament Test Area shoreline) into the Chesapeake Bay Water Range. Gun ammunition is also expended from a fastened aircraft or test stand into the Armament Test Area gun-firing tunnel. Gun ammunition is fired in support of weapons separation tests, other types of tests (such as counter-UAS), or military training activities.

Types of gun ammunition expended within the PRC include 5.56 mm, 7.62 mm, .50 caliber, 20 mm, 25 mm, 30 mm, and 40 mm. The projectiles for 5.56 mm and 7.62 mm gun ammunition have lead cores. The amount of lead in each of these projectiles has been estimated at 0.14 oz and 0.34 oz, respectively (Buxton, 1998). Projectiles for .50 caliber, 20 mm, 25 mm, 30 mm, and 40 mm gun ammunition are mostly steel with minor constituents of aluminum, copper, and lead. While cartridge cases are retained within aircraft or vessels after firing, the projectile (bullet) is deposited into the Chesapeake Bay. Ammunition fired into the firing tunnel is collected and expended bullets are properly disposed.

Decoys. Decoys are forms of EW countermeasures that allow an aircraft to foil or disable an adversary's offensive or defensive detection devices (e.g., communications and radar systems). The types of decoys tested in the PRC include chaff and flares. All decoys are expelled from an aircraft by the electronic firing of an impulse cartridge (known as a cartridge actuated detonator or CAD). The CAD contains 0.007 to 0.009 oz of propellant inside a steel body.

- **Chaff.** Chaff is the collective term for fiberglass fibers (or dipoles) coated with aluminum and biodegradable stearic acid and are released by an aircraft or ship to thwart radar and radar-controlled weapons. Chaff fibers are about the thickness of fine human hair, typically about (0.6 inch long, 0.01 inch wide, and 0.001 inch in diameter. Millions of these fibers are compressed into small packages or canisters. Only 1.6 oz of chaff are needed to cause an echo equal in size to a large bomber (US Naval Academy, December 1996). Each chaff package dropped independently can simulate additional aircraft.

  Chaff drops very slowly and can take many hours to reach the ground. Chaff settles at an estimated fall rate of 50 ft per minute or less. Initial chaff concentrations are about 120 micrograms per cubic meter (mg/m^3), but dissipate quickly because of its light weight and the effects of wind and air currents (US Air Force, November 1993). This causes the chaff to be widely dispersed, although clumps of chaff can be found occasionally.

- **Flares.** Flares are released by an aircraft to attract heat-seeking or IR-homing weapons targeted on that aircraft. When activated, an electrical firing mechanism ignites the flare and expels it from the aircraft. The flare begins burning immediately, reaching its highest temperature, 2,000EF, by the time it passes the tail of the aircraft (US Air Force, November 1993). The flare pellet is designed to provide a brief, high intensity heat source for up to ten seconds upon ejection (NAWCAD, January 1977). Normally, flares are completely consumed during this time (with the exception of small pieces of foil, felt, and plastic).

  Flares are composed of powdered or pelleted magnesium imbedded in a matrix such as polytetrafluoroethylene (teflon). Fluoroelastomer (viton, fluorel, or hytemp) may also be a constituent of the flare.

A.5 Patuxent River Complex Operational Tempo

Tables A-24 and A-25 are expanded versions of Chapter 2 (Proposed Action and Alternatives) Table 2.3-1 (Annual PRC Operational Tempo per Alternative: Activities and Assets) and Table 2.3-2 (Annual PRC Operational Tempo per Alternative: Number of Munitions, Other MEM, and Directed Energy Weapon Systems). These tables provide the quantitative numbers used for the analysis of alternatives for all activities, assets, munitions, other MEM, and directed energy weapons systems proposed for this EIS.

The No Action Alternative reflects the 10-year average of the 2008–2017 fiscal year baseline, as well as the highest individual (or peak) year within the 10-year period. Both averages and peaks were used by Navy subject matter experts to project activity levels needed to meet current and future military readiness requirements. Although averages reflect more typical levels of annual operational activity, peaks were analyzed to ensure the capacity to test and train at maximum levels required to meet military readiness in times of global conflict, and thereby meet the purpose and need in any given year.

Table A-24: Annual PRC Operational Tempo Per Alternative: Activities and Assets

Activity Name	*No Action Alternative*		*Alternative 1*		*Alternative 2*	*Location(s)*	*Recovery Rate*
	Annual Average	*Annual Peak*	*Annual Average*	*Annual Peak*	*Annual Peak*		
AIR-BASED ACTIVITIES							
Aircraft Flight Activities (# of Flight Hours)	**20,100**		**23,400**		**26,000**	Restricted Areas (80%) Helo OPAREAs (20%)	N/A
Below 3,000 ft AGL							
Fixed-Wing Jet	1,990		2,510		2,790	Restricted Areas	
Fixed-Wing Propeller	1,970		1,770		1,960	Restricted Areas & Helo OPAREAs	
Rotary-Wing	4,000		6,930		7,710	Restricted Areas & Helo OPAREAs	
Unmanned Aerial Systems	300		780		860	Restricted Areas	
Supersonic Activities (# of Supersonic Events)	180	247	175	180	198	Restricted Areas (98% in R-4008 above 30,000 feet; >2% below 30,000 feet [down to 10,000 feet] for supersonic weapons separation testing only); Chessie Air Traffic Control Assigned Airspace (1-3 events per year)	
AIR-BASED ASSETS							
Aerial (BQM) Targets (# of Targets)	<1	3	3	5	6	Launched from the Armament Test Area	100%
Unmanned Aerial System Targets (# of Targets)*	20	50	55	136	150	Restricted Areas (65% over land areas; 35% over water areas [25% Chesapeake Bay Water Range and 10% Bloodsworth Island Range Surface Danger Zone])	100% from land areas; 40% from water areas
LAND-BASED ACTIVITIES							
Aircraft Ground-Based Activities (Maintenance Runs, Taxis, Turns) (# of Hours)	**3,693**	**3,693**	**4,299**	**4,299**	**4,729**	PRC Installation airfields flight line, taxiways, tarmacs, and hanger aprons.	N/A
Outdoor Static Engine Runs (# of Events/Hours)	**61**	**92**	**61**	**92**	**101**	Open-Air Engine Test Cell Facility	

Table A-24: Annual PRC Operational Tempo Per Alternative: Activities and Assets, Continued

Activity Name	*No Action Alternative*		*Alternative 1*		*Alternative 2*	*Location(s)*	*Recovery Rate*
	Annual Average	*Annual Peak*	*Annual Average*	*Annual Peak*	*Annual Peak*		
Jet Engine Test Instrument (T-36)	21	31	21	31	34	Open-Air Engine Test Cell Facility	N/A
Turboprop Test Instrument	31	46	31	46	51		
Shaft Engine Test Instrument	8	12	8	12	13		
T-24	1	2	1	2	2		
T-26	< 1	1	< 1	1	1		
Armament Test Area (# of Events)	**10**	**25**	**10**	**27**	**30**	Armament Test Area	N/A
Gun Fire Test	5	11	5	12	13		
Weapons Compatibility Tests	5	14	5	15	17		
LAND-BASED ASSETS							
Ground Support Equipment (# of Hours)	**47,894**		**54,646**		**58,763**	On and around PRC Installation airfields	N/A
Aircraft Tow Tractor	9,918		11,316		12,169		
Mobile Electric Power Plant (Generator)	13,050		14,890		16,012		
Mobile Aircraft Start Unit	10,962		12,508		13,450		
Heavy Duty Land-based Tow Tractor	7,830		8,934		9,607		
Test Stand (Hydraulic Portable)	2,271		2,591		2,786		
Truck (Ammunition Loading, Transport)	1,566		1,787		1,921		
Air-Launched Weapons Loader	1,253		1,429		1,537		
Truck (Aerial Stores Lift)	1,044		1,191		1,281		

Table A-24: Annual PRC Operational Tempo Per Alternative: Activities and Assets, Continued

Activity Name	*No Action Alternative*		*Alternative 1*		*Alternative 2*	*Location(s)*	*Recovery Rate*
	Annual Average	*Annual Peak*	*Annual Average*	*Annual Peak*	*Annual Peak*		
Unmanned Ground Systems (# of Unmanned Ground Systems [Hours])	**2 *(4 Hours)***	**2 *(4 Hours)***	**40 *(80 Hours)***	**40 *(80 Hours)***	**44 *(88 Hours)***	PRC installations (primarily Outlying Field Webster); previously disturbed approved areas	
WATER-BASED ACTIVITIES							
Anti-Submarine Warfare Systems (# of Events [Hours])	**17 *(0.2)***	**34 *(0.4)***	**34 *(2)***	**68 *(4)***	**74 *(4.3)***	Sonar Dip Points	N/A
Active Dipping Sonar	2 *(0.2)*	4 *(0.4)*	18 *(2)*	36 *(4)*	39 *(4.3)*		
Passive Dipping Sonar	15	30	16	32	35		
Mine Countermeasure Systems (# of Events [Hours])	**21 *(40.2 Hours)***	**22 *(40.4 Hours)***	**22 *(40.4 Hours)***	**24 *(40.8 Hours)***	**26 *(43 Hours)***	Chesapeake Bay Water Range and Installation surrounding waters (Airborne Mine Neutralization System only in the Water Range)	N/A
Airborne Mine Neutralization System	1 *(0.2 Hours)*	2 *(0.4 Hours)*	2 *(0.4 Hours)*	4 *(0.8 Hours)*	5 *(1 Hour)*		
Organic Airborne and Surface Influence Sweep	2 *(4 Hours)*	2 *(4 Hours)*	2 *(4 Hours)*	2 *(4 Hours)*	2 *(4 Hours)*		
Magnetic Orange Pipe	18 *(36 Hours)*	18 *(36 Hours)*	18 *(36 Hours)*	18 *(36 Hours)*	19 *(38 Hours)*		
WATER-BASED ASSETS							
Vessels (# of Vessels [Hours])	**208 *(834 Hours)***	**593 *(2,364 Hours)***	**601 *(2,435 Hours)***	**605 *(2,473 Hours)***	**666 *(2,720 Hours)***	Chesapeake Bay Water Range (85-90%); Outside the Water Range but still within the PRC Study Area (10-15%)	N/A
Range Support Boats (Subtotals)	**202 *(786 Hours)***	**570 *(2,180 Hours)***	**570 *(2,180 Hours)***	**570 *(2,180 Hours)***	**627 *(2,398 Hours)***		
Small Vessels (< 50 Feet)	80 *(287 Hours)*	228 *(856 Hours)*	228 *(856 Hours)*	228 *(856 Hours)*	251 *(942 Hours)*		
Medium Vessel (50 to 100 Feet)	85 *(290)*	232 *(629 Hours)*	232 *(629 Hours)*	232 *(629 Hours)*	255 *(692 Hours)*		
Large Vessel (> 100 Feet)	37 *(209 Hours)*	110 *(695 Hours)*	110 *(695 Hours)*	110 *(695 Hours)*	121 *(765 Hours)*		

Table A-24: Annual PRC Operational Tempo Per Alternative: Activities and Assets, Continued

Activity Name	No Action Alternative		Alternative 1		Alternative 2	Location(s)	Recovery Rate
	Annual Average	Annual Peak	Annual Average	Annual Peak	Annual Peak		
Combatant and Patrol Craft (Subtotals)	**6** ***(48 Hours)***	**23** ***(184 Hours)***	**31** ***(255 Hours)***	**35** ***(293 Hours)***	**39** ***(322 Hours)***	Chesapeake Bay Water Range (85-90%); Outside the Water Range but still within the PRC Study Area (10-15%)	N/A
Small Vessels (< 50 Feet)	4 *(32 Hours)*	13 *(104 Hours)*	22 *(173 Hours)*	26 *(211 Hours)*	29 *(232 Hours)*		
Medium Vessel (50 to 90 Feet)	1 *(8 Hours)*	2 *(16 Hours)*	6 *(50 Hours)*	6 *(50 Hours)*	7 *(55 Hours)*		
Large Vessel (> 100 Feet)	1 *(8 Hours)*	8 *(64 Hours)*	3 *(32 Hours)*	3 *(32 Hours)*	3 *(35 Hours)*		
Amphibious Vehicles (#s included in Combatant and Patrol Craft numbers)	1	1	1	1	2	Surface Water Operations only; Chesapeake Bay Water Range (85-90%); Outside the Water Range but still within the PRC Study Area (10-15%)	
Unmanned Maritime Systems (# of Unmanned Maritime Systems [Hours])	**51** ***(153 Hours)***	**51** ***(153 Hours)***	**160** ***(480 Hours)***	**160** ***(480 Hours)***	**176** ***(528 Hours)***	Primarily installation surrounding waters but also within the Chesapeake Bay Water Range. Bottom crawlers may also operate on land along Installation surf zone or beaches.	N/A
Unmanned Surface Vehicles	5 *(15 Hours)*	5 *(15 Hours)*	40 *(120 Hours)*	40 *(120 Hours)*	44 *(132 Hours)*		
Unmanned Underwater Vehicles	46 *(138 Hours)*	46 *(138 Hours)*	120 *(360 Hours)*	120 *(360 Hours)*	132 *(396 Hours)*		
Bottom Crawlers (#s included in UUV numbers)	< 1 *(< 1 Hour)*	< 1 *(< 1 Hour)*	1 *(2 Hours)*	1 *(2 Hours)*	2 *(4 Hours)*		
Surface Targets (# of Targets [Hours])	**242** **(954 Hours)**	**476** ***(2,447 Hours)***	**487** ***(2,492 Hours)***	**489** ***(2,492 Hours)***	**539** ***(2,749 Hours)***	Chesapeake Bay Water Range (85-90%); Outside the Water Range but still within the PRC Study Area (10-15%)	Mobile and Stationary Targets = 100% Free Floating or Towed Targets = 95%
Mobile Surface Targets (Subtotals)	238 *(954 Hours)*	472 *(2,447 Hours)*	481 *(2,492 Hours)*	481 *(2,492 Hours)*	530 *(2,749 Hours)*		
Small Motorized Propeller	51 *(275 Hours)*	140 *(904 Hours)*	140 *(904 Hours)*	140 *(904 Hours)*	154 *(994 Hours)*		
Medium Motorized Propeller	182 *(654 Hours)*	326 *(1,513 Hours)*	326 *(1,513 Hours)*	326 *(1,513 Hours)*	359 *(1,664 Hours)*		

Table A-24: Annual PRC Operational Tempo Per Alternative: Activities and Assets, Continued

Activity Name	No Action Alternative		Alternative 1		Alternative 2	Location(s)	Recovery Rate
	Annual Average	***Annual Peak***	***Annual Average***	***Annual Peak***	***Annual Peak***		
Motorized Impeller	3 *(15 Hours)*	3 *(15 Hours)*	5 *(25 Hours)*	5 *(25 Hours)*	6 *(36 Hours)*	Chesapeake Bay Water Range (85-90%); Outside the Water Range but still within the PRC Study Area (10-15%)	Mobile and Stationary Targets = 100% Free Floating or Towed Targets = 95%
Free Floating or Towed	2 *(10 Hours)*	3 *(15 Hours)*	10 *(50 Hours)*	10 *(50 Hours)*	11 *(55 Hours)*		
Stationary Surface Targets	4	4	6	8	9		
Subsurface Targets (# of Targets [Hours])	**4 *(2 Hours)***	**5 *(3 Hours)***	**11 *(7 Hours)***	**16 *(12 Hours)***	**18 *(13 Hours)***		
Mobile Subsurface Targets	2 *(2 Hours)*	3 *(3 Hours)*	7 *(7 Hours)*	12 *(12 Hours)*	13 *(13 Hours)*	Chesapeake Bay Water Range and Installation surrounding waters	100%
Stationary Subsurface Targets	2	2	4	4	5	Chesapeake Bay Water Range and Installation surrounding waters	100%

Key: AGL = above ground level; ft = feet; N/A = not applicable; OPAREAs = operating areas; R- = restricted area
* = Associated aircraft flight hours are included in flight hour totals

Table A-25: Annual PRC Operational Tempo Per Alternative: Number of Munitions, Other MEM, and Directed Energy

Type	*No Action Alternative*		*Action Alternative 1*		*Action Alternative 2*	*Activity*	*Location(s)*	*Recovery Rate*
	Annual Average	*Annual Peak*	*Annual Average*	*Annual Peak*	*Annual Peak*			
NON-EXPLOSIVE MUNITIONS (Number Expended)								
Bombs	36	196	120	273	300	Test & Training Flights	Chesapeake Bay Water Range	0%
Mines (Mine Laying)	5	16	159	184	202	Test Flights		0%
Missiles	1	4	42	42	46			55%
Rockets*	110	385	405	534	587			0%
Rockets (Flechette Warhead)	10	33	35	46	51			
Torpedoes	8	37	37	37	41			80%
Small Caliber Gun Ammunition*	13,708	36,100	24,420	53,420	58,762	Test & Training Flights; Surface & Subsurface Testing & Training		0%
Medium Caliber Gun Ammunition*	3,049	8,961	5,100	17,150	18,865	Test Flights; Surface & Subsurface Testing & Training		
Rockets*	2	18	2	19	21	Weapons Compatibility Tests	Armament Test Area launch into Chesapeake Bay Water Range	0%
Small Caliber Gun Ammunition*	8,328	19,977	8,744	20,976	23,074	Gun Fire Tests	Armament Test Area (Gun Firing Tunnel)	Expended into Gun Firing Tunnel
Medium Caliber Gun Ammunition*	862	2,430	905	2,552	2,807			
OTHER MILITARY EXPENDED MATERIALS (Number Expended)								
Airborne Mine Neutralization System Munitions	1	2	2	4	5	Mine Countermeasure Systems Tests	Chesapeake Bay Water Range	0%
Chaff (Canisters [pounds])	19 (85)	121 (543)	246 (1,107)	246 (1,107)	271 (1,220)	Test & Training Flights		
Dye Markers	8	37	37	37	41	Test Flights		
Flares (Decoys)	85	320	255	255	281			

Table A-25: Annual PRC Operational Tempo Per Alternative: Number of Munitions, Other MEM, and Directed Energy, Continued

Type	No Action Alternative		Action Alternative 1		Action Alternative 2	Activity	Location(s)	Recovery Rate
	Annual Average	Annual Peak	Annual Average	Annual Peak	Annual Peak			
Flares (Illumination)	14	51	40	40	44	Test & Training Flights	Chesapeake Bay Water Range	0%
Launchers/Pods	3	7	9	14	15	Test Flights		
Miscellaneous Items (e.g., Mass Equivalents, Fuel Tanks)	<1	1	1	1	1			
Marine Markers	3	22	9	34	37	Other Flights	Chesapeake Bay Water Range (Alt 1&2 - 50% Patuxent River Seaplane Area)	0%
Search and Rescue Rafts and Kits	1	2	15	15	17	Test Flights	Chesapeake Bay Water Range	100%
Signal Cartridges/Spotting Charges	1	12	12	12	13			0%
Passive Sonobuoys	32	122	21	122	134			
Active Sonobuoys	0	0	6	24	26	Anti-Submarine Warfare Tests	Dip Points	0% - Scuttled Following Events
Cartridge Actuated Devices & Propellant Actuated Devices	176	513	185	539	593	Weapons Compatibility Tests	Armament Test Area	100%
Chaff (Pounds)	81	81	85	85	94			Chaff swept following events
Jet-Assisted Takeoff Bottles	2	6	6	10	12	Aerial (BQM) Target Launches	Armament Test Area launch into Chesapeake Bay Water Range	0%
DIRECTED ENERGY (Number of Events)								
High-Energy Laser (Events)	0	0	0	50	50	Directed Energy Weapons Tests	PRC Airspace, Land Areas, and Water Areas where the hazard pattern can be contained within the range and/or Installation boundary and exclusive use airspace can be provided.	N/A
High-Power Microwave (Events)	0	0	0	120	120			

* = Denotes Live-Fired Munition

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Appendix B
Military Expended Materials and Physical Disturbance and Strike Analysis

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Abbreviations and Acronyms

Acronym	***Definition***
AGM	air-to-ground missile
AIM	air intercept missile
AMNS	Airborne Mine Neutralization System
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ATA	Armament Test Area
cal	caliber
CBWR	Chesapeake Bay Water Range
GBU	guided bomb unit
JATO	jet-assisted take off
LAU	launch adapter unit
LUU	illumination unit
MEM	military expended materials
mm	millimeters
PRC	Patuxent River Complex
SAR	search and rescue
SDZ	surface danger zone
SLAM-ER	Standoff Land Attack Missile-Expanded Response
sq ft	square feet
SS	Supersonic
UAS	unmanned aerial systems

This appendix discusses the methods and results for quantifying the disturbance/strike footprint of military expended materials (MEM) on benthic habitats of the Chesapeake Bay and Patuxent River during peaks of activity. The purpose of this appendix is not to evaluate the footprints in terms of environmental impacts. The footprint is based on the peak annual quantity and dimensions of MEM categories representing the range of materials that are planned with the Proposed Action alternatives. The metrics resulting from this analysis include: (1) total 2-dimensional footprint of MEM relative to ordnance concentration areas (Figure 2.1-3, Chesapeake Bay Water Range Munition Concentration Areas) and elsewhere, and (2) total area of benthic habitat types (e.g., oyster beds) (Figure 3.3-3, Characterization of Chesapeake Bay Water Range Bottom Types).

The analysis requires four data elements: (1) number and location of MEM associated with each action alternative (Table 2.3-2, Annual PRC Operational Tempo per Alternative: Number of Munitions, Other MEM, and Directed Energy Weapon Systems), (2) the recovery rate, dimensions, and impact multiplier for each MEM (Table B-1), (3) area of benthic habitat types by study area locations (Table B-2), and (4) historic distribution of MEM types among munition concentration areas and elsewhere (Table B-3). The information for data element 2 is organized by material category and includes accessories, recovery rate, material dimensions, impact multiplier, and 2-dimensional impact footprint for analysis. The information for data element 4 includes an assumption that 5 percent of the footprint targeting a munition concentration area fall elsewhere within the Chesapeake Bay Water Range.

The 2-dimensional impact footprint of individual materials is calculated according to their dimensions multiplied by impact multipliers, to account for some initial lateral movement and/or overlapping separation during settlement. The impact multiplier is typically × 2, but can be higher to reflect that separating components overlap (e.g., bullets and bullet casings). Any subsequent movement of the typically heavy materials would be slow and likely only shift the impact to a slightly different location. Lighter materials, such as plastic, are not a primary constituent of any MEM except some accessories (e.g., small decelerator/parachutes, endcaps, compression pads, flare O-rings). The number of MEM and MEM accessories are then multiplied by the portion not recovered (1-proportion recovered) and their 2-dimensional impact footprint to get the annual total impact footprint of MEM by alternative to the total bottom area where it is typically expended (Table B-3 and Table B-4). However, the peak impact areas presented herein are much higher than a typical year of proposed activities, due to the highly variable nature of testing. The historic distribution of MEM types among munition concentration areas may also change under future scenarios.

In summary, the total footprint of MEM for each alternative is projected to be 10,485.67 (No Action alternative), 19,000.39 (Alternative 1), and 21,194.40 (Alternative 2) square feet per year. However, the percentage of munition concentration area impacted annually by MEM under a peak scenario (Alternative 2) ranges from less than 0.0001 to 0.0125 percent, with the Hannibal Target Area impacted by the highest percent coverage of MEM. The next highest percent coverage was for Hooper Target Complex, at 0.0047 percent of the munition concentration area.

Table B-1 Analysis Specifications for Various Expended Materials Planned with the Proposed Action Alternatives

MEM Category	*MEM Subcategory*	*Representative(s)*	*Accessories*	*Proportion Recovered*	*Diameter (inches)*	*Length (inches)*	*Multiplier*	*Footprint (sq ft)*
Live-Fired Munitions	Medium-Caliber Gun Ammunition	20 mm	None	0.00	0.787	6.600	2.50	0.09
		30 mm	None	0.00	1.18	11.50	2.50	0.24
	Rockets	2.75-inch. Hydra w/ MK-6 Motor and MK-149 Flechette Warhead (WDU4)	None	0.00	2.75	41.70	2.00	1.59
		2.75-inch. Hydra w/ MK-66 Motor	None	0.00	2.75	41.70	2.00	1.59
		2.75-inch. Hydra w/ MK-66 Motor (ATA Launched)	None	0.00	2.75	41.70	2.00	1.59
	Small-Caliber Gun Ammunition	.50 cal	None	0.00	0.51	5.45	2.50	0.05
		7.62 mm	None	0.00	0.31	2.75	2.50	0.01
Other Non-Explosive Munitions	Airborne Neutralization System (AMNS)	AMNS Neutralizer	Fiber-optic Cable	0.00	15.30	52.00	2.00	11.05
	Bombs	GBU-24 (Guided Bomb)	None	0.00	18.00	172.76	2.00	43.19
		MK-76 (Practice Bomb)	None	0.00	4.00	24.64	2.00	1.37
	Mines	MK-56	None	0.00	22.40	114.30	2.00	35.56
		MK-62	None	0.00	15.10	89.00	2.00	18.66
	Missiles	AGM-84K SLAM-ER	Small Decelerator/ Parachute	0.55	13.50	172.00	2.00	32.25
		AIM-120 AMRAAM	None	0.00	7.00	144.00	2.00	14.00
	Torpedoes	MK-54	Lightweight Torpedo Accessories, Small Decelerator/ Parachute	0.95	12.59	112.99	2.00	19.76
Other MEM	Aerial Targets	Small UAS Target – Fragments (only Alternatives 1 and 2)	None	0.40	24.00	24.00	2.00	8.00

Table B-1 Analysis Specifications for Various Expended Materials Planned with the Proposed Action Alternatives, Continued

MEM Category	*MEM Subcategory*	*Representative(s)*	*Accessories*	*Proportion Recovered*	*Diameter (inches)*	*Length (inches)*	*Multiplier*	*Footprint (sq ft)*
Other MEM	Chaff	Chaff	Endcap - Chaff, Chaff-Air Cartridge	0.00	0.00	0.00	0.00	0.00
	Flares	B5 (Decoy/Countermeasure)	Endcap - Flare, Compression Pad/Piston, Flare O-ring	0.00	1.40	5.80	2.00	0.11
		LUU-2 (Illumination)	Parachute (Medium)	1.00	5.00	36.00	2.00	2.50
	Miscellaneous Items	I-Beam	None	0.00	14.13	480.00	2.00	94.19
	Launchers	LAU-61	None	0.00	16.00	83.20	2.00	18.49
	Marine Marker	MK-58	None	0.00	4.90	21.70	2.00	1.48
	Search and Rescue	SAR Raft and Kit	None	1.00	-	-	-	-
	Sonobuoys	Sonobuoys (Active/Passive)	Sonobuoy Wires, Small Decelerator/ Parachute	0.00	4.50	36.00	0.00	0.00
	Spotting Charges	Spotting Charge	None	0.00	3.40	11.18	2.00	0.53
	Surface Targets	Towed Surface Target – Fragments	None	0.95	180.00	180.00	2.00	449.97
Accessory	Air Targets	JATO Bottle	None	0.00	6.60	26.40	2.00	2.42
		Parachute (Large)	None	1.00	531.74	531.74	2.00	3,926.80
	AMNS	Fiber-optic Cable	None	0.00	0.00	0.00	0.00	0.00
	Chaff	Chaff-Air Cartridge	None	0.00	1.40	5.80	2.00	0.11
		Endcap - Chaff	None	0.00	1.40	0.56	2.00	0.01
		Piston-Chaff	None	0.00	1.40	0.56	2.00	0.01
	Flares	Compression Pad or Plastic Piston	None	0.00	1.40	0.56	2.00	0.01
		Endcap - Flare	None	0.00	1.40	0.56	2.00	0.01
		Flare O-ring	None	0.00	1.40	1.40	2.00	0.03
		Parachute (Medium)	None	1.00	188.02	188.02	2.00	490.96
	Mines	Anchor - Mines	None	0.00	36.00	36.00	2.00	18.00
	Missiles	Small Decelerator/Parachute	None	0.95	36.00	36.00	2.00	18.00

Table B-1 Analysis Specifications for Various Expended Materials Planned with the Proposed Action Alternatives, Continued

MEM Category	*MEM Subcategory*	*Representative(s)*	*Accessories*	*Proportion Recovered*	*Diameter (inches)*	*Length (inches)*	*Multiplier*	*Footprint (sq ft)*
Accessory	Sonobuoys	Small Decelerator/Parachute	None	0.00	36.00	36.00	2.00	18.00
		Sonobuoy Wires	None	0.00	0.00	0.00	0.00	0.00
	Torpedoes	Lightweight Torpedo Accessories	None	0.00	12.06	12.06	2.00	2.02
		Small Decelerator/Parachute	None	0.95	36.00	36.00	2.00	18.00

Key: AGM = air-to-ground missile; AIM = air intercept missile; AMNS = Airborne Mine Neutralization System; AMRAAM = Advanced Medium-Range Air-to-Air Missile; ATA = Armament Test Area; cal = caliber; GBU = guided bomb unit; JATO = jet-assisted take off; LAU = launch adapter unit; LUU = illumination unit; MEM = military expended materials; mm = millimeters; SAR = search and rescue; SLAM-ER = Standoff Land Attack Missile-Expanded Response; sq ft = square feet; UAS = unmanned aerial systems.

Table B-2 Substrate Composition of Patuxent River Complex Locations Where Military Expended Materials May Be Expended

Location	*Munition Concentration Area/Target*	*Abiotic Substrate Types (% Coverage)*						*Total Area (sq ft)*
		Artificial (Hard)	*Gravel*	*Mud*	*Sand*	*Shell Bottom*	*Unknown*	
Chesapeake Bay Water Range	Bay Forest	0.00%	0.00%	86.36%	2.24%	11.40%	0.00%	28,336,024
	Hannibal Target	0.00%	0.00%	2.94%	92.11%	4.95%	0.00%	55,436,897
	Hooper Target Complex	0.00%	0.00%	91.47%	8.45%	0.08%	0.00%	228,746,453
	Shoal	0.00%	0.00%	4.64%	5.05%	24.39%	65.91%	7,108,353
	Supersonic Aim Points	0.00%	0.00%	65.38%	34.62%	0.00%	0.00%	277,567,652
	Elsewhere	0.04%	0.00%	46.52%	41.82%	5.14%	6.49%	4,543,760,191
Chesapeake Bay Water Range (Anywhere Total)		*0.03%*	*0.00%*	*49.23%*	*40.22%*	*4.70%*	*5.83%*	*5,140,955,570*
Patuxent River Seaplane Area		*0.66%*	*0.48%*	*52.02%*	*16.76%*	*10.15%*	*19.92%*	*86,610,209*
Bloodsworth Island Range SDZ (Water Area)		*0.00%*	*0.00%*	*5.15%*	*25.03%*	*5.49%*	*48.50%*	*1,002,851,040*

Key: GIS = geographic information system; SDZ = surface danger zone; sq ft = square feet.
Note: Refer Appendix N, Geographic Information System (GIS) References, for GIS data credits.

Table B-3 Typical Distribution of Non-explosive Munitions and Other Military Expended Materials in Munition Concentration Areas

MEM Category	*MEM Subcategory*	*Representatives*	*Percent Distribution within CBWR*							*Percent Distribution within Other Areas*		
			Bay Forest	*Hannibal*	*Hooper*	*Shoal*	*SS Aim Points*	*CBWR (Elsewhere)*	*CBWR (Anywhere)*	*Dip Points*	*Seaplane Area*	*Bloodsworth Island Range SDZ*
Live-Fired Munitions	Medium-Caliber Gun Ammunition	20 mm	-	93%	2%	-	-	5%	-	-	-	-
		30 mm	-	93%	2%	-	-	5%	-	-	-	-
	Rockets	2.75-inch. Hydra w/ MK-66 Motor (ATA Launched)	-	81%	14%	-	-	5%	-	-	-	-
		2.75-inch. Hydra w/ MK-6 Motor and MK-149 Flechette Warhead (WDU4)	-	81%	14%	-	-	5%	-	-	-	-
		2.75-inch. Hydra w/ MK-66 Motor	-	81%	14%	-	-	5%	-	-	-	-
	Small-Caliber Gun Ammunition	7.62 mm	-	90%	5%	-	-	5%	-	-	-	-
		.50 cal	-	90%	5%	-	-	5%	-	-	-	-
Other Non-Explosive Munitions	AMNS	AMNS Neutralizer	-	-	-	-	-	-	100%	-	-	-
	Bombs	GBU-24 (Guided Bomb)	5%	38%	38%	-	14%	5%	-	-	-	-
		MK-76 (Practice Bomb)	5%	38%	38%	-	14%	5%	-	-	-	-
	Mines	MK-62	-	-	95%	-	-	5%	-	-	-	-
		MK-56	-	-	95%	-	-	5%	-	-	-	-
	Missiles	AGM-84K SLAM-ER	-	-	95%	-	-	5%	-	-	-	-
		AIM-120 AMRAAM	-	-	95%	-	-	5%	-	-	-	-
	Torpedoes	MK-54	-	-	47%	47%	1%	5%	-	-	-	-
Other MEM	Aerial Targets	Small UAS Target – Fragments (Only Alternatives 1 and 2)	-	-	-	-	-	-	35%	-	-	10%
	Chaff	Chaff	28%	57%	10%	-	-	5%	-	-	-	-
	Flares	LUU-2 (Illumination)	-	28%	70%	-	-	5%	-	-	-	-
		B5 (Decoy/Countermeasure)	1%	28%	62%	-	4%	5%	-	-	-	-
	Miscellaneous Items	I-Beam	-	-	95%	-	-	5%	-	-	-	-
	Launchers	LAU-61	-	28%	67%	-	-	5%	-	-	-	-

Table B-3 Typical Distribution of Non-explosive Munitions and Other Military Expended Materials in Munition Concentration Areas, Continued

MEM Category	*MEM Subcategory*	*Representatives*	*Percent Distribution within CBWR*							*Percent Distribution within Other Areas*		
			Bay Forest	*Hannibal*	*Hooper*	*Shoal*	*SS Aim Points*	*CBWR (Elsewhere)*	*CBWR (Anywhere)*	*Dip Points*	*Seaplane Area*	*Bloodsworth Island Range SDZ*
Other MEM	Marine Marker	MK-58	10%	-	38%	-	-	5%	-	-	47%	-
	Search and Rescue	SAR Raft and Kit	-	-	-	-	-	-	100%	-	-	-
	Sonobuoys	Sonobuoys (Active)[1]	-	-	-	-	-	-	-	100%	-	-
		Sonobuoys (Passive)	-	-	95%	-	-	5%	-	-	-	-
	Spotting Charges	Spotting Charge	5%	38%	38%	-	14%	5%	-	-	-	-
	Surface Targets	Towed Surface Target - Fragments	-	-	-	-	-	-	100%	-	-	-

Key: AGM = air-to-ground missile; AIM = air intercept missile; AMNS = Airborne Mine Neutralization System; AMRAAM = Advanced Medium-Range Air-to-Air Missile; ATA = Armament Test Area; cal = caliber; CBWR = Chesapeake Bay Water Range; GBU = guided bomb unit; LAU = launch adapter unit ; LUU = illumination unit; MEM = military expended materials; mm = millimeters; SAR = search and rescue; SLAM-ER = Standoff Land Attack Missile-Expanded Response; SDZ = surface danger zone; SS = supersonic; UAS = unmanned aerial systems.

Note:

1. Released only around the dip points north of the Chesapeake Bay Water Range.

Table B-4 Annual Military Expended Material Footprints and Percent of Patuxent River Complex Locations/Bottom Areas

Location	*Munition Concentration Area/Target*	*No Action Alternative*		*Action Alternative 1*		*Action Alternative 2*	
		Square Feet	*Percent*	*Square Feet*	*Percent*	*Square Feet*	*Percent*
Chesapeake Bay Water Range	Bay Forest	229.52	0.0008%	315.11	0.0011%	346.94	0.0012%
	Hannibal Target	4130.29	0.0075%	6323.39	0.0114%	7,322.69	0.0125%
	Hooper Target Complex	4865.55	0.0021%	9829.39	0.0043%	11,342.56	0.0047%
	Shoal	52.30	0.0007%	52.30	0.0007%	61.66	0.0008%
	Supersonic Aim Points	615.38	0.0002%	855.11	0.0003%	1,006.59	0.0003%
	Elsewhere (Target Area Missed)	520.69	<0.0001%	936.52	<0.0001%	1004.50	<0.0001%
	Anywhere[1]	71.94	<0.0001%	278.86	<0.0001%	564.39	<0.0001%
Dip Points		0.00	N/A	410.37	N/A	467.97	N/A
Patuxent River Seaplane Area		0.00	0.0000%	8.33	<0.0001%	9.02	<0.0001%
Bloodsworth Island Range SDZ		0.00	0.0000%	71.99	<0.0001%	71.99	<0.0001%

Key: < = less than; N/A = not applicable; SDZ = surface danger zone.
Note:
1. Anywhere within the broader Chesapeake Bay Water Range area.

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Appendix C
A Noise Primer: Noise and Its Effect on the Environment

Acknowledgements

This appendix reflects a consolidation of information retained by the Navy for clarification of noise analysis terminology.

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Acronyms and Abbreviations

Acronym	Definition
μPa	micropascal
μPa^2-s	micropascal squared per second
AAD	Annual Average Daily
AGL	Above Ground Level
ANSI	American National Standards Institute
ASHLA	American Speech-Language-Hearing Association
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics
CNEL	Community Noise Equivalent Level
$CNEL_{mr}$	Onset-Rate Adjusted Monthly Community Noise Equivalent Level
dB	decibels
dB re 20 μPa	decibels referenced to 20 micropascals
dBA	A-Weighted Decibels
dB(A)	A-Weighted Decibels
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)
DNL	Day-Night Average Sound Level
DOD	Department of Defense
FAA	Federal Aviation Administration (US)
FICAN	Federal Interagency Committee on Aviation Noise
FICON	Federal Interagency Committee on Noise
HA	Highly Annoyed
HYENA	Hypertension and Exposure to Noise near Airports
Hz	Hertz
ISO	International Organization for Standardization
kHz	kilohertz
km	kilometer
kyd	kiloyard
L	Sound Level
L_{dn}	Day-Night Average Sound Level

Acronym	Definition
L_{dnmr}	Onset-Rate Adjusted Monthly Day-Night Average Sound Level
L_{eq}	Equivalent Sound Level
$L_{eq(16)}$	Equivalent Sound Level over 16 hours
$L_{eq(24)}$	Equivalent Sound Level over 24 hours
$L_{eq(30min)}$	Equivalent Sound Level over 30 minutes
$L_{eq(8)}$	Equivalent Sound Level over 8 hours
$L_{eq(h)}$	Hourly Equivalent Sound Level
L_{max}	Maximum Sound Level
L_{pk}	Peak Sound Level
mmHg	millimeters of mercury
MOA	Military Operations Area
MTR	Military Training Route
NA	Number of Events At or Above a Selected Threshold
NATO	North Atlantic Treaty Organization
NDI	Noise Depreciation Index
NIPTS	Noise-induced Permanent Threshold Shift
NSDI	Noise Sensitivity Depreciation Index
OR	Odd Ratio
POI	Point of Interest
PTS	Permanent Threshold Shift
RANCH	Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health
SEL	Sound Exposure Level
SIL	Speech Interference Level
SPL	sound pressure level
SUA	Special Use Airspace
TA	Time Above
TTS	Temporary Threshold Shift
U.S.	United States
UKDFES	United Kingdom Department for Education and Skills
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
WHO	World Health Organization

This appendix discusses sound and noise and their potential effects on the human and natural environment. Section C.1 provides an overview of the basics of sound and noise. Section C.2 defines and describes the different metrics used to describe noise. The largest section, Section C.5, reviews the potential effects of noise, focusing on effects on humans but also addressing effects on property values, terrain, structures, and animals. Section C.6 contains the list of references cited.

C.1 Basics of Sound

Section C.1.1 describes sound waves and decibels. Section C.1.3 reviews sounds levels and types of sounds.

C.1.1 Sound Waves and Decibels

Sound consists of minute vibrations in the air that travel through the air and are sensed by the human ear. Figure C-1 is a sketch of sound waves from a tuning fork. The waves move outward as a series of crests where the air is compressed and troughs where the air is expanded. The height of the crests and the depth of the troughs are the amplitude or sound pressure of the wave. The pressure determines its energy or intensity. The number of crests or troughs that pass a given point each second is called the frequency of the sound wave.

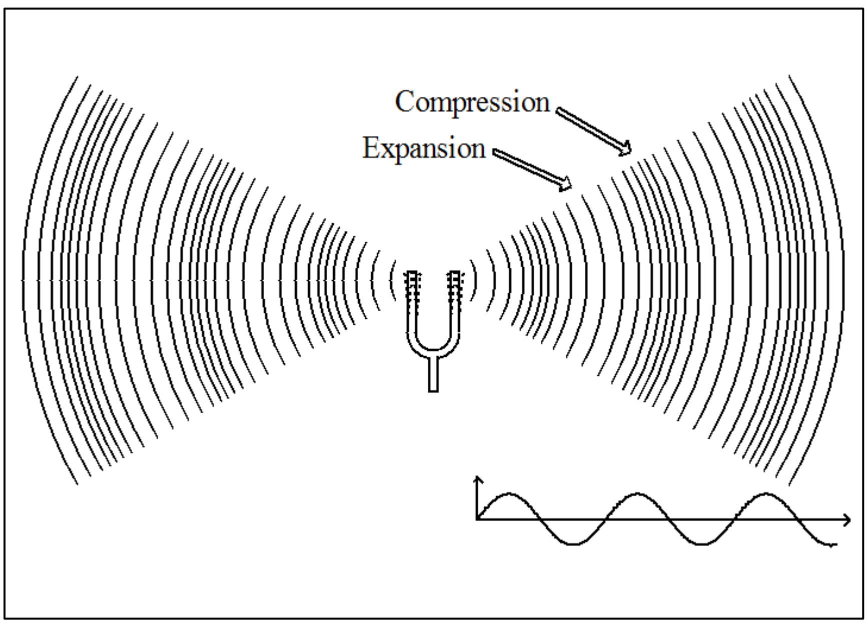


Figure C-1 Sound Waves from a Vibrating Tuning Fork

The measurement and human perception of sound involves three basic physical characteristics: intensity, frequency, and duration

- **Intensity** is a measure of the acoustic energy of the sound and is related to sound pressure. The greater the sound pressure, the more energy carried by the sound and the louder the perception of that sound.
- **Frequency** is the physical attribute most closely associated with the subjective attribute "pitch"— the higher the frequency, the higher the pitch. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or

screeches. Frequency is defined by the number of oscillations in the sound pressure or particle motion per second.

- **<u>Duration</u>** is the length of time the sound can be detected. Duty cycle describes the portion of time that a sound source actually generates sound. It is defined as the percentage of time during which a sound is generated over a total operational time period. For example, if a sonar source produces a one-second ping every 10 seconds, the duty cycle is 10 percent. Duty cycles vary among different acoustic sources; in general, a low-duty cycle could be considered 20 percent or less and a high-duty cycle 80 percent or higher.

The loudest sounds that can be comfortably heard by the human ear have intensities a trillion times higher than those of sounds barely heard. Because of this vast range, it is unwieldy to use a linear scale to represent the intensity of sound. Furthermore, the perceived relative loudness of two sounds relates to the ratio of the sound pressure level (SPL) rather than to the difference in the sound pressure's absolute values. Use of the logarithmic decibel (dB) unit of measure both compresses the wide range of sound pressure levels into a more useful scale and reflects the relative way in which different sound pressure levels are perceived. Decibel values are the logarithm of the ratio of the sound pressure being described to a reference pressure. By convention, sound levels in air are stated for a reference pressure of 20 micropascals (μPa), and sound levels in water are stated for a reference pressure of 1 μPa. Because of the differences in reference units, the same sound pressure would result in different decibel values in air and in water, and sound pressure levels in air and in water should never be directly compared. Sounds that do not have a reference level stated can be assumed to be referenced to 20 μPa, while sounds in water are typically specifically denoted as being referenced to 1 μPa.

An in-air sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level of approximately 60 dB. Sound levels above 120 dB begin to be felt inside the human ear as discomfort. Sound levels between 130 and 140 dB are felt as pain (Berglund and Lindvall 1995).

As shown in Figure C-2, the sound from a tuning fork spreads out uniformly as it travels from the source. The spreading causes the sound's intensity to decrease with increasing distance from the source. For a source such as an aircraft in flight, the sound level will decrease by about 6 dB for every doubling of the distance. For a busy highway, the sound level will decrease by 3-4.5 dB for every doubling of distance.

As sound travels from the source, it also gets absorbed by the air. The amount of absorption depends on the frequency composition of the sound, the temperature, and the humidity conditions. Sound with high-frequency content gets absorbed by the air more than sound with low-frequency content. More sound is absorbed in colder and drier conditions than in hot and wet conditions. Sound is also affected by wind and temperature gradients, terrain (elevation and ground cover) and structures.

Because of the logarithmic nature of the decibel unit, sound levels cannot simply be added or subtracted and are somewhat cumbersome to handle mathematically. However, some simple rules are useful in dealing with sound levels. First, if a sound's intensity is doubled, the sound level increases by 3 dB, regardless of the initial sound level. For example:

$$60 \text{ dB} + 60 \text{ dB} = 63 \text{ dB, and}$$

$$80 \text{ dB} + 80 \text{ dB} = 83 \text{ dB.}$$

Second, the total sound level produced by two sounds of different levels is usually only slightly more than the higher of the two. For example:

$$60.0 \text{ dB} + 70.0 \text{ dB} = 70.4 \text{ dB}.$$

Because the addition of sound levels is different than that of ordinary numbers, this process is often referred to as "decibel addition."

The minimum change in the sound level of individual events that an average human ear can detect is about 3 dB. On average, a person perceives a change in sound level of about 10 dB as a doubling (or halving) of the sound's loudness. This relation holds true for loud and quiet sounds. A decrease in sound level of 10 dB actually represents a 90% decrease in sound intensity but only a 50% decrease in perceived loudness because the human ear does not respond linearly.

Sound frequency is measured in terms of cycles per second or hertz (Hz). The normal ear of a young person can detect sounds that range in frequency from about 20 Hz to 20,000 Hz. As we get older, we lose the ability to hear high frequency sounds. Not all sounds in this wide range of frequencies are heard equally. Human hearing is most sensitive to frequencies in the 1,000 to 4,000 Hz range. The notes on a piano range from just over 27 Hz to 4,186 Hz, with middle C equal to 261.6 Hz. Most sounds (including a single note on a piano) are not simple pure tones like the tuning fork in Figure C-1, but contain a mix, or spectrum, of many frequencies.

In this document, sounds are generally described as either low- (less than 1 kilohertz [kHz]), mid- (1 kHz–10 kHz), high- (10 kHz–100 kHz), or very high- (greater than 100 kHz) frequency. Hearing ranges of marine animals (e.g., fish, birds, sea turtles, and marine mammals) are quite varied and are species-dependent. For example, some fish can hear sounds below 100 Hz and some species of marine mammals have hearing capabilities that extend above 100 kHz. Acoustic impact analysis must, therefore, focus not only on the sound amplitude (i.e., pressure or particle motion), but on the sound frequency and the hearing capabilities of the species being considered.

The wavelength of a sound is the distance between wave peaks. Wavelength decreases as frequency increases. The frequency multiplied by the wavelength equals the speed of sound in a medium, as shown in this equation:

Frequency (s^{-1}) x wavelength (m) = sound speed (m/s)

The approximate speed of sound in sea water is 1,500 meters per second and in air is 340 meters per second, although speed varies depending on environmental conditions (e.g., pressure, temperature, and in the case of sea water, salinity).

Sounds with different spectra are perceived differently even if the sound levels are the same. Weighting curves have been developed to correspond to the sensitivity and perception of different types of sound. A-weighting and C-weighting are the two most common weightings. These two curves, shown in Figure C-2, are adequate to quantify most environmental noises. A-weighting puts emphasis on the 1,000 to 4,000 Hz range.

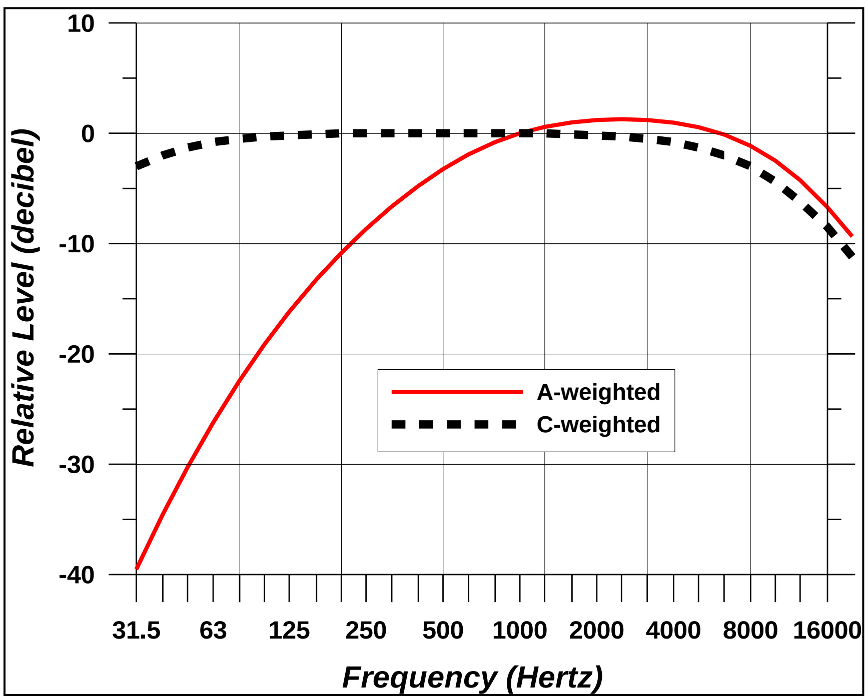
Very loud or impulsive sounds, such as explosions or sonic booms, can sometimes be felt, and can cause secondary effects, such as shaking of a structure or rattling of windows. These types of sounds can add to annoyance, and are best measured by C-weighted sound levels, denoted dBC. C-weighting is nearly flat throughout the audible frequency range, and includes low frequencies that may not be heard but cause shaking or rattling. C-weighting approximates the human ear's sensitivity to higher intensity sounds.

C.1.2 Acoustic Impedance

Acoustic impedance is a property of the propagation medium (air, water, or tissue) that can be simply described as the opposition to flow of a pressure wave. Acoustic impedance is a function of the density and speed of sound in a medium. Sound transmits more readily through materials of similar acoustic impedance, such as water and animal tissue. When sound waves encounter a medium with different acoustic impedance (e.g., an air-water interface), they reflect and refract, creating more complex propagation conditions. For example, sound traveling in air (low impedance) encountering the water surface (high impedance) will be largely reflected, preventing most sound energy in the air from being transmitted into the water.

C.1.3 Sound Levels and Types of Sounds

Most environmental sounds are measured using A-weighting. They are called A-weighted decibel sound levels, and sometimes use the unit dBA or dB(A) rather than dB. An example of the weighting would be if the unweighted received level of a 500 Hz tone at a human receiver was 90 dB referenced to 20 µPa, the A-weighted sound level would be 87 dBA, because the A-weighting function amplitude at 500 Hz is -3dB (Figure C-2). When the use of A-weighting is understood, the term “A-weighted” is often omitted and the unit dB is used. Unless otherwise stated, dB units refer to A-weighted sound levels.



Source: ANSI S1.4A -1985 “Specification of Sound Level Meters”

Figure C-2 Frequency Characteristics of A- and C-Weighting

When sound is purposely created to convey information, communicate, or obtain information about the environment, it is often referred to as a signal. Examples of sounds that could be considered signals are sonar pings, marine mammal vocalizations and echolocation clicks, and tones used in hearing experiments.

Sound becomes noise when it is unwelcome and interferes with normal activities, such as sleep or conversation. Noise is unwanted sound. Sounds produced by naval aircraft and vessel propulsion are considered noise because they represent possible inefficiencies and increased detectability. Noise can become an issue when its level exceeds the ambient or background sound level. Whether a sound is perceived as noise often depends on the receiver (i.e., the animal or system that detects the sound). For example, sonar used to generate sounds that can locate an enemy submarine produce signals that are useful to sailors engaged in anti-submarine warfare, but are assumed to be noise when detected by marine mammals.

The combination of all sounds at a particular location, whether these sources are located near or far, is ambient noise (American National Standards Institute, 1994). Ambient noise includes natural sources, such as sound from crashing waves, rain, and animals and anthropogenic sources, such as seismic surveys and vessel noise. Ambient noise in urban areas typically varies from 60 to 70 dB, but can be as high as 80 dB in the center of a large city. Quiet suburban neighborhoods experience ambient noise levels around 45-50 dB (U.S. Environmental Protection Agency (USEPA) 1978).

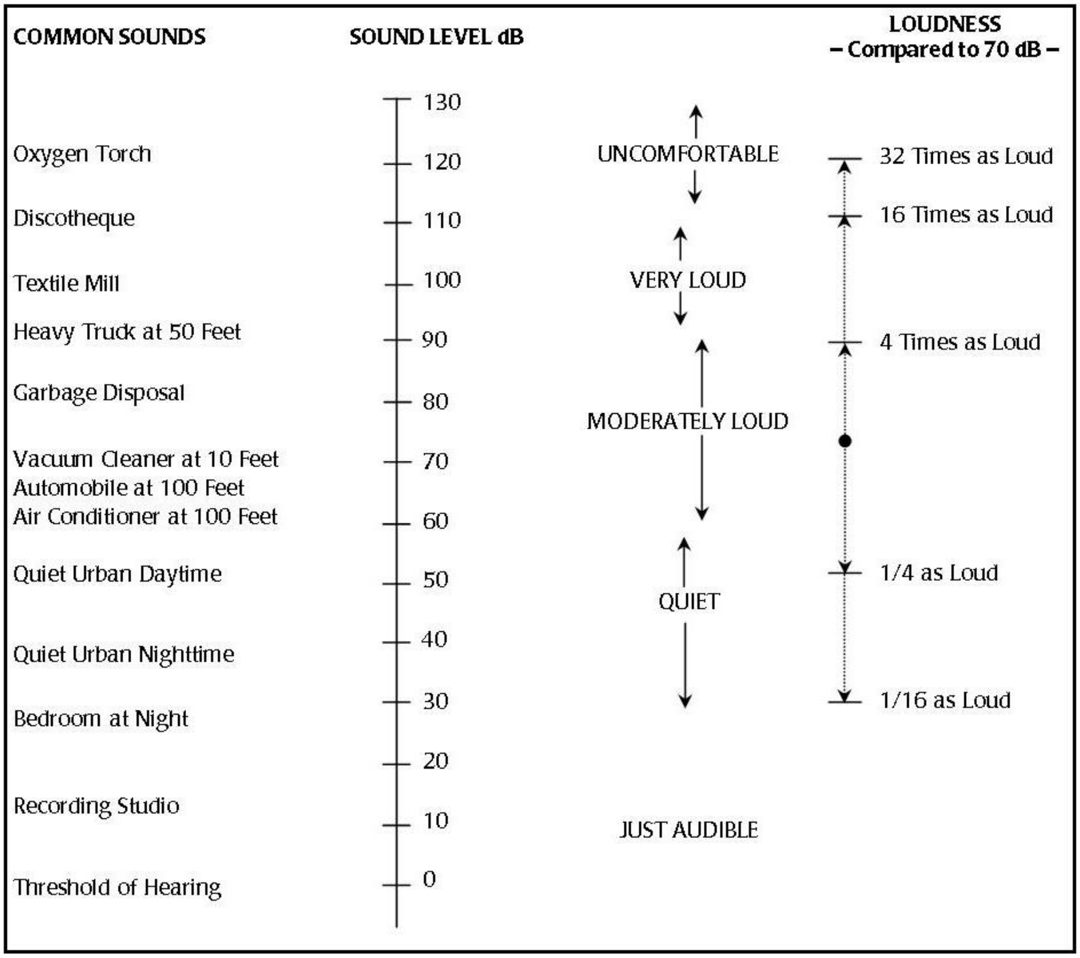
Figure C-3 is a chart of A-weighted sound levels from common sources. Some sources, like the air conditioner and vacuum cleaner, are continuous sounds whose levels are constant for some time. Some sources, like the automobile and heavy truck, are the maximum sound during an intermittent event like a vehicle pass-by. Some sources like “urban daytime” and “urban nighttime” are averages over extended periods. A variety of noise metrics have been developed to describe noise over different time periods. These are discussed in detail in Section C.2.

Aircraft noise consists of two major types of sound events: flight (including takeoffs, landings and flyovers), and stationary, such as engine maintenance run-ups. The former are intermittent and the latter primarily continuous. Noise from aircraft overflights typically occurs beneath main approach and departure paths, in local air traffic patterns around the airfield, and in areas near aircraft parking ramps and staging areas. As aircraft climb, the noise received on the ground drops to lower levels, eventually fading into the background or ambient levels.

Impulsive noises are generally short, loud events. Their single-event duration is usually less than 1 second. Examples of impulsive noises are small-arms gunfire, hammering, pile driving, metal impacts during rail-yard shunting operations, and riveting. Examples of high-energy impulsive sounds are quarry/mining explosions, sonic booms, demolition, and industrial processes that use high explosives, military ordnance (e.g., armor, artillery and mortar fire, and bombs), explosive ignition of rockets and missiles, and any other explosive source where the equivalent mass of dynamite exceeds 25 grams (American National Standards Institute [ANSI] 1996).

C.2 Noise Metrics

Noise metrics quantify sounds so they can be compared with each other, and with their effects, in a standard way. The simplest metric is the A-weighted level, which is appropriate by itself for constant noise such as an air conditioner. Aircraft noise varies with time. During an aircraft overflight, noise starts at the background level, rises to a maximum level as the aircraft flies close to the observer, then returns to the background as the aircraft recedes into the distance. This is sketched in Figure C-4, which also indicates two metrics (maximum sound level [L_{max}] and sound exposure level [SEL]) that are described in Sections C.2.1 and C.2.3 below. Over time there can be a number of events, not all the same.



Sources: Harris 1979.

Figure C-3 Typical A-weighted Sound Levels of Common Sounds

There are a number of metrics that can be used to describe a range of situations, from a particular individual event to the cumulative effect of all noise events over a long time. This section describes the metrics relevant to environmental noise analysis.

C.2.1 Single-events

Maximum Sound Level (L_{max})

The highest A-weighted sound level measured during a single event in which the sound changes with time is called the maximum A-weighted sound level or Maximum Sound Level and is abbreviated L_{max}. The L_{max} is depicted for a sample event in Figure C-4.

L_{max} is the maximum level that occurs over a fraction of a second. For aircraft noise, the "fraction of a second" is one-eighth of a second, denoted as "fast" response on a sound level measuring meter (ANSI 1988). Slowly varying or steady sounds are generally measured over 1 second, denoted "slow" response. L_{max} is important in judging if a noise event will interfere with conversation, TV or radio listening, or other common activities. Although it provides some measure of the event, it does not fully describe the noise, because it does not account for how long the sound is heard.

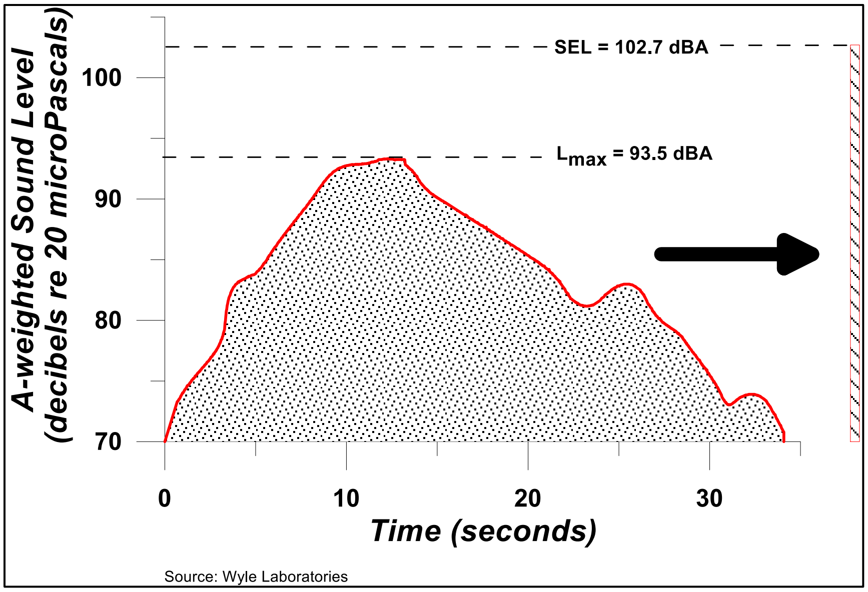


Figure C-4 Example Time History of Aircraft Noise Flyover

Peak Sound Pressure Level (L_{pk})

The Peak Sound Pressure Level is the highest instantaneous level measured by a sound level measurement meter. L_{pk} is typically measured every 20 microseconds, and usually based on unweighted or linear response of the meter. It is used to describe individual impulsive events such as blast noise. Because blast noise varies from shot to shot and varies with meteorological (weather) conditions, the U.S. Department of Defense (DOD) usually characterizes L_{pk} by the metric PK 15(met), which is the L_{pk} exceeded 15% of the time. The "met" notation refers to the metric accounting for varied meteorological or weather conditions.

Sound Exposure Level (SEL)

Sound Exposure Level combines both the intensity of a sound (sound pressure level) and its duration. For an aircraft flyover, SEL includes the maximum and all lower noise levels produced as part of the overflight, together with how long each part lasts. It represents the total sound energy in the event. In addition, SEL can be provided for a single exposure such as a single sonar ping, or for an entire acoustic event such as multiple sonar pings. Figure C-4 indicates the SEL for an example event, representing it as if all the sound energy were contained within 1 second.

Because aircraft noise events last more than a few seconds, the SEL value is larger than L_{max}. It does not directly represent the sound level heard at any given time, but rather the entire event.

SEL is determined by calculating the dB level of the cumulative sum-of-squared pressures over the duration of a sound, with units of dB referenced to 1 micropascal squared per second (μPa^2-s) for sounds in water and dB referenced to 20 μPa^2-s for sounds in air. Some rules of thumb for SEL are as follows:

- The numeric value of SEL is equal to the sound pressure level of a 1-second sound that has the same total energy as the exposure event. If the sound duration is 1 second, sound pressure level and SEL have the same numeric value (but not the same reference quantities). For example, a 1-second sound with a sound pressure level of 100 µPa has an SEL of 100 dB referenced to 1 μPa^2-s.
- If the sound duration is constant but the sound pressure level changes, SEL will change by the same number of dBs as the sound pressure level.
- If the sound pressure level is held constant and the duration changes, SEL will change as a function of 10 $\log_{10}$(duration):
  - 10 $\log_{10}(10) = 10$, so increasing duration by a factor of 10 raises SEL by 10 dB.
  - 10 $\log_{10}(0.1) = -10$, so decreasing duration by a factor of 10 lowers SEL by 10 dB.
  - 10 $\log_{10}(2) = 3$, so doubling the duration increases SEL by 3 dB.
  - 10 $\log_{10}(1/2) = -3$, so halving the duration lowers SEL by 3 dB.

C.2.2 Cumulative Events

Equivalent Sound Level (L_{eq})

Equivalent Sound Level is a "cumulative" metric that combines a series of noise events over a period of time. L_{eq} is the sound level that represents the decibel average SEL of all sounds in the time period. Just as SEL has proven to be a good measure of a single event, L_{eq} has proven to be a good measure of series of events during a given time period.

The time period of an L_{eq} measurement is usually related to some activity, and is given along with the value. The time period is often shown in parenthesis (e.g., $L_{eq(24)}$ for 24 hours). The L_{eq} from 7 a.m. to 3 p.m. may give exposure of noise for a school day.

Figure C-5 gives an example of $L_{eq(24)}$ using notional hourly average noise levels ($L_{eq(h)}$) for each hour of the day as an example. The $L_{eq(24)}$ for this example is 61 dB.

Day-Night Average Sound Level (DNL or L_{dn}) and Community Noise Equivalent Level (CNEL)

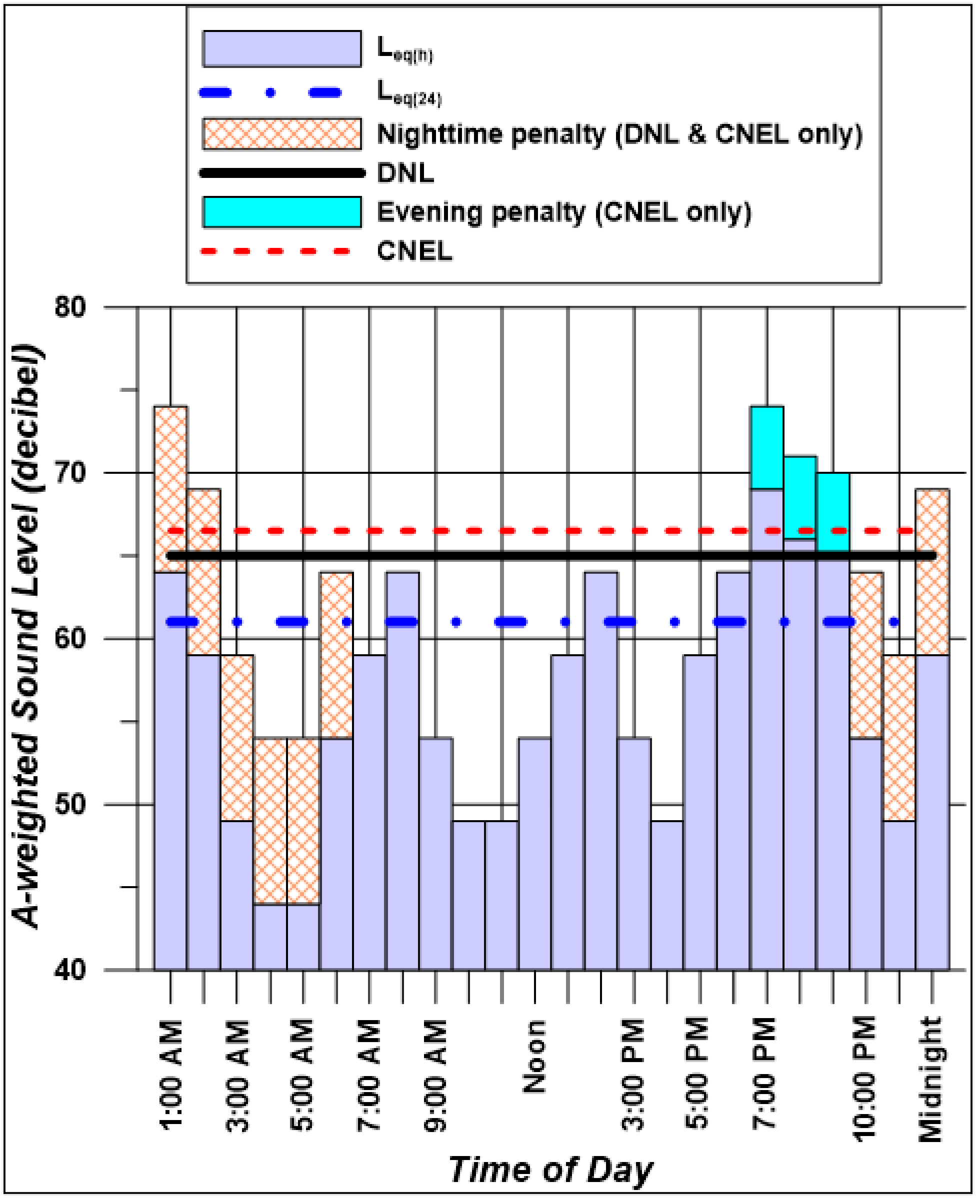
Day-Night Average Sound Level is a cumulative metric that accounts for all noise events in a 24-hour period. However, unlike $L_{eq(24)}$, DNL contains a nighttime noise penalty. To account for our increased sensitivity to noise at night, DNL applies a 10 dB penalty to events during the nighttime period, defined as 10:00 p.m. to 7:00 a.m. The notations DNL and L_{dn} are both used for Day-Night Average Sound Level and are equivalent.

CNEL is a variation of DNL specified by law in California (California Code of Regulations Title 21, *Public Works*) (Wyle Laboratories 1970). CNEL has the 10 dB nighttime penalty for events between 10:00 p.m. and 7:00 a.m. but also includes a 4.8 dB penalty for events during the evening period of 7:00 p.m. to 10:00 p.m. The evening penalty in CNEL accounts for the added intrusiveness of sounds during that period.

For airports and military airfields, DNL and CNEL represent the average sound level for annual average daily aircraft events.

Figure C-5 gives an example of DNL and CNEL using notional hourly average noise levels ($L_{eq(h)}$) for each hour of the day as an example. Note the $L_{eq(h)}$ for the hours between 10 p.m. and 7 a.m. have a 10 dB penalty assigned. For CNEL the hours between 7p.m. and 10 p.m. have a 4.8 dB penalty assigned. The DNL for this example is 65 dB. The CNEL for this example is 66 dB.

Figure C-6 shows the ranges of DNL or CNEL that occur in various types of communities. Under a flight path at a major airport the DNL may exceed 80 dB, while rural areas may experience DNL less than 45 dB.



Source: Wyle Laboratories

Figure C-5 Example of $L_{eq(24)}$, DNL and CNEL Computed from Hourly Equivalent Sound Levels

The decibel summation nature of these metrics causes the noise levels of the loudest events to control the 24-hour average. As a simple example, consider a case in which only one aircraft overflight occurs during the daytime over a 24-hour period, creating a sound level of 100 dB for 30 seconds. During the remaining 23 hours, 59 minutes, and 30 seconds of the day, the ambient sound level is 50 dB. The DNL for this 24-hour period is 65.9 dB. Assume, as a second example that 10 such 30-second overflights occur during daytime hours during the next 24-hour period, with the same ambient sound level of 50 dB during the remaining 23 hours and 55 minutes of the day. The DNL for this 24-hour period is 75.5 dB. Clearly, the averaging of noise over a 24-hour period does not ignore the louder single events and tends to emphasize both the sound levels and number of those events.

A feature of the DNL metric is that a given DNL value could result from a very few noisy events or a large number of quieter events. For example, 1 overflight at 90 dB creates the same DNL as 10 overflights at 80 dB.

DNL or CNEL do not represent a level heard at any given time, but represent long term exposure. Scientific studies have found good correlation between the percentages of groups of people highly annoyed and the level of average noise exposure measured in DNL (Schultz 1978; USEPA 1978).

Onset-Rate Adjusted Monthly Day-Night Average Sound Level (L_{dnmr}) and Onset-Rate Adjusted Monthly Community Noise Equivalent Level ($CNEL_{mr}$)

Military aircraft utilizing Special Use Airspace (SUA) such as Military Training Routes (MTRs), Military Operations Areas (MOAs), and Restricted Areas/Ranges generate a noise environment that is somewhat different from that around airfields. Rather than regularly occurring operations like at airfields, activity in SUAs is highly sporadic. It is often seasonal, ranging from 10 per hour to less than 1 per week. Individual military overflight events also differ from typical community noise events in that noise from a low-altitude, high-airspeed flyover can have a rather sudden onset, with rates of up to 150 dB per second.

The cumulative daily noise metric devised to account for the “surprise” effect of the sudden onset of aircraft noise events on humans and the sporadic nature of SUA activity is the Onset-Rate Adjusted Monthly Day-Night Average Sound Level (L_{dnmr}). Onset rates between 15 and 150 dB per second require an adjustment of 0 to 11 dB to the event’s SEL, while onset rates below 15 dB per second require no adjustment to the event’s SEL (Stusnick et al. 1992). The term “monthly” in L_{dnmr} refers to the noise assessment being conducted for the month with the most operations or sorties -- the so-called busiest month.

In California, a variant of the L_{dnmr} includes a penalty for evening operations (7 p.m. to 10 p.m.) and is denoted $CNEL_{mr}$.

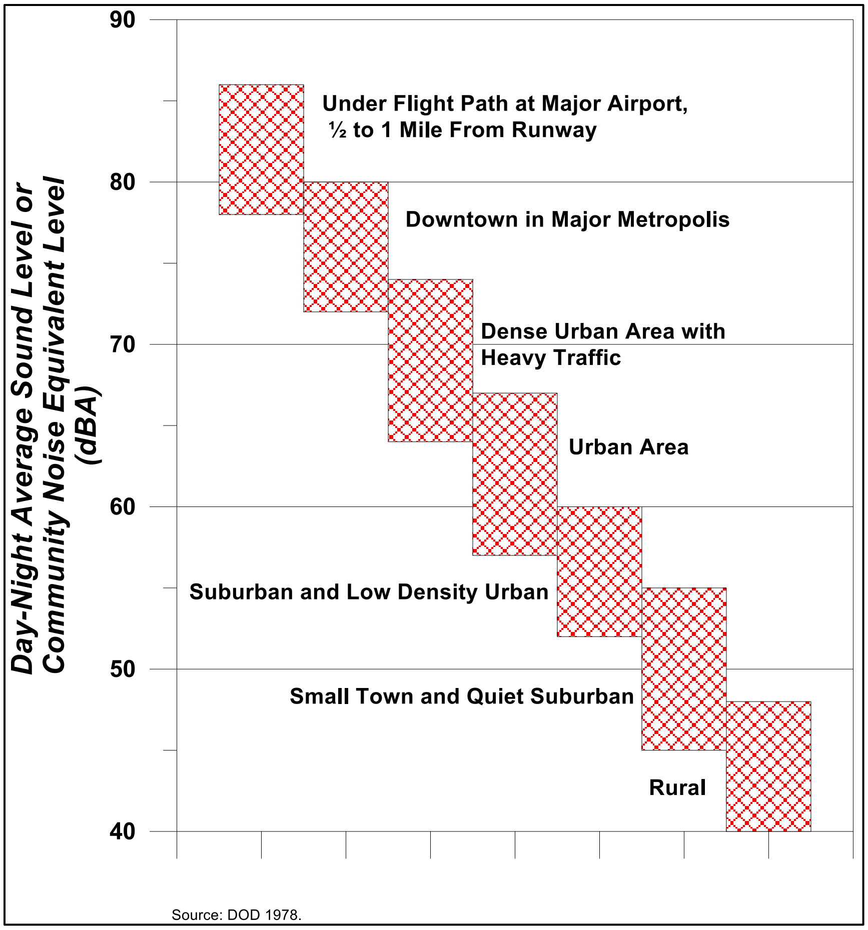


Figure C-6 Typical DNL or CNEL Ranges in Various Types of Communities

C.2.3 Supplemental Metrics

Number-of-Events Above (NA) a Threshold Level (L)

The Number-of-Events Above (NA) metric gives the total number of events that exceed a noise level threshold (L) during a specified period of time. Combined with the selected threshold, the metric is denoted NAL. The threshold can be either SEL or L_{max}, and it is important that this selection is shown in the nomenclature. When labeling a contour line or point of interest (POI), NAL is followed by the number of events in parentheses. For example, where 10 events exceed an SEL of 90 dB over a given period of time, the nomenclature would be NA90SEL(10). Similarly, for L_{max} it would be NA90L_{max}(10). The period of time can be an average 24-hour day, daytime, nighttime, school day, or any other time period appropriate to the nature and application of the analysis.

NA is a supplemental metric. It is not supported by the amount of science behind DNL/CNEL, but it is valuable in helping to describe noise to the community. A threshold level and metric are selected that best meet the need for each situation. An L_{max} threshold is normally selected to analyze speech interference, while an SEL threshold is normally selected for analysis of sleep disturbance.

The NA metric is the only supplemental metric that combines single-event noise levels with the number of aircraft operations. In essence, it answers the question of how many aircraft (or range of aircraft) fly over a given location or area at or above a selected threshold noise level.

Time Above (TA) a Specified Level (L)

The Time Above (TA) metric is the total time, in minutes, that the A-weighted noise level is at or above a threshold. Combined with the threshold level (L), it is denoted TAL. TA can be calculated over a full 24-hour annual average day, the 15-hour daytime and 9-hour nighttime periods, a school day, or any other time period of interest, provided there is operational data for that time.

TA is a supplemental metric, used to help understand noise exposure. It is useful for describing the noise environment in schools, particularly when assessing classroom or other noise sensitive areas for various scenarios. TA can be shown as contours on a map similar to the way DNL contours are drawn.

TA helps describe the noise exposure of an individual event or many events occurring over a given time period. When computed for a full day, the TA can be compared alongside the DNL in order to determine the sound levels and total duration of events that contribute to the DNL. TA analysis is usually conducted along with NA analysis so the results show not only how many events occur, but also the total duration of those events above the threshold.

C.3 Predicting How Sound Travels

While the concept of a sound wave traveling from its source to a receptor is relatively simple, sound propagation is quite complex because of the simultaneous presence of numerous sound waves of different frequencies and source levels, and other phenomena such as reflections of sound waves and subsequent constructive (additive) or destructive (cancelling) interferences between reflected and incident waves. Other factors such as refraction, diffraction, bottom types, and surface conditions also affect sound propagation. While simple examples are provided here for illustration, the Navy Acoustic Effects Model used to quantify acoustic exposures to marine mammals and sea turtles, takes into account the influence of multiple factors to predict acoustic propagation. Refer to the technical report entitled *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing* (Navy, 2018).

C.3.1 Speed of Sound

The speed of sound is not affected by the SPL or frequency of the sound, but rather depends wholly on characteristics of the medium through which it is passing (e.g., the density and the compressibility). Sound travels faster through a medium that is harder to compress. For example, water is more difficult to compress than air, and sound travels approximately 340 meters per second in air and 1,500 meters per second in seawater.

The speed of sound in air is primarily influenced by temperature, relative humidity, and pressure, because these factors affect the density and compressibility of air. Generally, the speed of sound in air increases as air temperature increases.

The speed of sound in seawater also increases with increasing temperature and, to a lesser degree, with increasing hydrostatic pressure and salinity. In seawater, temperature has the most important effect on sound speed for depths less than approximately 300 meters. Below 1,500 meters, the increasing hydrostatic pressure is the dominant factor because the water temperature is relatively constant. The variation of sound speed with depth in the ocean is called a sound velocity profile.

C.3.2 Source Directivity

Most active acoustic sources do not radiate sound in all directions. Rather, they emit sounds over a limited range of angles, in order to focus sound energy on a specific area or object of interest. The specific angles are sometimes given as horizontal or vertical beam width. Some sources can be described qualitatively as "forward-looking," when sound energy is radiated in a limited direction in front of the source, or "downward-looking," when sound energy is directed toward the bottom.

C.3.3 Sound Attenuation

As a sound wave passes through a medium, the sound level decreases with distance from the sound source. This phenomenon is known as attenuation, which is described in terms of transmission loss (TL). The transmission loss is used to relate the source **sound pressure level** (SL), defined as the **sound pressure level** produced by a sound source at a distance of one meter, and the received **sound pressure level** (RL) at a particular location, as follows:

RL = SL – TL

The main contributors to sound attenuation are as follows (Urick, 1983):

- geometric spreading of the sound wave as it propagates away from the source
- sound absorption (conversion of sound energy into heat)
- scattering, diffraction, multipath interference, and boundary effects

C.3.3.1 Geometric Spreading Loss

Spreading loss is a geometric effect representing regular weakening of a sound wave as it spreads out from a source. Spreading describes the reduction in sound pressure caused by the increase in surface area as the distance from a sound source increases. Spherical and cylindrical spreading are common types of spreading loss.

In the simple case of sound propagating from a point source without obstruction or reflection, the sound waves take on the shape of an expanding sphere. An example of spherical spreading loss is shown in Figure C-7. As spherical propagation continues, the sound energy is distributed over an ever-larger area following the inverse square law: the pressure of a sound wave decreases inversely with the square of the distance between the source and the receptor. For example, doubling the distance between the receptor and a sound source results in a reduction in the pressure of the sound to one-fourth of its initial value, tripling the distance results in one-ninth of the original pressure, and so on. Since the surface area of a sphere is 4πr2, where r is the sphere radius, the change in SPL with distance *r* from the source is proportional to the radius squared. This relationship is known as the spherical spreading law. The transmission loss for spherical spreading between two locations is:

TL = 20 $\log_{10}$ (r2/r1),

where r1 and r2 are distances from the source. Spherical spreading results in a 6 dB reduction in SPL for each doubling of distance from the sound source. For example, calculated transmission loss for spherical spreading is 40 dB at 100 meters and 46 dB at 200 meters.

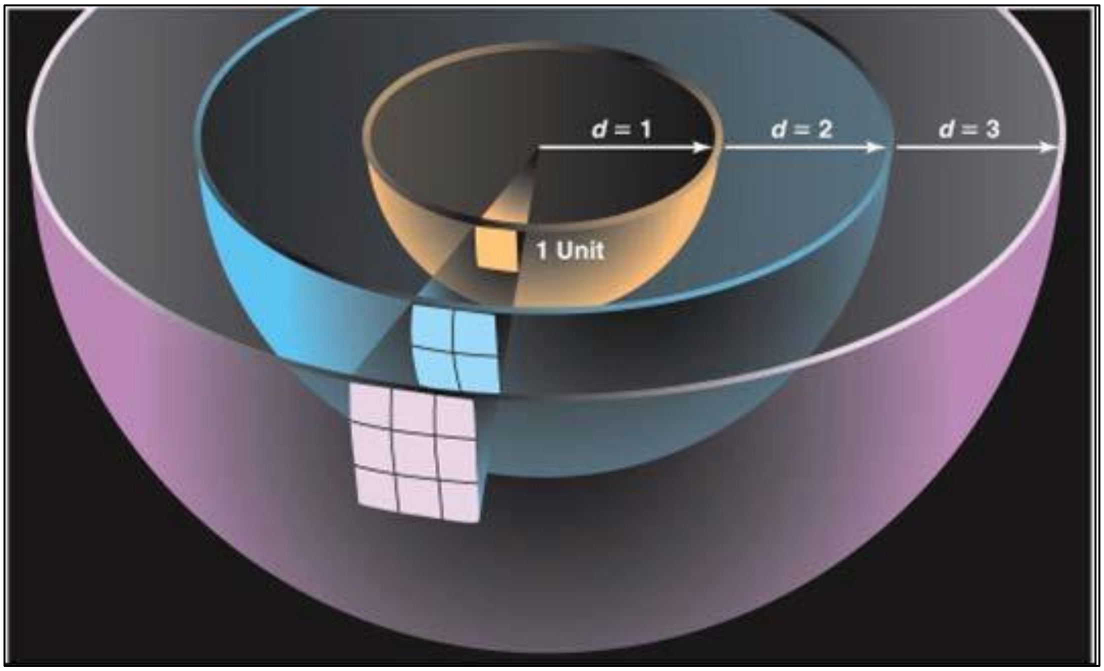


Figure C-7 Graphical Representation of the Inverse Square Relationship in Spherical Spreading

In cylindrical spreading, spherical waves expanding from the source are constrained by the water surface and the sea floor and take on a cylindrical shape. In this case, the sound wave expands in the shape of a cylinder rather than a sphere, and the transmission loss is:

$TL = 10 \log_{10}(r2/r1)$

Cylindrical spreading is an approximation of sound propagation in a water-filled channel with horizontal dimensions much larger than the depth. Cylindrical spreading predicts a 3-dB reduction in SPL for each doubling of distance from the source. For example, calculated transmission loss for cylindrical spreading is 30 dB at 1,000 meters and 33 dB at 2,000 meters.

The cylindrical and spherical spreading equations above represent two simple hypothetical cases. In reality, geometric spreading loss is more spherical near a source and more cylindrical with distance, and is better predicted using more complex models that account for environmental variables, such as the Navy Acoustic Effects Model. Refer to the technical report entitled *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing* (Navy, 2018).

However, when conducting simple spreading loss calculations in near-shore environments, “practical spreading loss” can be applied, where:

$TL = 15 \log_{10} (r2/r1)$

Practical spreading loss accounts for other realistic losses in the environment, such as absorption and scattering, which are not accounted for in geometrical spreading.

C.3.3.2 Absorption

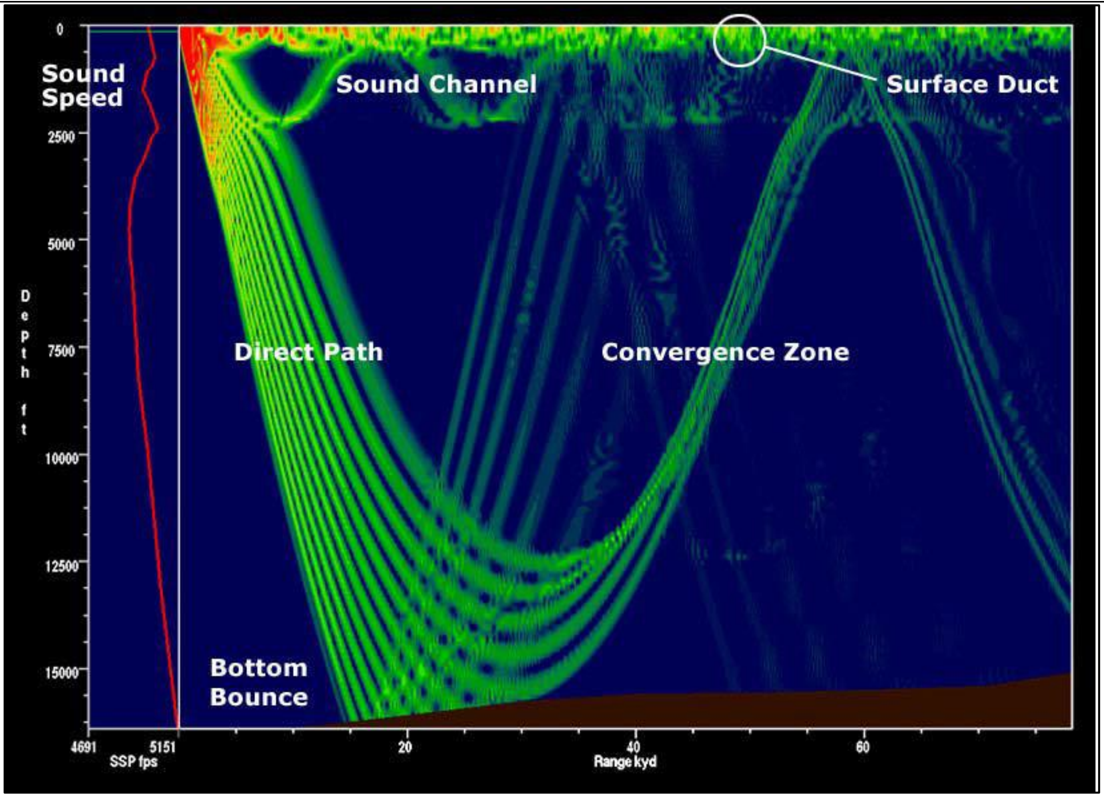
Absorption is the conversion of acoustic energy to kinetic energy in the particles of the propagation medium (Urick, 1983). Absorption is directly related to sound frequency, with higher frequencies having higher rates of absorption. Absorption rates range from 0.07 dB/kilometer for a 1 kHz sound to about 30 dB/kilometer for a 100 kHz sound. Therefore, absorption is the cause of a significant amount of attenuation for high- and very high-frequency sound sources, reducing the distance over which these sources may be perceived compared to mid- and low-frequency sound sources with the same source level.

C.3.3.3 Refraction

When a sound wave propagating in a medium encounters a second medium with a different density (e.g., the air-water boundary), part of the incident sound will be reflected back into the first medium and part will be transmitted into the second medium (Kinsler et al., 1982). The propagation direction will change as the sound wave enters the second medium; this phenomenon is called refraction. Refraction may also occur within a single medium if the properties of the medium change enough to cause a variation in the sound speed. Refraction of sound resulting from spatial variations in the sound speed is one of the most important phenomena that affect sound propagation in water (Urick, 1983).

As discussed in Section C.3.1, the sound speed in the ocean primarily depends on hydrostatic pressure (i.e., depth) and temperature. Although the actual variations in sound speed are small, the existence of sound speed gradients in the ocean has an enormous effect on the propagation of sound in the ocean. If one pictures sound as rays emanating from an underwater source, the propagation of these rays changes as a function of the sound speed profile in the water column. Specifically, the directions of the rays bend toward regions of slower sound speed. This phenomenon creates ducts in which sound becomes “trapped,” allowing it to propagate with high efficiency for large distances within certain depth boundaries. During winter months, the reduced sound speed at the surface due to cooling can create a surface duct that efficiently propagates sound such as commercial shipping noise (Figure C-8). Sources located within this surface duct can have their sounds trapped, but sources located below this layer would have their sounds refracted downward. The deep sound channel, or sound frequency and ranging channel, is another duct that exists where sound speeds are slowest deeper in the water column (600–1,200-meter depth at the mid-latitudes).

Similarly, the path of sound will bend toward regions of lower sound speed in air. Air temperature typically decreases with altitude, meaning sounds produced in air tend to bend skyward. When an atmospheric temperature inversion is present, air is cooler near the earth’s surface. In inversion conditions, sound waves near the earth’s surface will tend to refract downward.



[1 kiloyard (kyd) = 0.9 kilometers (km)]

Figure C-8 Sound Propagation Showing Multipath Propagation and Conditions for Surface Duct

C.3.3.4 Reflection and Multipath Propagation

In multipath propagation, sound may not only travel a direct path (with no reflection) from a source to a receiver, but also be reflected from the surface or bottom multiple times before reaching the receiver (Urick, 1983). Reflection is shown in Figure C-8 at the sea floor (bottom bounce) and at the water surface. At some distances, the reflected wave will be in phase with the direct wave (their waveforms add together), and at other distances the two waves will be out of phase (their waveforms cancel). The existence of multiple sound paths, or rays, arriving at a single point can result in multipath interference, a condition that permits the addition and cancellation between sound waves, resulting in the fluctuation of sound levels over short distances.

Reflection plays an important role in the pressures observed at different locations in the water column. Near the bottom, the direct path pressure wave may sum with the bottom-reflected pressure wave, increasing the exposure. Near the surface, however, the surface-reflected pressure wave may destructively interfere with the direct path pressure wave, “cutting off” the wave and reducing exposure (called the Lloyd mirror effect). This can cause the sound level to decrease dramatically within the top few meters of the water column.

C.3.3.5 Diffraction, Scattering, and Reverberation

Diffraction, scattering, and reverberation are examples of what happens when sound waves interact with obstacles in the propagation path.

Diffraction may be thought of as the change of direction of a sound wave as it passes around an obstacle. Diffraction depends on the size of the obstacle and the sound frequency. The wavelength of the sound must be larger than the obstacle for notable diffraction to occur. If the obstacle is larger than the wavelength of sound, an acoustic shadow zone will exist behind the obstacle where the sound is unlikely to be detected. Common examples of diffraction include sound heard from a source around the corner of a building and sound propagating through a small gap in an otherwise closed door or window.

An obstacle or inhomogeneity (e.g., smoke, suspended particles, gas bubbles due to waves, and marine life) in the path of a sound wave causes scattering as these inhomogeneities reradiate incident sound in a variety of directions (Urick, 1983). Reverberation refers to the prolongation of a sound, after the source has stopped emitting, caused by multiple reflections at water boundaries (surface and bottom) and scattering.

C.3.3.6 Surface and Bottom Effects

Because the sea surface reflects and scatters sound, it has a major effect on the propagation of underwater sound in applications where either the source or receiver is at a shallow depth (Urick 1983). If the sea surface is smooth, the reflected sound pressure is nearly equal to the incident sound pressure; however, if the sea surface is rough, the amplitude of the reflected sound wave will be reduced. Sound waves reflected from the sea surface experience a phase reversal. When the surface-reflected waves interact with the direct path waves near the surface, a destructive interference pattern is created in which the received pressure approaches zero.

The sea bottom is also a reflecting and scattering surface, similar to the sea surface. Sound interaction with the sea bottom is more complex, however, primarily because the acoustic properties of the sea bottom are more variable, and the bottom is often layered into regions of differing density. As sound travels into the sea floor, it reflects off of these different density layers in complex ways. For sources in contact with the bottom, such as during pile driving or bottom-placed explosives, a ground wave is produced that travels through the bottom sediment and may refract back into the water column.

For a hard bottom such as rock, the reflected wave will be approximately in phase with the incident wave. Thus, near the ocean bottom, the incident and reflected sound pressures may add together (constructive interference), resulting in an increased sound pressure near the sea bottom. Soft bottoms, such as mud or sediment, absorb sound waves and reduce the level in the water column overall.

C.3.3.7 Air-Water Interface

Sound from aerial sources, such as aircraft and weapons firing, may be transmitted into the water under certain conditions. The most studied of these sources are fixed-wing aircraft and helicopters, which create noise with most energy below 500 Hz. Noise levels in water are highest at the surface and are highly dependent on the altitude of the aircraft and the angle at which the aerial sound encounters the ocean surface. Transmission of the sound once it is in the water is identical to any other sound as described in the sections above.

Transmission of sound from a moving airborne source to a receptor underwater is influenced by numerous factors and has been addressed by Young (1973), Urick (1983), Richardson et al. (1995), Eller and Cavanagh (2000), Laney and Cavanagh (2000), and others. Sound is transmitted from an airborne source to a receptor underwater by four principal means: (1) a direct path, refracted upon passing through the air-water interface; (2) direct-refracted paths reflected from the bottom in shallow water; (3) evanescent transmission in which sound travels laterally close to the water surface; and (4) scattering from interface roughness due to wave motion.

When sound waves in air meet the water surface, the sound can either be transmitted across the air-water boundary or reflected off the water surface. When sound waves meet the water at a perpendicular angle (e.g., straight down from an in-air source to a flat water surface), the sound waves are both transmitted directly across the water surface in the same direction of travel and reflected 180 degrees back toward the original direction of travel. This can create a localized condition at the water surface where the incident and reflected waves sum, doubling the in-air overpressure (+6 dB). As the incident angle of the in-air sound wave changes from perpendicular, this phenomena is reduced, ultimately reaching the angle where sound waves are parallel to the water surface and there is no surface reflection.

The sound that enters the water is refracted due to the difference in sound velocity between air and water, as shown in Figure C-9. As the angle of the in-air incident wave moves away from perpendicular, the direction of travel of the underwater refracted waves becomes closer to parallel to the water surface. When the incident angle is reached where the underwater refracted sound wave is parallel to the water surface, all of the sound is reflected back into the air and no sound enters the water. This occurs at an angle of about 13–14 degrees. As a result, most of the acoustic energy is transmitted into the water through a relatively narrow cone extending vertically downward from the in-air source. The width of the footprint would be a function of the source altitude. Lesser amounts of sound may enter the water outside of this cone due to surface scattering (e.g., from water surface waves that can vary the angle of incidence over an area) and evanescent waves that are only present very near the surface.

If a sound wave is ideally transmitted into water (that is, with no surface transmission loss, such as due to foamy, wave conditions that could decrease sound entering the water), the sound pressure level underwater is calculated by changing the pressure reference unit from 20 μPa in air to 1 μPa in water. For a sound with the same pressure in air and water, this calculation results in a +26 dB sound pressure level in water compared to air. For this reason, sound pressure levels in water and sound pressure levels in air should never be directly compared.

C.4 Auditory Perception

Animals with an eardrum or similar structure, including mammals, birds, and reptiles, directly detect the pressure component of sound. Some marine fish also have specializations to detect pressure changes, although most invertebrates and many marine fish do not have anatomical structures that enable them to detect the pressure component of sound, and are only sensitive to the particle motion component of sound. This difference in acoustic energy sensing mechanisms limits the range at which these animals can detect most sound sources analyzed in this document. This is because, far from a sound source (i.e., in the far field), particle velocity and sound pressure are directly proportional. But close to a source (i.e., in the near field), particle velocity increases relative to sound pressure and may become more detectable to certain animals. As sound frequency increases, the wavelength becomes shorter, resulting in a smaller near field.

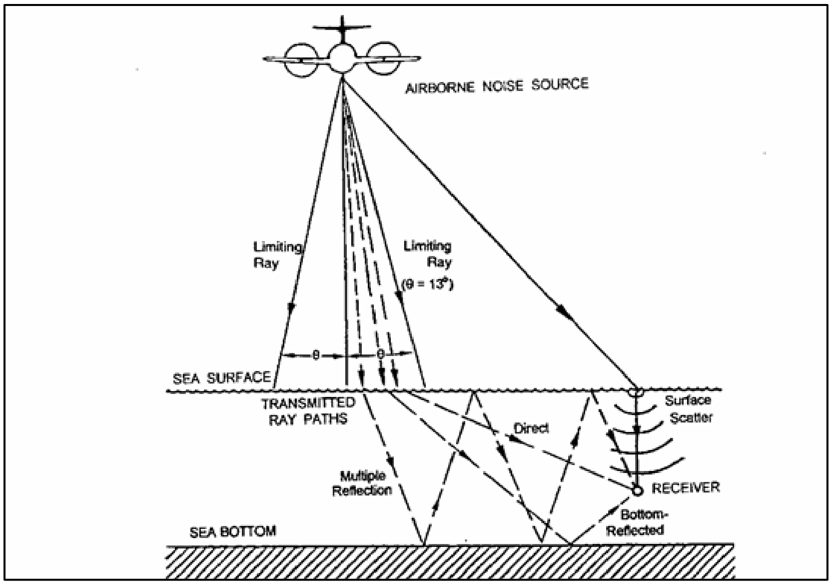


Figure C-9 Characteristics of Sound Transmission Through the Air-Water Interface

Because mammalian ears can detect large pressure ranges and humans judge the relative loudness of sounds by the ratio of the sound pressures (a logarithmic behavior), sound amplitude is described by the SPL, calculated by taking the logarithm of the ratio of the sound pressure to a reference pressure (see Section C.2.1). Use of a logarithmic scale compresses the wide range of pressure values into a more usable numerical scale. On the dB scale, the smallest audible sound in air (near total silence) to a human is 0 decibels referenced to 20 micropascals (dB re 20 µPa). If the sound intensity increases by a factor of 10, the SPL would increase to 10 dB re 20 µPa. If the sound intensity increases by a factor of 100, the SPL would increase to 20 dB re 20 µPa, and if the sound intensity increases by a factor of 1000, the SPL would be 30 dB re 20 µPa. A quiet conversation has an SPL of about 50 dB re 20 µPa, while the threshold of pain is around 120–140 dB re 20 µPa.

As described in Section C.2.1, SPLs under water differ from those in air because they rely on different reference pressures in their calculation; therefore, the two should never be directly compared.

While sound pressure and frequency are physical measures of the sound, loudness is a subjective attribute that varies with not only sound pressure, but also other attributes of the sound, such as frequency. For example, a human listener would perceive a 60 dB re 20 µPa sound at 2 kHz to be louder than a 60 dB re 20 µPa sound at 50 Hz, even though the SPLs are identical. This effect is most noticeable at lower sound pressure levels; however, at very high sound pressure levels, the difference in perceived loudness at different frequencies becomes smaller.

Many measurements of sound in air appear as dBAs in the literature because the intent of the authors is to assess noise impacts on humans. The auditory weighting concept can be applied to other species. When used in analyzing the impacts of sound on an animal, auditory weighting functions adjust received sound levels to emphasize ranges of best hearing and de-emphasize ranges of less or no sensitivity. Auditory weighting functions were developed for marine mammals and sea turtles and are used to assess acoustic impacts. For more information on weighting functions and their derivation for this analysis, see the technical report entitled *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis* (Navy, 2017).

C.5 Noise Effects

Noise is of concern because of potential adverse effects. The following subsections describe how noise can affect communities and the environment, and how those effects are quantified. The specific topics discussed are:

- annoyance
- speech interference
- sleep disturbance
- noise-induced hearing impairment
- non-auditory health effects
- performance effects
- noise effects on children
- property values
- noise-induced vibration effects on structures and humans
- noise effects on terrain
- noise effects on historical and archaeological sites
- effects on domestic animals and wildlife

C.5.1 Annoyance

With the introduction of jet aircraft in the 1950s, it became clear that aircraft noise annoyed people and was a significant problem around airports. Early studies, such as those of Rosenblith et al. (1953) and Stevens et al. (1953) showed that effects depended on the quality of the sound, its level, and the number of flights. Over the next 20 years considerable research was performed refining this understanding and setting guidelines for noise exposure. In the early 1970s, the USEPA published its "Levels Document" (USEPA 1974) that reviewed the factors that affected communities. DNL (still known as L_{dn} at the time) was identified as an appropriate noise metric, and threshold criteria were recommended.

Threshold criteria for annoyance were identified from social surveys, where people exposed to noise were asked how noise affects them. Surveys provide direct real-world data on how noise affects actual residents.

Surveys in the early years had a range of designs and formats, and needed some interpretation to find common ground. In 1978, Schultz showed that the common ground was the number of people "highly annoyed," defined as the upper 28% range of whatever response scale a survey used (Schultz 1978). With that definition, he was able to show a remarkable consistency among the majority of the surveys for which data were available. Figure C-10 shows the result of his study relating DNL to individual annoyance measured by percent highly annoyed (%HA).

Schultz's original synthesis included 161 data points. Figure C-11 compares revised fits of the Schultz data set with an expanded set of 400 data points collected through 1989 (Finegold et al. 1994). The new form is the preferred form in the U.S., endorsed by the Federal Interagency Committee on Aviation Noise (FICAN 1997). Other forms have been proposed, such as that of Fidell and Silvati (2004), but have not gained widespread acceptance.

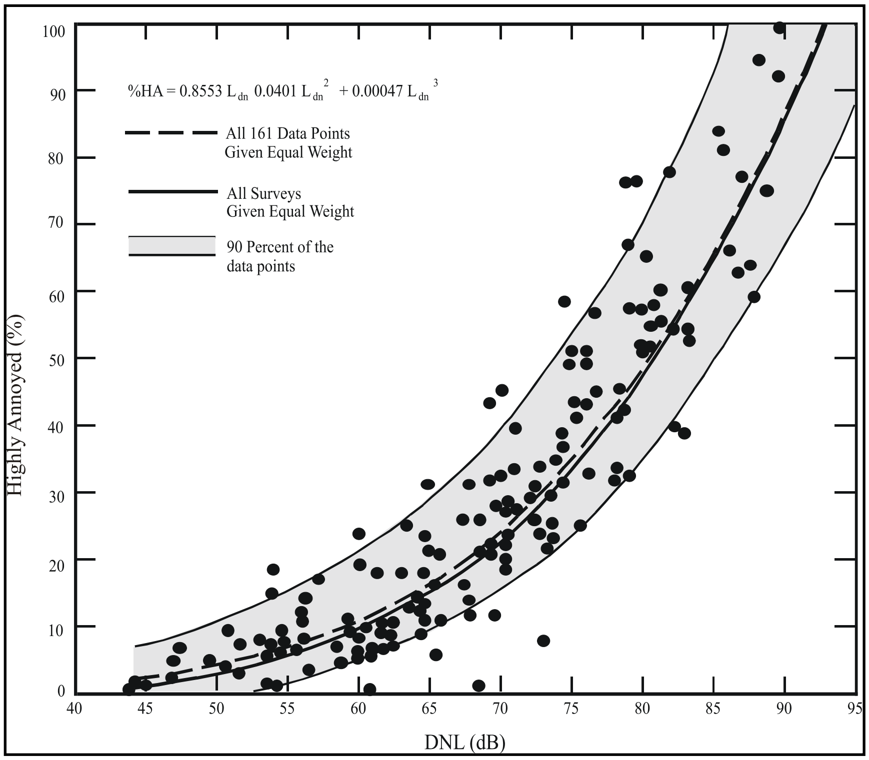


Figure C-10 Schultz Curve Relating Noise Annoyance to DNL (Schultz 1978)

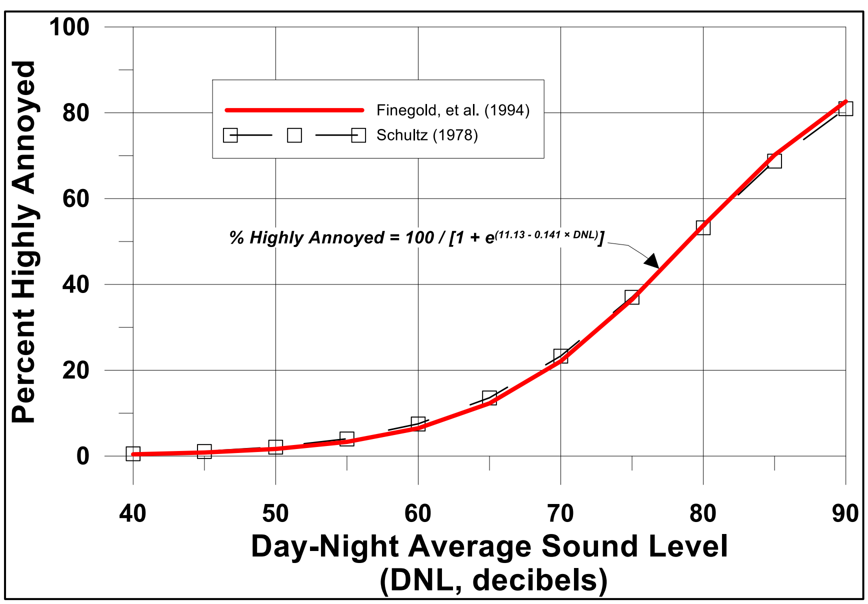


Figure C-11 Response of Communities to Noise; Comparison of Original Schultz (1978) with Finegold et al. (1994)

When the goodness of fit of the Schultz curve is examined, the correlation between groups of people is high, in the range of 85-90%. However, the correlation between individuals is much lower, at 50% or less. This is not surprising, given the personal differences between individuals. The surveys underlying the Schultz curve include results that show that annoyance to noise is also affected by non-acoustical factors. Newman and Beattie (1985) divided the non-acoustic factors into the emotional and physical variables shown in Table C-1.

Table C-1 Non-Acoustic Variables Influencing Aircraft Noise Annoyance

Emotional Variables	*Physical Variables*
• Feeling about the necessity or preventability of the noise • Judgement of the importance and value of the activity that is producing the noise; • Activity at the time an individual hears the noise; • Attitude about the environment; • General sensitivity to noise; • Belief about the effect of noise on health; and • Feeling of fear associated with the noise.	• Type of neighborhood; • Time of day; • Season; • Predictability of the noise; • Control over the noise source; and • Length of time individual is exposed to a noise.

Schreckenberg and Schuemer (2010) recently examined the importance of some of these factors on short term annoyance. Attitudinal factors were identified as having an effect on annoyance. In formal regression analysis, however, sound level (L_{eq}) was found to be more important than attitude. A series of studies at three European airports showed that less than 20 percent of the variance in annoyance can be explained by noise alone (Marki 2013)

A recent study by Plotkin et al. (2011) examined updating DNL to account for these factors. It was concluded that the data requirements for a general analysis were much greater than are available from most existing studies. It was noted that the most significant issue with DNL is that it is not readily understood by the public, and that supplemental metrics such as TA and NA were valuable in addressing attitude when communicating noise analysis to communities (DOD 2009a).

A factor that is partially non-acoustical is the source of the noise. Miedema and Vos (1998) presented synthesis curves for the relationship between DNL and percentage “Annoyed” and percentage “Highly Annoyed” for three transportation noise sources. Different curves were found for aircraft, road traffic, and railway noise. Table C-2 summarizes their results. Comparing the updated Schultz curve suggests that the percentage of people highly annoyed by aircraft noise may be higher than previously thought.

As noted by the World Health Organization (WHO), however, even though aircraft noise seems to produce a stronger annoyance response than road traffic, caution should be exercised when interpreting synthesized data from different studies (WHO 1999).

Consistent with WHO’s recommendations, the Federal Interagency Committee on Noise (FICON 1992) considered the Schultz curve to be the best source of dose information to predict community response to noise, but recommended further research to investigate the differences in perception of noise from different sources. Recent studies suggest that annoyance response to aircraft noise may have increased over the years (Basner, et al., 2017). However, current Department of Defense guidelines continue to recommend application of the Schultz curve in reaction of community reaction to noise (DoD, 2009d).

Table C-2 Percent Highly Annoyed for Different Transportation Noise Sources

DNL (dB)	*Percent Highly Annoyed (%HA)*			
	Miedema and Vos			*Schultz Combined*
	Air	*Road*	*Rail*	
55	12	7	4	3
60	19	12	7	6
65	28	18	11	12
70	37	29	16	22
75	48	40	22	36

Sources: (Miedema and Vos, 1998)
Key: dB = decibel; DNL = Day-Night Average Sound Level; HA = Highly Annoyed.

C.5.2 Speech Interference

Speech interference from noise is a primary cause of annoyance for communities. Disruption of routine activities such as radio or television listening, telephone use, or conversation leads to frustration and annoyance. The quality of speech communication is important in classrooms and offices. In the workplace, speech interference from noise can cause fatigue and vocal strain in those who attempt to talk over the noise. In schools it can impair learning.

There are two measures of speech comprehension:

1. **Word Intelligibility:** the percent of words spoken and understood. This might be important for students in the lower grades who are learning the English language, and particularly for students who have English as a Second Language.

2. **Sentence Intelligibility:** *the percent of sentences spoken and understood. This might be important for high-school students and adults who are familiar with the language, and who do not necessarily have to understand each word in order to understand sentences.*

U.S. Federal Criteria for Interior Noise

In 1974, the USEPA identified a goal of an indoor $L_{eq(24)}$ of 45 dB to minimize speech interference based on sentence intelligibility and the presence of steady noise (USEPA 1974). Figure C-12 shows the effect of steady indoor background sound levels on sentence intelligibility. For an average adult with normal hearing and fluency in the language, steady background indoor sound levels of less than 45 dB L_{eq} are expected to allow 100% sentence intelligibility.

The curve in Figure C-12 shows 99% intelligibility at L_{eq} below 54 dB, and less than 10% above 73 dB. Recalling that L_{eq} is dominated by louder noise events, the USEPA $L_{eq(24)}$ goal of 45 dB generally ensures that sentence intelligibility will be high most of the time.

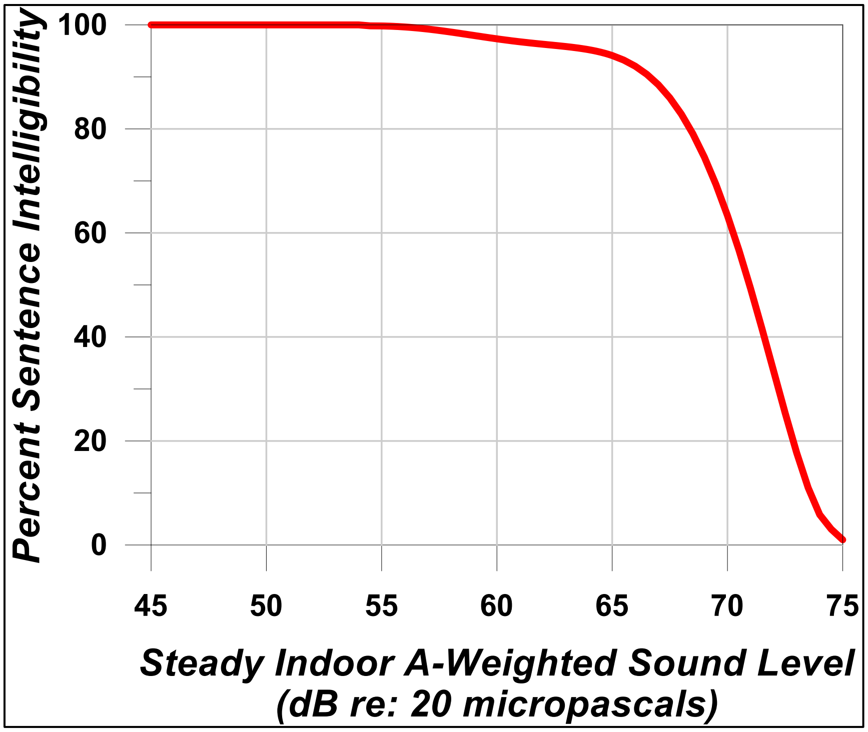


Figure C-12 Speech Intelligibility Curve (digitized from USEPA 1974)

Classroom Criteria

For teachers to be understood, their regular voice must be clear and uninterrupted. Background noise has to be below the teacher's voice level. Intermittent noise events that momentarily drown out the teacher's voice need to be kept to a minimum. It is therefore important to evaluate the steady background level, the level of voice communication, and the single-event level due to aircraft overflights that might interfere with speech.

Lazarus (1990) found that for listeners with normal hearing and fluency in the language, complete sentence intelligibility can be achieved when the signal-to-noise ratio (i.e., a comparison of the level of the sound to the level of background noise) is in the range of 15 to 18 dB. The initial ANSI classroom noise standard (ANSI 2002) and American Speech-Language-Hearing Association (ASLHA 2005) guidelines concur, recommending at least a 15 dB signal-to-noise ratio in classrooms. If the teacher's voice level is at least 50 dB, the background noise level must not exceed an average of 35 dB. The National Research Council of Canada (Bradley 1993) and WHO (1999) agree with this criterion for background noise.

For eligibility for noise insulation funding, the Federal Aviation Administration (FAA) guidelines state that the design objective for a classroom environment is 45 dB L_{eq} during normal school hours (FAA 1985).

Most aircraft noise is not continuous. It consists of individual events like the one sketched in Figure C-4. Since speech interference in the presence of aircraft noise is caused by individual aircraft flyover events, a time-averaged metric alone, such as L_{eq}, is not necessarily appropriate. In addition to the background level criteria described above, single-event criteria that account for those noisy events are also needed.

A 1984 study by Wyle for the Port Authority of New York and New Jersey recommended using Speech Interference Level (SIL) for classroom noise criteria (Sharp and Plotkin 1984). SIL is based on the maximum sound levels in the frequency range that most affects speech communication (500-2,000 Hz). The study identified an SIL of 45 dB as the goal. This would provide 90% word intelligibility for the short time periods during aircraft overflights. While SIL is technically the best metric for speech interference, it can be approximated by an L_{max} value. An SIL of 45 dB is equivalent to an A-weighted L_{max} of 50 dB for aircraft noise (Wesler 1986).

Lind et al. (1998) also concluded that an L_{max} criterion of 50 dB would result in 90% word intelligibility. Bradley (1985) recommends SEL as a better indicator. His work indicates that 95% word intelligibility would be achieved when indoor SEL did not exceed 60 dB. For typical flyover noise this corresponds to an L_{max} of 50 dB. While WHO (1999) only specifies a background L_{max} criterion, they also note the SIL frequencies and that interference can begin at around 50 dB.

The United Kingdom Department for Education and Skills (UKDfES) established in its classroom acoustics guide a 30-minute time-averaged metric of $L_{eq(30min)}$ for background levels and the metric of $L_{A1,30min}$ for intermittent noises, at thresholds of 30-35 dB and 55 dB, respectively. $L_{A1,30min}$ represents the A-weighted sound level that is exceeded 1% of the time (in this case, during a 30-minute teaching session) and is generally equivalent to the L_{max} metric (UKDfES 2003).

Table C-3 summarizes the criteria discussed. Other than the FAA (1985) 45 dB L_{max} criterion, they are consistent with a limit on indoor background noise of 35-40 dB L_{eq} and a single event limit of 50 dB L_{max}. It should be noted that these limits were set based on students with normal hearing and no special needs. At-risk students may be adversely affected at lower sound levels.

Table C-3 Indoor Noise Level Criteria Based on Speech Intelligibility

Source	*Metric/Level (dB)*	*Effects and Notes*
U.S. FAA (1985)	L_{eq}(during school hours) = 45 dB	Federal assistance criteria for school sound insulation; supplemental single-event criteria may be used.
Lind et al. (1998), Sharp and Plotkin (1984), Wesler (1986)	L_{max} = 50 dB / SIL 45	Single event level permissible in the classroom.
WHO (1999)	L_{eq} = 35 dB L_{max} = 50 dB	Assumes average speech level of 50 dB and recommends signal to noise ratio of 15 dB.
U.S. ANSI (2010)	L_{eq} = 35 dB, based on Room Volume (e.g., cubic feet)	Acceptable background level for continuous and intermittent noise.
UKDFES (2003)	$L_{eq(30min)}$ = 30-35 dB L_{max} = 55 dB	Minimum acceptable in classroom and most other learning environs.

Key: ANSI = American National Standards Institute; dB = Decibel; FAA = Federal Aviation Administration (US); L_{eq} = Equivalent Sound Level; L_{max} = Maximum Sound Level; SIL = Speech Interference Level; UK DFES = United Kingdom Department for Education and Skills; U.S. = United States; WHO = World Health Organization.

C.5.3 Sleep Disturbance

Sleep disturbance is a major concern for communities exposed to aircraft noise at night. A number of studies have attempted to quantify the effects of noise on sleep. This section provides an overview of the major noise-induced sleep disturbance studies. Emphasis is on studies that have influenced U.S. federal noise policy. The studies have been separated into two groups:

1. Initial studies performed in the 1960s and 1970s, where the research was focused on sleep observations performed under laboratory conditions.
2. Later studies performed in the 1990s up to the present, where the research was focused on field observations.

Initial Studies

The relation between noise and sleep disturbance is complex and not fully understood. The disturbance depends not only on the depth of sleep and the noise level, but also on the non-acoustic factors cited for annoyance. The easiest effect to measure is the number of arousals or awakenings from noise events. Much of the literature has therefore focused on predicting the percentage of the population that will be awakened at various noise levels.

FICON's 1992 review of airport noise issues (FICON 1992) included an overview of relevant research conducted through the 1970s. Literature reviews and analyses were conducted from 1978 through 1989 using existing data (Griefahn 1978; Lukas 1978; Pearsons et. al. 1989). Because of large variability in the data, FICON did not endorse the reliability of those results.

FICON did, however, recommend an interim dose-response curve, awaiting future research. That curve predicted the percent of the population expected to be awakened as a function of the exposure to SEL. This curve was based on research conducted for the U.S. Air Force (Finegold 1994). The data included most of the research performed up to that point, and predicted a 10% probability of awakening when exposed to an interior SEL of 58 dB. The data used to derive this curve were primarily from controlled laboratory studies.

Recent Sleep Disturbance Research – Field and Laboratory Studies

It was noted that early sleep laboratory studies did not account for some important factors. These included habituation to the laboratory, previous exposure to noise, and awakenings from noise other than aircraft. In the early 1990s, field studies in people's homes were conducted to validate the earlier laboratory work conducted in the 1960s and 1970s. The field studies of the 1990s found that 80-90% of sleep disturbances were not related to outdoor noise events, but rather to indoor noises and non-noise factors. The results showed that, in real life conditions, there was less of an effect of noise on sleep than had been previously reported from laboratory studies. Laboratory sleep studies tend to show more sleep disturbance than field studies because people who sleep in their own homes are used to their environment and, therefore, do not wake up as easily (FICAN 1997).

FICAN

Based on this new information, in 1997 FICAN recommended a dose-response curve to use instead of the earlier 1992 FICON curve (FICAN 1997). Figure C-13 shows FICAN's curve, the red line, which is based on the results of three field studies shown in the figure (Ollerhead et al. 1992; Fidell et al. 1994; Fidell et al. 1995a, 1995b), along with the data from six previous field studies.

The 1997 FICAN curve represents the upper envelope of the latest field data. It predicts the maximum percent awakened for a given residential population. According to this curve, a maximum of 3% of people would be awakened at an indoor SEL of 58 dB. An indoor SEL of 58 dB is equivalent to an outdoor SEL of about 83 dB, with the windows closed (73 dB with windows open).

Number of Events and Awakenings

It is reasonable to expect that sleep disturbance is affected by the number of events. The German Aerospace Center (DLR Laboratory) conducted an extensive study focused on the effects of nighttime aircraft noise on sleep and related factors (Basner 2004). The DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance. It involved both laboratory and in-home field research phases. The DLR investigators developed a dose-response curve that predicts the number of aircraft events at various values of L_{max} expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies.

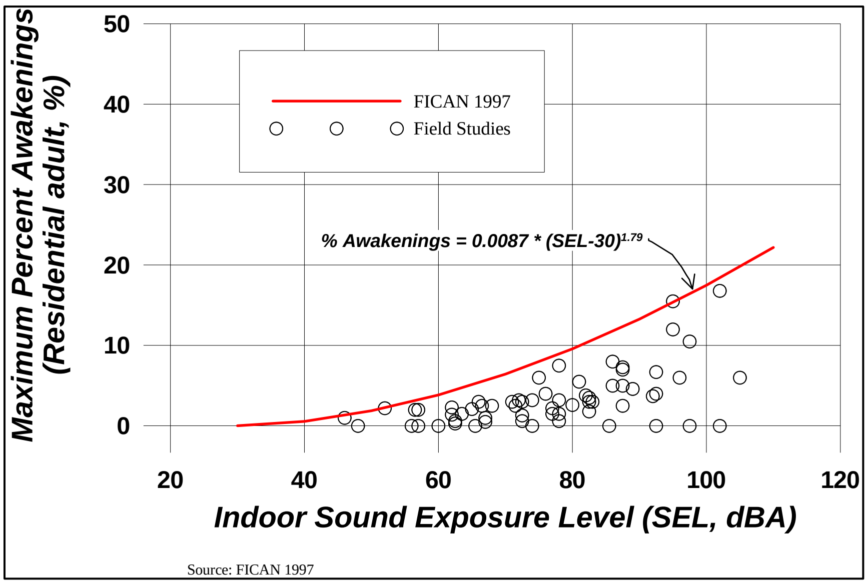


Figure C-13 FICAN 1997 Recommended Sleep Disturbance Dose-Response Relationship

Later studies by DLR conducted in the laboratory comparing the probability of awakenings from different modes of transportation showed that aircraft noise led to significantly lower awakening probabilities than either road or rail noise (Basner et al. 2011). Furthermore, it was noted that the probability of awakening, per noise event, decreased as the number of noise events increased. The authors concluded that by far the majority of awakenings from noise events merely replaced awakenings that would have occurred spontaneously anyway.

A different approach was taken by an ANSI standards committee (ANSI 2008). The committee used the average of the data shown in Figure C-13 rather than the upper envelope, to predict average awakening from one event. Probability theory is then used to project the awakening from multiple noise events.

Currently, there are no established criteria for evaluating sleep disturbance from aircraft noise, although recent studies have suggested a benchmark of an outdoor SEL of 90 dB as an appropriate tentative criterion when comparing the effects of different operational alternatives. The corresponding indoor SEL would be approximately 25 dB lower (at 65 dB) with doors and windows closed, and approximately 15 dB lower (at 75 dB) with doors or windows open. According to the ANSI (2008) standard, the probability of awakening from a single aircraft event at this level is between 1 and 2% for people habituated to the noise sleeping in bedrooms with windows closed, and 2-3% with windows open. The probability of the exposed population awakening at least once from multiple aircraft events at noise levels of 90 dB SEL is shown in Table C-4.

In December 2008, FICAN recommended the use of this new standard. FICAN also recognized that more research is underway by various organizations, and that work may result in changes to FICAN's position. Until that time, FICAN recommends the use of the ANSI (2008) standard (FICAN 2008). ANSI recently withdrew the 2008 standard due primarily to concerns that the method described overestimates impacts (American National Standards Institute, 2018). The method has not been replaced to date and remains a commonly used, conservative method for estimation of sleep disturbance.

Table C-4 Probability of Awakening from NA 90 SEL

Number of Aircraft Events at 90 dB SEL for Average 9-Hour Night	*Minimum Probability of Awakening at Least Once*	
	Windows Closed	*Windows Open*
1	1%	2%
3	4%	6%
5	7%	10%
9 (1 per hour)	12%	18%
18 (2 per hour)	22%	33%
27 (3 per hour)	32%	45%

Source: (DOD, 2009b)
Key: dB = decibel; NA = Number of Events At or Above a Selected Threshold; SEL = Sound Exposure Level.

Summary

Sleep disturbance research still lacks the details to accurately estimate the population awakened for a given noise exposure. The procedure described in the ANSI (2008) Standard and endorsed by FICAN is based on probability calculations that have not yet been scientifically validated. While this procedure certainly provides a much better method for evaluating sleep awakenings from multiple aircraft noise events, the estimated probability of awakenings can only be considered approximate.

C.5.4 Noise-Induced Hearing Impairment

Residents in surrounding communities express concerns regarding the effects of aircraft noise on hearing. This section provides a brief overview of hearing loss caused by noise exposure. The goal is to provide a sense of perspective as to how aircraft noise (as experienced on the ground) compares to other activities that are often linked with hearing loss.

Hearing Threshold Shifts

Hearing loss is generally interpreted as a decrease in the ear's sensitivity or acuity to perceive sound (i.e., a shift in the hearing threshold to a higher level). This change can either be a Temporary Threshold Shift (TTS) or a Permanent Threshold Shift (PTS) (Berger et al. 1995).

TTS can result from exposure to loud noise over a given amount of time. An example of TTS might be a person attending a loud music concert. After the concert is over, there can be a threshold shift that may last several hours. While experiencing TTS, the person becomes less sensitive to low-level sounds, particularly at certain frequencies in the speech range (typically near 4,000 Hz). Normal hearing eventually returns, as long as the person has enough time to recover within a relatively quiet environment.

PTS usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover. A common example of PTS is the result of regularly working in a loud factory. A TTS can eventually become a PTS over time with repeated exposure to high noise levels. Even if the ear is given time to recover from TTS, repeated occurrence of TTS may eventually lead to permanent hearing loss. The point at which a TTS results in a PTS is difficult to identify and varies with a person's sensitivity.

Criteria for Permanent Hearing Loss

It has been well established that continuous exposure to high noise levels will damage human hearing (USEPA 1978). A large amount of data on hearing loss have been collected, largely for workers in manufacturing industries, and analyzed by the scientific/medical community. The Occupational Safety and Health Administration (OSHA) regulation of 1971 places the limit on workplace noise exposure at an average level of 90 dB over an 8-hour work period or 85 dB over a 16-hour period (U.S. Department of Labor 1971). Some hearing loss is still expected at those levels. The most protective criterion, with no measurable hearing loss after 40 years of exposure, is an average sound level of 70 dB over a 24-hour period.

The USEPA established 75 dB $L_{eq(8)}$ and 70 dB $L_{eq(24)}$ as the average noise level standard needed to protect 96% of the population from greater than a 5 dB PTS (USEPA 1978). The National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) identified 75 dB as the lowest level at which hearing loss may occur (CHABA 1977). WHO concluded that environmental and leisure-time noise below an $L_{eq(24)}$ value of 70 dB "will not cause hearing loss in the large majority of the population, even after a lifetime of exposure" (WHO 1999).

Hearing Loss and Aircraft Noise

The 1982 USEPA Guidelines report (USEPA 1982) addresses noise-induced hearing loss in terms of the "Noise-Induced Permanent Threshold Shift" (NIPTS). This defines the permanent change in hearing caused by exposure to noise. Numerically, the NIPTS is the change in threshold that can be expected from daily exposure to noise over a normal working lifetime of 40 years. A grand average of the NIPTS over time and hearing sensitivity is termed the Average NIPTS, or Ave. NIPTS for short. The Ave. NIPTS that can be expected for noise measured by the $L_{eq(24)}$ metric is given in Table C-5. Table C-5 assumes exposure to the full outdoor noise throughout the 24 hours. When inside a building, the exposure will be less (Eldred and von Gierke 1993).

The Ave. NIPTS is estimated as an average over all people exposed to the noise. The actual value of NIPTS for any given person will depend on their physical sensitivity to noise – some will experience more hearing loss than others. The USEPA Guidelines provide information on this variation in sensitivity in the form of the NIPTS exceeded by 10% of the population, which is included in Table C-5 in the "10th Percentile NIPTS" column (USEPA 1982). For individuals exposed to $L_{eq(24)}$ of 80 dB, the most sensitive of the population would be expected to show degradation to their hearing of 7 dB over time.

To put these numbers in perspective, changes in hearing level of less than 5 dB are generally not considered noticeable or significant. Furthermore, there is no known evidence that a NIPTS of 5 dB is perceptible or has any practical significance for the individual. Lastly, the variability in audiometric testing is generally assumed to be ±5 dB (USEPA 1974).

The scientific community has concluded that noise exposure from civil airports has little chance of causing permanent hearing loss (Newman and Beattie 1985). For military airbases, DOD policy requires that hearing risk loss be estimated for population exposed to $L_{eq(24)}$ of 80 dB or higher (DOD 2012), including residents of on-base housing. Exposure of workers inside the base boundary is assessed using DOD regulations for occupational noise exposure.

Table C-5 Average NIPTS and 10th Percentile NIPTS as a Function of $L_{eq(24)}$

$L_{eq(24)}$	*Average NIPTS (dB)**	*10th Percentile NIPTS (dB)**
75-76	1.0	4.0
76-77	1.0	4.5
77-78	1.6	5.0
78-79	2.0	5.5
79-80	2.5	6.0
80-81	3.0	7.0
81-82	3.5	8.0
82-83	4.0	9.0
83-84	4.5	10.0
84-85	5.5	11.0
85-86	6.0	12.0
86-87	7.0	13.5
87-88	7.5	15.0
88-89	8.5	16.5
89-90	9.5	18.0

Source: (DOD 2012)

Key: dB = decibel; $L_{eq(24)}$ = Equivalent Sound Level over 24 hours; NIPTS = Noise-induced Permanent Threshold Shift.

Note: * rounded to the nearest 0.5 dB

Noise in low-altitude military airspace, especially along MTRs where L_{max} can exceed 115 dB, is of concern. That is the upper limit used for occupational noise exposure (e.g., U.S. Department of Labor 1971). One laboratory study (Ising et al. 1999) concluded that events with L_{max} above 114 dB have the potential to cause hearing loss. Another laboratory study of participants exposed to levels between 115 and 130 dB (Nixon et al. 1993), however, showed conflicting results. For an exposure to four events across that range, half the subjects showed no change in hearing, a quarter showed a temporary 5 dB decrease in sensitivity, and a quarter showed a temporary 5 dB increase in sensitivity. For exposure to eight events of 130 dB, subjects showed an increase in sensitivity of up to 10 dB (Nixon et al. 1993).

Summary

Aviation noise levels are not comparable to the occupational noise levels associated with hearing loss of workers in manufacturing industries. There is little chance of hearing loss at levels less than 75 dB DNL. Noise levels equal to or greater than 75 dB DNL can occur near military airbases, and DOD policy specifies that NIPTS be evaluated when exposure exceeds 80 dB $L_{eq(24)}$ (DOD 2009c). There is some concern about L_{max} exceeding 115 dB in low altitude military airspace, but no research results to date have definitely related permanent hearing impairment to aviation noise.

C.5.5 Non-auditory Health Effects

The potential for aircraft noise to impair one's health deserves special attention and accordingly has been the subject of numerous epidemiological studies and meta-analyses of the gathered data. The basic premise is that noise can cause annoyance, annoyance can cause stress, and prolonged stress is known to be a contributor to a number of health disorders, such as hypertension, myocardial infarction (heart attack), cardiovascular disease, and stroke. According to Kryter and Poza (1980) "It is more likely that noise related general ill-health effects are due to the psychological annoyance from the noise interfering with normal everyday behavior, than it is from the noise eliciting, because of its intensity, reflexive response in the autonomic or other physiological systems of the body."

An early study by Cantrell (1974) confirmed that noise can provoke stress, but noted that results on its effect on cardiovascular health were contradictory. Some studies in the 1990s found a connection between aircraft noise and increased blood pressure (Michalak et al. 1990; Rosenlund et al. 2001), while others did not (Pulles et al. 1990). This inconsistency in results led the World Health Organization in 2000 to conclude that there was only a weak association between long-term noise exposure and hypertension and cardiovascular effects, and that a dose-response relationship could not be established (WHO 2000). Later, van Kempen concluded that "Whereas noise exposure can contribute to the prevalence of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive" (van Kempen et al. 2002)

More recently, major studies have been conducted in an attempt to identify an association between noise and health effects, develop a dose-response relationship, and identify a threshold below which the effects are minimal. The most important of these are briefly described below. In these studies researchers usually present their results in terms of the Odds Ratio, or OR, which is the ratio of the odds that health will be impaired by an increase in noise level of 10 dB to the odds that health would be impaired without any noise exposure. An OR of 1.25 means that there is a 25 percent increase in likelihood that noise will impair health. To put the OR number in context, an OR of 1.5 would be considered a weak relationship between noise and health; 3.5 would be a moderate relationship; 9.0 would be a strong relationship; and 32 a very strong relationship (Cohen 1988). The OR for the relationship between obesity and hypertension is 3.4 (Pikilidou et al. 2013), and that between smoking and coronary heart disease is 4.4 (Rosengren et al. 2009).

- A carefully designed study, Hypertension and Exposure to Noise near Airports (HYENA), was conducted around six European airports from 2002 through 2006 (Jarup et al. 2005, 2008, Babisch et al. 2008). There were 4,861 subjects, aged between 45 and 70. Blood pressure was measured and questionnaires administered for health, socioeconomic and lifestyle factors, including diet and physical exercise. Noise from aircraft and highways was predicted from models.

HYENA results showed an OR less than 1 for the association between daytime aircraft noise and hypertension which was not statistically significant[1], indicating no positive association. The OR for the relationship between nighttime aircraft noise and hypertension was 1.14 – a result that was marginally statistically significant. For daytime road traffic noise, the OR was 1.1 and marginally significant. The

[1] In many of the studies reported above the researchers use the word "significant" to describe a relationship between noise and health, conjuring up the idea that the relationship is strong and that the effect is large. But this is an inappropriate and misleading use of the word in statistical analysis. What the researchers really mean is that the relationship is "statistically significant" in that they are sure that it is real. It does not mean that the effect is large or important, or that it has any decision-making utility. A relationship can be statistically significant, i.e., real, while being weak, or small and insignificant.

measured effects were small, and not necessarily distinct from other events. A close review of the data for nighttime aircraft noise raised some questions about the data and the methods employed (ACRP 2008). Using data from the HYENA study Haralabidis et al. (2008) reported an increase in systolic blood pressure of 6.2 millimeters of mercury (mmHg) for aircraft noise events (about 6 (about 5 percent) percent), and an increase of 7.4 mmHg (about 7 percent) for other indoor noises, such as snoring - a snoring partner and road traffic had similar impact on blood pressure.

- Ancona et al. (2010) reports a study on a randomly selected sample of subjects aged 45–70 years who had lived in the study area for at least 5 years. Personal data was collected via interview and blood pressure measurements were taken for a study population of 578 subjects. No statistically significant association was found between aircraft noise levels and hypertension for noise levels above 75 dB $L_{eq(24)}$ compared to levels below 65 dB. However, there was an increase in nocturnal systolic pressure of 5.4 mmHg (about 5 percent), for subjects in the highest exposure category (greater than or equal to 75 dB).
- Huss (2010) examined the risk of mortality from myocardial infarction (heart attack) resulting from exposure to aircraft noise using the Swiss National database of mortality records for the period 2000 to 2005. The analysis was conducted on a total of 4.6 million people with 15,500 deaths from acute myocardial infarction. The results showed that the risk of death from all circulatory diseases combined was not associated with aircraft noise, nor was there any association between noise and the risk of death from stroke. The overall risk of death from myocardial infarction alone was 1.07 and not statistically significant, but higher (OR = 1.3 and not statistically significant) in people exposed to aircraft noise of 60 dB DNL or greater for 15 years or more. The risk of death from myocardial infarction was also higher (OR = 1.10), and statistically significant, for those living near a major road. Cardiovascular risk factors, such as smoking, were not directly taken into account in this study.
- Floud (2013) used the HYENA data to examine the relationship between noise levels and self-reported heart disease and stroke. There was no association for daytime noise, and no statistically significant association for nighttime noise. However, for those exposed to nighttime aircraft noise for more than 20 years, the OR was 1.25 per 10 dB increase in noise (L_{night}) and marginally significant.
- Correia et al. (2013) evaluated the risk of hospitalization for cardiovascular diseases in older people (≥65 years) residing in areas exposed to DNL of at least 45 dB around U.S. airports. Health insurance data from 2009 Medicare records were examined for approximately 6 million people living in neighborhoods around 89 airports in the United States. The potential confounding effect of socioeconomic status was extracted from several zip code level variables from the 2000 U.S. census. No controls were included for smoking or diet, both of which are strong risk factors for cardiovascular disease. Noise levels were calculated at census block centroids. Taking into account the potential effects of air pollution, they report an OR of 1.035 that was marginally statistically significant. While the overall results show a link between increased noise and increased health risk, some of the individual airport data show a decreased health risk with increased aircraft noise exposure.
- Hansell et al.(2013) investigated the association of aircraft noise with risk of hospital admission for, and mortality from, stroke, coronary heart disease, and cardiovascular disease in neighborhoods around London’s Heathrow airport exposed to $L_{eq(16)}$ of at least 50 dB. The data

were adjusted for age, sex, ethnicity, deprivation, and a smoking proxy (lung cancer mortality) at the census area level, but not at the individual level. It was important to consider the effect of ethnicity (in particular South Asian ethnicity, which is itself strongly associated with risk of coronary heart disease). The reported OR for stroke, heart disease, and cardiovascular disease were 1.24, 1.21, and 1.14 respectively. Similar results were reported for mortality.

The results suggest a higher risk of mortality from coronary heart disease than cardiovascular disease, which seems counter intuitive given that cardiovascular disease encompasses all the diseases of the heart and circulation, including coronary heart disease and stroke along with heart failure and congenital heart disease (ERCD 2014).

- Evrard et al. (2015) studied mortality rates for 1.9 million residents living in 161 communes near three major French airports (Paris-Charles de Gaulle, Lyon Saint-Exupéry, and Toulouse-Blagnac) for the period 2007 to 2010. Noise levels in the communes ranged from 42 to 64 dB L_{den}. Lung cancer mortality at the commune level was used as a proxy measure for smoking because data on individual smoking or smoking prevalence were not available. Noise exposure was expressed in terms of a population weighted level for each commune. After adjustment for concentration of nitrogen dioxide (NO_2), Risk Ratios (similar to Odds Ratios) per 10 dB increase in noise were found to be 1.18 for mortality from cardiovascular disease, 1.23 for mortality from coronary heart disease, and 1.31 for mortality from myocardial infarction. There was no association between mortality from stroke and aircraft noise. As the author notes, results at the commune level may not be applicable to the individual level.
- Matsui et al. (2008) reported higher OR for noise levels greater than L_{den} 70 dB, but not altogether statistically significant, for hypertension from the effects of military aircraft noise at Kadena Air Base in Okinawa. The study was conducted in 1995-1996 but used older noise data that was not necessarily appropriate for the same time period.
- A study of Noise-Related Annoyance, Cognition and Health (NORAH) designed to identify transportation noise effects in communities around German airports has reported results of self-monitoring of blood pressure of approximately 2,000 residents near Frankfurt airport exposed to aircraft $L_{eq(24)}$ in the range of 40 to 65 dB over the period 2012 to 2014 after the opening of a new runway (Shrekenberg 2015). The results showed small positive effects of noise on blood pressure without statistical significance. No statistically significant effect was determined between aircraft noise and hypertension as defined by WHO.

The NORAH study also included an examination of the effect of aircraft noise on cardiovascular disease (heart attack and stroke) based on examination of health insurance data between 2006 and 2010 for approximately 1 million people over the age of 40 exposed to aircraft $L_{eq(24)}$ in the range of 40 to 65 dB. A questionnaire was used to obtain information on confounding factors. The results showed non-statistically significant increase in risk for heart attack and stroke, and there was no apparent linear relationship between noise level and either effect. There was however a marginally significant but small increase in risk for heart failure (OR of 1.016). The risk of cardiovascular disease was found to be greater for road and rail noise than for aircraft noise.

The risk for unipolar depression was found to increase with exposure to aircraft noise (OR of 1.09), but the relationship was not linear - the risk decreasing at the higher noise levels, so this result was not considered reliable.

In many of the studies reported above the researchers use the word "significant" to describe a relationship between noise and health, conjuring up the idea that the relationship is strong and that the effect is large. But this is an inappropriate and misleading use of the word in statistical analysis. What the researchers really mean is that the relationship is "statistically significant" in that they are sure that it is real. It does not mean that the effect is large or important, or that it has any decision-making utility. A relationship can be statistically significant, i.e., real, while being weak, or small and insignificant.

In decision-making one would hardly rely on the results of a single study. Rather, one would like to see consistent results amongst studies and derive effect estimates from the different studies for a quantitative risk assessment (Babisch 2013). This has led to meta-analyses of the pooled results from field studies.

- Babisch and Kamp (2009) and Babisch (2013). The focus in this meta-analysis is on epidemiological studies or surveys directly related to associations between aircraft noise and cardiovascular disease (CVD) outcomes. Considering studies at 10 airports covering over 45,000 people, the pooled effect estimate of the relative risk for hypertension was 1.13 per 10 dB(A) and only marginally significant (WHO 2011). One of the studies included in the analysis was for military aircraft noise at Okinawa (see Matsui et al. 2008) for which the OR was 1.27 but not statistically significant. The authors conclude that "No single, generalized and empirically supported exposure-response relationship can be established yet for the association between aircraft noise and cardiovascular risk due to methodological differences between studies." The pooled results show different slopes from different studies with different noise level ranges and methods being used.
- Huang el al. (2015) examined four research studies comprising a total of 16,784 residents. The overall OR for hypertension in residents with aircraft noise exposure was 1.36 for men and statistically significant, and 1.31 and not statistically significant for women. No account was taken for any confounding factors. The meta-analysis suggests that aircraft noise could contribute to the prevalence of hypertension, but the evidence for a relationship between aircraft noise exposure and hypertension is still inconclusive because of limitations in study populations, exposure characterization, and adjustment for important confounders.

  The four studies in Huang's analysis include one by Black et al. (2007) that purports to show relatively high OR values for self-reported hypertension, but these results only applied to a select subset of those surveyed that reported high noise stress. When this data set is excluded, Huang's meta-analysis yields results similar to those obtained in the HYENA and NORAH studies. Furthermore, the longitudinal study included in the analysis that followed 4721 people for 8 years (Eriksson et al. 2010) reported an OR of 1.02 that was not statistically significant.
- A meta-analysis of 11 studies on road and aircraft noise exposure conducted since the mid-1990s showed a marginally significant pooled relative risk for the incidence of ischemic heart disease of 1.08 per 10 dB increase in noise exposure (OR approximately 1.08), and 1.03 and not statistically significant for mortality from ischemic heart disease with the linear exposure-response starting at L_{den} 50 dB (Vienneau et al. 2015).

The connection from annoyance to stress to health issues requires careful experimental design because of the large number of confounding issues, such as heredity, medical history, smoking, diet, lack of exercise, air pollution, etc. Some highly publicized reports on health effects have, in fact, been rooted in poor science. Meecham and Shaw (1979) apparently found a relation between noise levels and mortality rates in neighborhoods under the approach path to Los Angeles International Airport. When the same data were analyzed by others (Frerichs et al. 1980) no relationship was found. Jones and Tauscher (1978) found a high rate of birth defects for the same neighborhood. But when the Centers For Disease Control performed a more thorough study near Atlanta's Hartsfield International Airport, no relationships were found for DNL greater than 65 dB (Edmonds et al. 1979).

Moreover, the public's understanding of the possible effects of aircraft noise has been hindered by the publication of overly sensational and misleading articles in the popular press, such as "Death by Aircraft Noise is a Real Concern for People Living Under the Flight Path" (Deutsche Welle 2013). Similarly, statements by reputed scientists have proved less than useful in the debate on the effects of aircraft noise on health ("It's quite clear that living near an airport is very dangerous for your health," says Eberhard Greiser, an emeritus professor of epidemiology at Bremen University. "Jet noise is more dangerous than any other kind of road-traffic noise or rail noise because it is especially acute and sharp and it induces stress hormones" (Time 2009)). Such conclusions have been firmly criticized by other German researchers as lacking in rigor by not considering other known factors that cause health problems, and for analyzing only a selection of the available data (ANR 2010).

Summary

Research studies seem to indicate that aircraft noise may contribute to the risk of health disorders, along with other factors such as heredity, medical history, smoking, alcohol use, diet, lack of exercise, air pollution, etc., but that the measured effect is small compared to these other factors, and often not statistically significant, i.e., not necessarily real. Despite some sensational articles purporting otherwise, and the intuitive feeling that noise in some way must impair health, there are no studies that definitively show a causal and significant relationship between aircraft noise and health. Such studies are notoriously difficult to conduct and interpret because of the large number of confounding factors that have to be considered for their effects to be excluded from the analysis. The WHO notes that there is still considerable variation among studies (WHO 2011). And, almost without exception, research studies conclude that additional research is needed to determine if such a causal relationship exists. The European Network on Noise and Health (ENNAH 2013) in its summary report of 2013 concludes that "…while the literature on non-auditory health effects of environmental noise is extensive, the scientific evidence of the relationship between noise and non-auditory effects is still contradictory".

As a result, it is not possible to state that there is sound scientific evidence that aircraft noise is a significant contributor to health disorders.

C.5.6 Performance Effects

The effect of noise on the performance of activities or tasks has been the subject of many studies. Some of these studies have found links between continuous high noise levels and performance loss. Noise-induced performance losses are most frequently reported in studies where noise levels are above 85 dB. Little change has been found in low-noise cases. Moderate noise levels appear to act as a stressor for more sensitive individuals performing a difficult psychomotor task.

While the results of research on the general effect of periodic aircraft noise on performance have yet to yield definitive criteria, several general trends have been noted including:

- A periodic intermittent noise is more likely to disrupt performance than a steady-state continuous noise of the same level. Flyover noise, due to its intermittent nature, might be more likely to disrupt performance than a steady-state noise of equal level.
- Noise is more inclined to affect the quality than the quantity of work.

- Noise is more likely to impair the performance of tasks that place extreme demands on workers.

C.5.7 Noise Effects on Children

Recent studies on school children indicate a potential link between aircraft noise and both reading comprehension and learning motivation. The effects may be small but may be of particular concern for children who are already scholastically challenged.

C.5.7.1 Effects on Learning and Cognitive Abilities

Early studies in several countries (Cohen et al. 1973, 1980, 1981; Bronzaft and McCarthy 1975; Green et al. 1982; Evans et al. 1998; Haines et al. 2002; Lercher et al. 2003) showed lower reading scores for children living or attending school in noisy areas than for children away from those areas. In some studies noise exposed children were less likely to solve difficult puzzles or more likely to give up.

A longitudinal study reported by Evans et al. (1998) conducted prior to relocation of the old Munich airport in 1992, reported that high noise exposure was associated with deficits in long term memory and reading comprehension in children with a mean age of 10.8 years. Two years after the closure of the airport, these deficits disappeared, indicating that noise effects on cognition may be reversible if exposure to the noise ceases. Most convincing was the finding that deficits in memory and reading comprehension developed over the two year follow-up for children who became newly noise exposed near the new airport: deficits were also observed in speech perception for the newly noise-exposed children

More recently, the Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) study (Stansfeld et al. 2005; Clark et al. 2005) compared the effect of aircraft and road traffic noise on over 2.000 children in three countries. This was the first study to derive exposure-effect associations for a range of cognitive and health effects, and was the first to compare effects across countries.

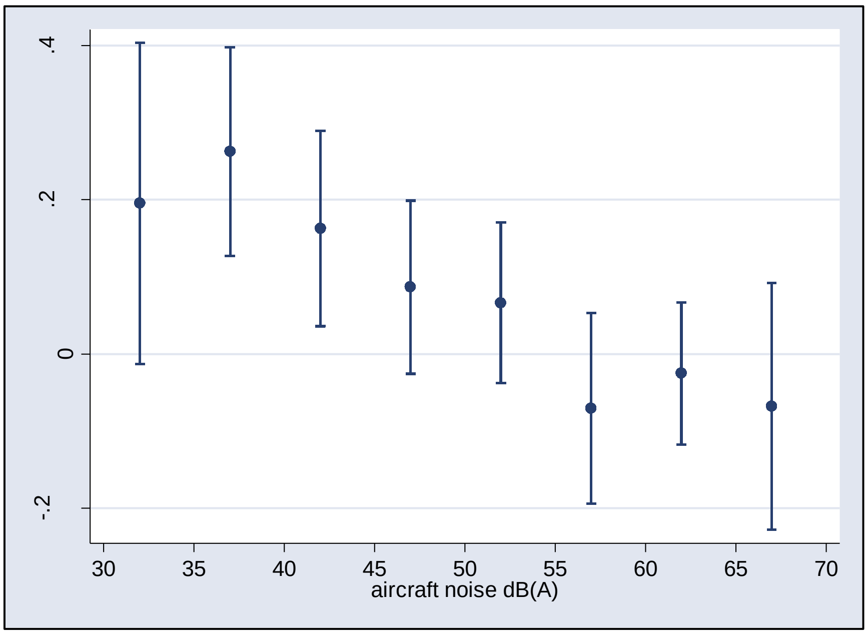
The study found a linear relation between chronic aircraft noise exposure and impaired reading comprehension and recognition memory. No associations were found between chronic road traffic noise exposure and cognition. Conceptual recall and information recall surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory (Stansfeld et al. 2005; Clark et al. 2006).

Figure C-14 shows RANCH's result relating noise to reading comprehension. It shows that reading falls below average (a z-score of 0) at L_{eq} greater than 55 dB. Because the relationship is linear, reducing exposure at any level should lead to improvements in reading comprehension.

An observation of the RANCH study was that children may be exposed to aircraft noise for many of their childhood years and the consequences of long-term noise exposure were unknown. A follow-up study of the children in the RANCH project is being analyzed to examine the long-term effects on children's reading comprehension (Clark et al. 2009). Preliminary analysis indicated a trend for reading comprehension to be poorer at 15-16 years of age for children who attended noise-exposed primary schools. There was also a trend for reading comprehension to be poorer in aircraft noise exposed secondary schools. Further analysis adjusting for confounding factors is ongoing, and is needed to confirm these initial conclusions.

FICAN funded a pilot study to assess the relationship between aircraft noise reduction and standardized test scores (Eagan et al. 2004; FICAN 2007). The study evaluated whether abrupt aircraft noise reduction within classrooms, from either airport closure or sound insulation, was associated with improvements in test scores. Data were collected in 35 public schools near three airports in Illinois and Texas. The study used several noise metrics. These were, however, all computed indoor levels, which makes it hard to compare with the outdoor levels used in most other studies.

The FICAN study found a significant association between noise reduction and a decrease in failure rates for high school students, but not middle or elementary school students. There were some weaker associations between noise reduction and an increase in failure rates for middle and elementary schools. Overall the study found that the associations observed were similar for children with or without learning difficulties, and between verbal and math/science tests. As a pilot study, it was not expected to obtain final answers, but provided useful indications (FICAN 2007).



Sources: Stansfeld et al. 2005; Clark et al. 2006

Figure C-14 RANCH Study Reading Scores Varying with L_{eq}

A recent study of the effect of aircraft noise on student learning (Sharp et al. 2013) examined student test scores at a total of 6,198 U.S. elementary schools, 917 of which were exposed to aircraft noise at 46 airports with noise exposures exceeding 55 dB DNL. The study found small but statistically significant associations between airport noise and student mathematics and reading test scores, after taking demographic and school factors into account. Associations were also observed for ambient noise and total noise on student mathematics and reading test scores, suggesting that noise levels per se, as well as from aircraft, might play a role in student achievement.

As part of the Noise-Related Annoyance, Cognition and Health (NORAH) study conducted at Frankfurt airport, reading tests were conducted on 1,209 school children at 29 primary schools. It was found that there was a small decrease in reading performance that corresponded to a one-month reading delay.

While there are many factors that can contribute to learning deficits in school-aged children, there is increasing awareness that chronic exposure to high aircraft noise levels may impair learning. This awareness has led WHO and a North Atlantic Treaty Organization (NATO) working group to conclude that daycare centers and schools should not be located near major sources of noise, such as highways, airports, and industrial sites (NATO 2000; WHO 1999). The awareness has also led to the classroom noise standard discussed earlier (ANSI 2002) (Basner, et al., 2017).

C.5.7.2 Health Effects on Children

A number of studies, including some of the cognitive studies discussed above, have examined the potential for effects on children's health. Health effects include annoyance, psychological health, coronary risk, stress hormones, sleep disturbance and hearing loss.

Annoyance. Chronic noise exposure causes annoyance in children (Bronzaft and McCarthy 1975; Evans et al. 1995). Annoyance among children tends to be higher than for adults, and there is little habituation (Haines et al. 2001a). The RANCH study found annoyance may play a role in how noise affects reading comprehension (Clark et al. 2005).

Psychological Health. Lercher et al. (2002) found an association between noise and teacher ratings of psychological health, but only for children with biological risk defined by low birth weight and/or premature birth. Haines et al. (2001b) found that children exposed to aircraft noise had higher levels of psychological distress and hyperactivity. Stansfeld et al. (2009) replicated the hyperactivity result, but not distress.

As with studies of adults, the evidence suggests that chronic noise exposure is probably not associated with serious psychological illness, but there may be effects on well-being and quality of life. Further research is needed, particularly on whether hyperactive children are more susceptible to stressors such as aircraft noise.

Coronary Risk. The HYENA study discussed earlier indicated a possible relation between noise and hypertension in older adults. Cohen et al. (1980, 1981) found some increase in blood pressure among school children, but within the normal range and not indicating hypertension. Hygge et al. (2002) found mixed effects. The RANCH study found some effect for children at home and at night, but not at school (van Kempen 2006). However, the relationship between aircraft noise and blood pressure was not fully consistent between surveys in different countries. These findings, taken together with those from previous studies, suggest that no univocal conclusions can be drawn about the association between aircraft noise exposure and blood pressure. Overall the evidence for noise effects on children's blood pressure is mixed, and less certain than for older adults.

Stress Hormones. Some studies investigated hormonal levels between groups of children exposed to aircraft noise compared to those in a control group. Two studies analyzed cortisol and urinary catecholamine levels in school children as measurements of stress response to aircraft noise (Haines et al. 2001a, 2001b). In both instances, there were no differences between the aircraft-noise-exposed children and the control groups.

Sleep Disturbance. A sub-study of RANCH in a Swedish sample used sleep logs and the monitoring of rest/activity cycles to compare the effect of road traffic noise on child and parent sleep (Ohrstrom et al. 2006). An exposure-response relationship was found for sleep quality and daytime sleepiness for children. While this suggests effects of noise on children's sleep disturbance, it is difficult to generalize from one study.

Hearing loss. A few studies have examined hearing loss from exposure to aircraft noise. Noise-induced hearing loss for children who attended a school located under a flight path near a Taiwan airport was greater than for children at another school far away (Chen et al. 1997). Another study reported that hearing ability was reduced significantly in individuals who lived near an airport and were frequently exposed to aircraft noise (Chen and Chen 1993). In that study, noise exposure near the airport was greater than 75 dB DNL and L_{max} were about 87 dB during overflights. Conversely, several other studies reported no difference in hearing ability between children exposed to high levels of airport noise and children located in quieter areas (Andrus et al. 1975; Fisch 1977; Wu et al. 1995). It is not clear from those results whether children are at higher risk than adults, but the levels involved are higher than those desirable for learning and quality of life.

Ludlow and Sixsmith (1999) conducted a cross-sectional pilot study to examine the hypothesis that military jet noise exposure early in life is associated with raised hearing thresholds. The authors concluded that there were no significant differences in audiometric test results between military personnel who as children had lived in or near stations where fast jet operations were based, and a similar group who had no such exposure as children.

C.5.8 Property Values

Noise can affect the value of homes. Economic studies of property values based on selling prices and noise have been conducted to find a direct relation.

The value-noise relation is usually presented as the Noise Depreciation Index (NDI) or Noise Sensitivity Depreciation Index (NSDI), the percent loss of value per dB (measured by the DNL metric). An early study by Nelson (1978) at three airports found an NDI of 1.8-2.3% per dB. Nelson also noted a decline in NDI over time which he theorized could be due to either a change in population or the increase in commercial value of the property near airports. Crowley (1973) reached a similar conclusion. A larger study by Nelson (1980) looking at 18 airports found an NDI from 0.5 to 0.6% per dB.

In a review of property value studies, Newman and Beattie (1985) found a range of NDI from 0.2 to 2% per dB. They noted that many factors other than noise affected values.

Fidell et al. (1996) studied the influence of aircraft noise on actual sale prices of residential properties in the vicinity of a military base in Virginia and one in Arizona. They found no meaningful effect on home values. Their results may have been due to non-noise factors, especially the wide differences in homes between the two study areas.

Recent studies of noise effects on property values have recognized the need to account for non-noise factors. Nelson (2004) analyzed data from 33 airports, and discussed the need to account for those factors and the need for careful statistics. His analysis showed NDI from 0.3 to 1.5% per dB, with an average of about 0.65% per dB. Nelson (2007) and Andersson et al. (2013) discuss statistical modeling in more detail.

Enough data is available to conclude that aircraft noise has a real effect on property values. This effect falls in the range of 0.2 to 2.0% per dB, with the average on the order of 0.5% per dB. The actual value varies from location to location, and is very often small compared to non-noise factors.

C.5.9 Noise-Induced Vibration Effects on Structures and Humans

The sound from an aircraft overflight travels from the exterior to the interior of the house in one of two ways: through the solid structural elements and directly through the air. Figure C-15 illustrates the sound transmission through a wall constructed with a brick exterior, stud framing, interior finish wall, and absorbent material in the cavity. The sound transmission starts with noise impinging on the wall exterior. Some of this sound energy will be reflected away and some will make the wall vibrate. The vibrating wall radiates sound into the airspace, which in turn sets the interior finish surface vibrating, with some energy lost in the airspace. This surface then radiates sound into the dwelling interior. As the figure shows, vibrational energy also bypasses the air cavity by traveling through the studs and edge connections.

High noise levels can cause buildings to vibrate. If high enough, building components can be damaged. The most sensitive components of a building are the windows, followed by plaster walls and ceilings. Possibility of damage depends on the peak sound pressures and the resonances of the building. While certain frequencies (such as 30 Hertz for window breakage) may be of more concern than other frequencies, in general, only sounds lasting more than one second greater than an unweighted sound level of 130 dB in the 1 Hz to 1,000 Hz frequency range are potentially damaging to structural components (CHABA 1977; von Gierke and Ward 1991). Sound levels from normal aircraft operations are typically much less than 130 dB. Even sound from low altitude flyovers of heavy aircraft do not reach the potential for damage (Sutherland 1990).

Noise-induced structural vibration may cause annoyance to dwelling occupants because of induced secondary vibrations, or “rattle”, of objects within the dwelling – hanging pictures, dishes, plaques, and bric-a-brac. Loose window panes may also vibrate noticeably when exposed to high levels of airborne noise, causing homeowners to fear breakage. In general, rattling occurs at peak unweighted sound levels that last for several seconds at levels greater than 110 dB.

A field study (Schomer and Neathammer, 1985; Schomer and Neathammer, 1987) examined the role of structural vibration and rattle in human response to helicopter noise. It showed that human response is strongly and negatively influenced when the noise induces noticeable vibration and rattles in the house structure. The A-frequency-weighting was adequate to assess community response to helicopter noise when no vibration or rattle was induced. When rattle or vibrations were induced by the helicopter noise, however, A-weighting alone did not assess the community response adequately, such that significant corrections from 12 dB (for little vibration or rattles) to 20 dB (high level of vibration or rattles) needed to be applied for subjects indoors. It was also found that the presence or absence of high level noise-induced vibration and rattles was strongly dependent on the helicopter's slant distance. It was recommended that no housing or noise-sensitive land uses should be located in zones where high levels of vibration or rattle are induced by helicopter noise.

Community reactions to conventional helicopter noise from low numbers of operations for two helicopter types were studied by (Fields and Powell, 1987). Using resident interviews in combination with controlled helicopter operations, they obtained relations between the annoyance score and noise exposure for short-term (9-hour daytime) periods. It was determined that annoyance increased steadily with noise exposure measured in L_{eq} from 45 to 60 dBA for that period. Annoyance response in terms of percentage annoyed was also presented on this scale for various annoyance rating values. The shape of these curves is similar to the well-known dose-response relationship (Shultz curve) for general transportation noise, but relate to only the 9-hour daytime period, with no direct comparison with long-term noise exposure.

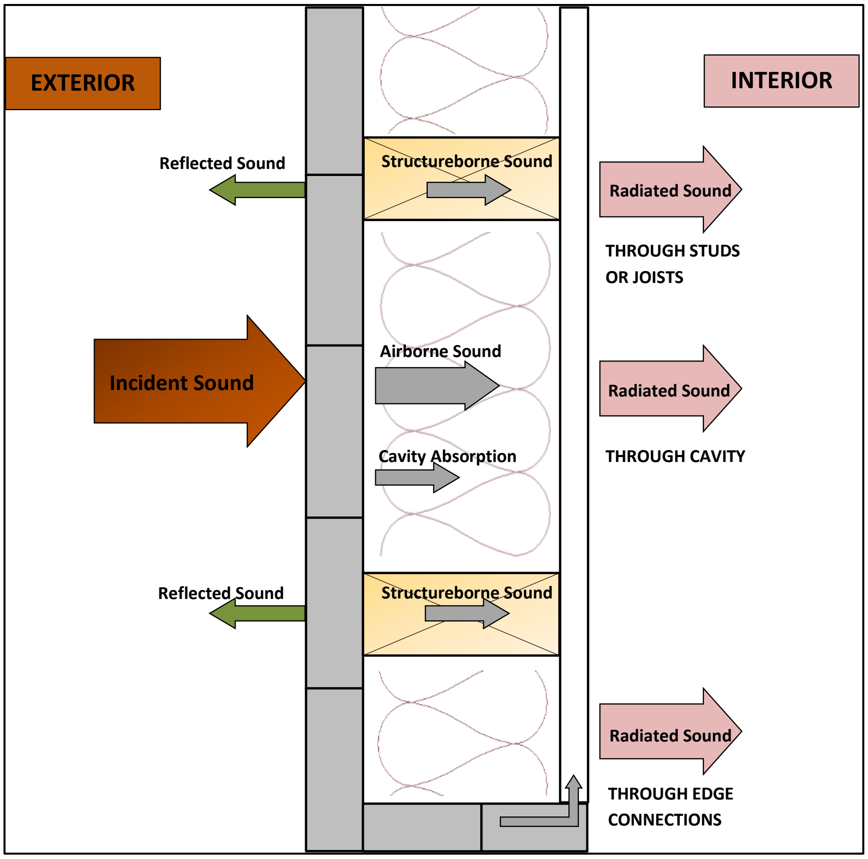


Figure C-15 Depiction of Sound Transmission through Built Construction

In a later review of human response to aircraft noise and induced building vibration, (Powell and Shepherd, 1989) also indicate that in aircraft noise surveys the annoyance scores are on average greater when vibration is detected than with no vibration detected. Based on the results of the study by (Fields and Powell, 1987) they conclude, however, that no effect of increased annoyance was found for cases where the helicopter noise level and slant distance were such that appreciable rattle was expected to occur, in contrast to the results of (Schomer and Neathammer, 1987). Powell and Shepherd also quote a laboratory study (Cawthorn et al., 1978), where the sound of rattling glassware added to the aircraft flyover noises did not increase the level of annoyance.

Community annoyance in the vicinity of airports due to noise-induced vibration and rattle resulted from aircraft ground operations was studied by (Fidell et al., 1999) and summarized in the Minneapolis-St. Paul International Airport Low Frequency Noise (LFN) Expert Panel Report (Sutherland et al., 2000). These field surveys of operations in the vicinity of a major international airport indicated that low-frequency aircraft noise can lead to secondary vibration and rattle in residential structures, which may significantly increase annoyance. These studies, however, have been criticized (FICAN 2002) due to the absence of direct measurements of vibration in support of the findings on the presence of perceptible vibration and rattle. These issues were further addressed by (Hodgdon et al., 2007). It was confirmed that the highest levels of noise near the runway during start-of-takeoff-roll and acceleration and during thrust reversal are at frequencies below 200 Hz. It was also found that aircraft noise exposure that contained audible rattle were not the most annoying, likely because the rattle content was audible, but not loud compared to the overall noise content. This result is consistent with an earlier study of human response to aircraft noise and induced building vibration (Powell and Shepherd, 1989).

In the assessment of vibration on humans, the following factors determine if a person will perceive and possibly react to building vibrations:

1. Type of excitation: steady state, intermittent, or impulsive vibration.
2. Frequency of the excitation. International Organization for Standardization (ISO) standard 2631-2 (ISO 1989) recommends a frequency range of 1 to 80 Hz for the assessment of vibration on humans.
3. Orientation of the body with respect to the vibration.
4. The use of the occupied space (i.e., residential, workshop, hospital).
5. Time of day.

Table C-6 lists the whole-body vibration criteria from ISO 2631-2 for one-third octave frequency bands from 1 to 80 Hz.

Table C-6 Vibration Criteria for the Evaluation of Human Exposure to Whole-Body Vibration

Frequency (Hz)	RMS Acceleration (m/s/s)		
	Combined Criteria Base Curve	Residential Night	Residential Day
1.00	0.0036	0.0050	0.0072
1.25	0.0036	0.0050	0.0072
1.60	0.0036	0.0050	0.0072
2.00	0.0036	0.0050	0.0072
2.50	0.0037	0.0052	0.0074
3.15	0.0039	0.0054	0.0077
4.00	0.0041	0.0057	0.0081
5.00	0.0043	0.0060	0.0086
6.30	0.0046	0.0064	0.0092
8.00	0.0050	0.0070	0.0100
10.00	0.0063	0.0088	0.0126
12.50	0.0078	0.0109	0.0156
16.00	0.0100	0.0140	0.0200
20.00	0.0125	0.0175	0.0250
25.00	0.0156	0.0218	0.0312
31.50	0.0197	0.0276	0.0394
40.00	0.0250	0.0350	0.0500
50.00	0.0313	0.0438	0.0626
63.00	0.0394	0.0552	0.0788
80.00	0.0500	0.0700	0.1000

Source: ISO 1989.

C.5.10 Noise Effects on Terrain

It has been suggested that noise levels associated with low-flying aircraft may affect the terrain under the flight path by disturbing fragile soil or snow, especially in mountainous areas, causing landslides or avalanches. There are no known instances of such events. It is improbable that such effects would result from routine subsonic aircraft operations.

C.5.11 Noise Effects on Historical and Archaeological Sites

Historical buildings and sites can have elements that are more fragile than conventional structures. Aircraft noise may affect such sites more severely than newer, modern structures. In older structures, seemingly insignificant surface cracks caused by vibrations from aircraft noise may lead to greater damage from natural forces (Hanson et al. 1991). There are few scientific studies of such effects to provide guidance for their assessment.

One study involved measurements of noise and vibration in a restored plantation house, originally built in 1795. It is located 1,500 feet from the centerline at the departure end of Runway 19L at Washington Dulles International Airport. The aircraft measured was the Concorde. There was special concern for the building's windows, since roughly half of the house's 324 panes were original. No instances of structural damage were found. Interestingly, despite the high levels of noise during Concorde takeoffs, the induced structural vibration levels were actually less than those induced by touring groups and vacuum cleaning (Wesler 1977).

As for conventional structures, noise exposure levels for normally compatible land uses should also be protective of historic and archaeological sites. Unique sites should, of course, be analyzed for specific exposure.

C.5.12 Effects on Domestic Animals and Wildlife

Hearing is critical to an animal's ability to react, compete, reproduce, hunt, forage, and survive in its environment. While the existing literature does include studies on possible effects of jet aircraft noise and sonic booms on wildlife, there appears to have been little concerted effort in developing quantitative comparisons of aircraft noise effects on normal auditory characteristics. Behavioral effects have been relatively well described, but the larger ecological context issues, and the potential for drawing conclusions regarding effects on populations, has not been well developed.

The relationships between potential auditory/physiological effects and species interactions with their environments are not well understood. Manci et al. (1988), assert that the consequences that physiological effects may have on behavioral patterns are vital to understanding the long-term effects of noise on wildlife. Questions regarding the effects (if any) on predator-prey interactions, reproductive success, and intra-inter specific behavior patterns remain.

The following discussion provides an overview of the existing literature on noise effects (particularly jet aircraft noise) on animal species. The literature reviewed here involves those studies that have focused on the observations of the behavioral effects that jet aircraft and sonic booms have on animals.

A great deal of research was conducted in the 1960s and 1970s on the effects of aircraft noise on the public and the potential for adverse ecological impacts. These studies were largely completed in response to the increase in air travel and as a result of the introduction of supersonic jet aircraft. According to Manci et al. (1988), the foundation of information created from that focus does not necessarily correlate or provide information specific to the impacts to wildlife in areas overflown by aircraft at supersonic speed or at low altitudes.

The abilities to hear sounds and noise and to communicate assist wildlife in maintaining group cohesiveness and survivorship. Social species communicate by transmitting calls of warning, introduction, and other types that are subsequently related to an individual's or group's responsiveness.

Animal species differ greatly in their responses to noise. Noise effects on domestic animals and wildlife are classified as primary, secondary, and tertiary. Primary effects are direct, physiological changes to the auditory system, and most likely include the masking of auditory signals. Masking is defined as the inability of an individual to hear important environmental signals that may arise from mates, predators, or prey. There is some potential that noise could disrupt a species' ability to communicate or could interfere with behavioral patterns (Manci et al. 1988). Although the effects are likely temporal, aircraft noise may cause masking of auditory signals within exposed faunal communities. Animals rely on hearing to avoid predators, obtain food, and communicate with, and attract, other members of their species. Aircraft noise may mask or interfere with these functions. Other primary effects, such as ear drum rupture or temporary and permanent hearing threshold shifts, are not as likely given the subsonic noise levels produced by aircraft overflights.

Secondary effects may include non-auditory effects such as stress and hypertension; behavioral modifications; interference with mating or reproduction; and impaired ability to obtain adequate food, cover, or water. Tertiary effects are the direct result of primary and secondary effects, and include population decline and habitat loss. Most of the effects of noise are mild enough that they may never be detectable as variables of change in population size or population growth against the background of normal variation (Bowles 1995). Other environmental variables (e.g., predators, weather, changing prey base, ground-based disturbance) also influence secondary and tertiary effects, and confound the ability to identify the ultimate factor in limiting productivity of a certain nest, area, or region (Smith et al. 1988). Overall, the literature suggests that species differ in their response to various types, durations, and sources of noise (Manci et al. 1988).

Many scientific studies have investigated the effects of aircraft noise on wildlife, and some have focused on wildlife "flight" due to noise. Animal responses to aircraft are influenced by many variables, including size, speed, proximity (both height above the ground and lateral distance), engine noise, color, flight profile, and radiated noise. The type of aircraft (e.g., fixed-wing versus rotor-wing [helicopter] aircraft) and type of flight mission may also produce different levels of disturbance, with varying animal responses (Smith et al. 1988). Consequently, it is difficult to generalize animal responses to noise disturbances across species.

One result of the Manci et al. (1988) literature review was the conclusion that, while behavioral observation studies were relatively limited, a general behavioral reaction in animals from exposure to aircraft noise is the startle response. The intensity and duration of the startle response appears to be dependent on which species is exposed, whether there is a group or an individual, and whether there have been some previous exposures. Responses range from flight, trampling, stampeding, jumping, or running, to movement of the head in the apparent direction of the noise source. Manci et al. (1988) reported that the literature indicated that avian species may be more sensitive to aircraft noise than mammals.

C.5.12.1 Domestic Animals

Although some studies report that the effects of aircraft noise on domestic animals is inconclusive, a majority of the literature reviewed indicates that domestic animals exhibit some behavioral responses to military overflights but generally seem to habituate to the disturbances over a period of time. Mammals in particular appear to react to noise at sound levels higher than 90 dB, with responses including the startle response, freezing (i.e., becoming temporarily stationary), and fleeing from the sound source. Many studies on domestic animals suggest that some species appear to acclimate to some forms of sound disturbance (Manci et al. 1988). Some studies have reported such primary and secondary effects as reduced milk production and rate of milk release, increased glucose concentrations, decreased levels of hemoglobin, increased heart rate, and a reduction in thyroid activity. These latter effects appear to represent a small percentage of the findings occurring in the existing literature.

Some reviewers have indicated that earlier studies, and claims by farmers linking adverse effects of aircraft noise on livestock, did not necessarily provide clear-cut evidence of cause and effect (Cottereau 1978). In contrast, many studies conclude that there is no evidence that aircraft overflights affect feed intake, growth, or production rates in domestic animals.

Cattle

In response to concerns about overflight effects on pregnant cattle, milk production, and cattle safety, the U.S. Air Force prepared a handbook for environmental protection that summarized the literature on the impacts of low-altitude flights on livestock (and poultry) and includes specific case studies conducted in numerous airspaces across the country. Adverse effects have been found in a few studies but have not been reproduced in other similar studies. One such study, conducted in 1983, suggested that 2 of 10 cows in late pregnancy aborted after showing rising estrogen and falling progesterone levels. These increased hormonal levels were reported as being linked to 59 aircraft overflights. The remaining eight cows showed no changes in their blood concentrations and calved normally. A similar study reported abortions occurred in three out of five pregnant cattle after exposing them to flyovers by six different aircraft. Another study suggested that feedlot cattle could stampede and injure themselves when exposed to low-level overflights (U.S. Air Force 1994a).

A majority of the studies reviewed suggests that there is little or no effect of aircraft noise on cattle. Studies presenting adverse effects to domestic animals have been limited. A number of studies (Parker and Bayley 1960; Casady and Lehmann 1967; Kovalcik and Sottnik 1971) investigated the effects of jet aircraft noise and sonic booms on the milk production of dairy cows. Through the compilation and examination of milk production data from areas exposed to jet aircraft noise and sonic boom events, it was determined that milk yields were not affected. This was particularly evident in those cows that had been previously exposed to jet aircraft noise.

A study examined the causes of 1,763 abortions in Wisconsin dairy cattle over a 1-year time period and none were associated with aircraft disturbances (U.S. Air Force 1993). In 1987, researchers contacted seven livestock operators for production data, and no effects of low-altitude and supersonic flights were noted. Of the 43 cattle previously exposed to low-altitude flights, 3 showed a startle response to an F/A-18 aircraft flying overhead at 500 feet above ground level (AGL) and 400 knots by running less than 10 meters (m). They resumed normal activity within 1 minute (U.S. Air Force 1994a). Beyer (1983) found that helicopters caused more reaction than other low-aircraft overflights, and that the helicopters at 30-60 feet overhead did not affect milk production and pregnancies of 44 cows in a 1964 study (U.S. Air Force 1994a).

Additionally, Beyer (1983) reported that five pregnant dairy cows in a pasture did not exhibit fright-flight tendencies or disturb their pregnancies after being overflown by 79 low-altitude helicopter flights and 4 low-altitude, subsonic jet aircraft flights. A 1956 study found that the reactions of dairy and beef cattle to noise from low-altitude, subsonic aircraft were similar to those caused by paper blowing about, strange persons, or other moving objects (U.S. Air Force 1994a).

In a report to Congress, the U. S. Forest Service concluded that “evidence both from field studies of wild ungulates and laboratory studies of domestic stock indicate that the risks of damage are small (from aircraft approaches of 50-100 m), as animals take care not to damage themselves (U.S. Forest Service 1992). If animals are overflown by aircraft at altitudes of 50-100 m, there is no evidence that mothers and young are separated, that animals collide with obstructions (unless confined) or that they traverse dangerous ground at too high a rate." These varied study results suggest that, although the confining of cattle could magnify animal response to aircraft overflight, there is no proven cause-and-effect link between startling cattle from aircraft overflights and abortion rates or lower milk production.

Horses

Horses have also been observed to react to overflights of jet aircraft. Several of the studies reviewed reported a varied response of horses to low-altitude aircraft overflights. Observations made in 1966 and 1968 noted that horses galloped in response to jet flyovers (U.S. Air Force 1993). Bowles (1995) cites Kruger and Erath as observing horses exhibiting intensive flight reactions, random movements, and biting/kicking behavior. However, no injuries or abortions occurred, and there was evidence that the mares adapted somewhat to the flyovers over the course of a month (U.S. Air Force 1994a). Although horses were observed noticing the overflights, it did not appear to affect either survivability or reproductive success. There was also some indication that habituation to these types of disturbances was occurring.

LeBlanc et al. (1991), studied the effects of F-14 jet aircraft noise on pregnant mares. They specifically focused on any changes in pregnancy success, behavior, cardiac function, hormonal production, and rate of habituation. Their findings reported observations of "flight-fright" reactions, which caused increases in heart rates and serum cortisol concentrations. The mares, however, did habituate to the noise. Levels of anxiety and mass body movements were the highest after initial exposure, with intensities of responses decreasing thereafter. There were no differences in pregnancy success when compared to a control group.

Swine

Generally, the literature findings for swine appear to be similar to those reported for cows and horses. While there are some effects from aircraft noise reported in the literature, these effects are minor. Studies of continuous noise exposure (i.e., 6 hours, 72 hours of constant exposure) reported influences on short-term hormonal production and release. Additional constant exposure studies indicated the observation of stress reactions, hypertension, and electrolyte imbalances (Dufour 1980). A study by Bond et al. (1963), demonstrated no adverse effects on the feeding efficiency, weight gain, ear physiology, or thyroid and adrenal gland condition of pigs subjected to observed aircraft noise. Observations of heart rate increase were recorded; noting that cessation of the noise resulted in the return to normal heart rates. Conception rates and offspring survivorship did not appear to be influenced by exposure to aircraft noise.

Similarly, simulated aircraft noise at levels of 100-135 dB had only minor effects on the rate of feed utilization, weight gain, food intake, or reproduction rates of boars and sows exposed, and there were no injuries or inner ear changes observed (Gladwin et al. 1988; Manci et al. 1988).

Domestic Fowl

According to a 1994 position paper by the U.S. Air Force on effects of low-altitude overflights (below 1,000 feet) on domestic fowl, overflight activity has negligible effects (U.S. Air Force 1994b). The paper did recognize that given certain circumstances, adverse effects can be serious. Some of the effects can be panic reactions, reduced productivity, and effects on marketability (e.g., bruising of the meat caused during "pile-up" situations).

The typical reaction of domestic fowl after exposure to sudden, intense noise is a short-term startle response. The reaction ceases as soon as the stimulus is ended, and within a few minutes all activity returns to normal. More severe responses are possible depending on the number of birds, the frequency of exposure, and environmental conditions. Large crowds of birds, and birds not previously exposed, are more likely to pile up in response to a noise stimulus (U.S. Air Force 1994b). According to studies and interviews with growers, it is typically the previously unexposed birds that incite panic crowding, and the tendency to do so is markedly reduced within five exposures to the stimulus (U.S. Air Force 1994b). This suggests that the birds habituate relatively quickly. Egg productivity was not adversely affected by infrequent noise bursts, even at exposure levels as high as 120-130 dB.

Between 1956 and 1988, there were 100 recorded claims against the Navy for alleged damage to domestic fowl. The number of claims averaged three per year, with peak numbers of claims following publications of studies on the topic in the early 1960s. Many of the claims were disproved or did not have sufficient supporting evidence. The claims were filed for the following alleged damages: 55% for panic reactions, 31% for decreased production, 6% for reduced hatchability, 6% for weight loss, and less than 1% for reduced fertility (U.S. Air Force 1994b).

The review of the existing literature suggests that there has not been a concerted or widespread effort to study the effects of aircraft noise on commercial turkeys. One study involving turkeys examined the differences between simulated versus actual overflight aircraft noise, turkey responses to the noise, weight gain, and evidence of habituation (Bowles et al. 1990). Findings from the study suggested that turkeys habituated to jet aircraft noise quickly, that there were no growth rate differences between the experimental and control groups, and that there were some behavioral differences that increased the difficulty in handling individuals within the experimental group.

Low-altitude overflights were shown to cause turkey flocks that were kept inside turkey houses to occasionally pile up and experience high mortality rates due to the aircraft noise and a variety of disturbances unrelated to aircraft (U.S. Air Force 1994b).

C.5.12.2 Wildlife

Studies on the effects of overflights and sonic booms on wildlife have been focused mostly on avian species and ungulates such as caribou and bighorn sheep. Few studies have been conducted on marine mammals, small terrestrial mammals, reptiles, amphibians, and carnivorous mammals. Generally, species that live entirely below the surface of the water have also been ignored due to the fact they do not experience the same level of sound as terrestrial species (National Park Service 1994). Wild ungulates appear to be much more sensitive to noise disturbance than domestic livestock. This may be due to previous exposure to disturbances. One common factor appears to be that low-altitude flyovers seem to be more disruptive in terrain where there is little cover (Manci et al. 1988).

Mammals

<u>*Terrestrial Mammals*</u>

Studies of terrestrial mammals have shown that noise levels of 120 dB can damage mammals' ears, and levels at 95 dB can cause temporary loss of hearing acuity. Noise from aircraft has affected other large carnivores by causing changes in home ranges, foraging patterns, and breeding behavior. One study recommended that aircraft not be allowed to fly at altitudes below 2,000 feet AGL over important grizzly and polar bear habitat. Wolves have been frightened by low-altitude flights that were 25-1,000 feet AGL.

However, wolves have been found to adapt to aircraft overflights and noise as long as they were not being hunted from aircraft (Dufour 1980).

Wild ungulates (American bison, caribou, bighorn sheep) appear to be much more sensitive to noise disturbance than domestic livestock (Weisenberger et al. 1996). Behavioral reactions may be related to the past history of disturbances by such things as humans and aircraft. Common reactions of reindeer kept in an enclosure exposed to aircraft noise disturbance were a slight startle response, rising of the head, pricking ears, and scenting of the air. Panic reactions and extensive changes in behavior of individual animals were not observed. Observations of caribou in Alaska exposed to fixed-wing aircraft and helicopters showed running and panic reactions occurred when overflights were at an altitude of 200 feet or less. The reactions decreased with increased altitude of overflights, and, with more than 500 feet in altitude, the panic reactions stopped. Also, smaller groups reacted less strongly than larger groups. One negative effect of the running and avoidance behavior is increased expenditure of energy. For a 90-kilogram animal, the calculated expenditure due to aircraft harassment is 64 kilocalories per minute when running and 20 kilocalories per minute when walking. When conditions are favorable, this expenditure can be counteracted with increased feeding; however, during harsh winter conditions, this may not be possible. Incidental observations of wolves and bears exposed to fixed-wing aircraft and helicopters in the northern regions suggested that wolves are less disturbed than wild ungulates, while grizzly bears showed the greatest response of any animal species observed (Weisenberger et al. 1996).

It has been proven that low-altitude overflights do induce stress in animals. Increased heart rates, an indicator of excitement or stress, have been found in pronghorn antelope, elk, and bighorn sheep. As such reactions occur naturally as a response to predation, infrequent overflights may not, in and of themselves, be detrimental. However, flights at high frequencies over a long period of time may cause harmful effects. The consequences of this disturbance, while cumulative, are not additive. It may be that aircraft disturbance may not cause obvious and serious health effects, but coupled with a harsh winter, it may have an adverse impact. Research has shown that stress induced by other types of disturbances produces long-term decreases in metabolism and hormone balances in wild ungulates.

Behavioral responses can range from mild to severe. Mild responses include head raising, body shifting, or turning to orient toward the aircraft. Moderate disturbance may be nervous behaviors, such as trotting a short distance. Escape is the typical severe response.

Marine Mammals

The physiological composition of the ear in aquatic and marine mammals exhibits adaptation to the aqueous environment. These differences (relative to terrestrial species) manifest themselves in the auricle and middle ear (Manci et al. 1988). Some mammals use echolocation to perceive objects in their surroundings and to determine the directions and locations of sound sources (Simmons 1983 in Manci et al. 1988).

In 1980, the Acoustical Society of America held a workshop to assess the potential hazard of manmade noise associated with proposed Alaska Arctic (North Slope-Outer Continental Shelf) petroleum operations on marine wildlife and to prepare a research plan to secure the knowledge necessary for proper assessment of noise impacts (Acoustical Society of America 1980). Since 1980 it appears that research on responses of aquatic mammals to aircraft noise and sonic booms has been limited. Research conducted on northern fur seals, sea lions, and ringed seals indicated that there are some differences in how various animal groups receive frequencies of sound. It was observed that these species exhibited varying intensities of a startle response to airborne noise, which was habituated over time. The rates of habituation appeared to vary with species, populations, and demographics (age, sex). Time of day of exposure was also a factor (Muyberg 1978 in Manci et al. 1988).

Studies accomplished near the Channel Islands were conducted near the area where the space shuttle launches occur. It was found that there were some response differences between species relative to the loudness of sonic booms. Those booms that were between 80 and 89 dB caused a greater intensity of startle reactions than lower-intensity booms at 72-79 dB. However, the duration of the startle responses to louder sonic booms was shorter (Jehl and Cooper 1980).

Jehl and Cooper (1980) indicated that low-flying helicopters, loud boat noises, and humans were the most disturbing to pinnipeds. According to the research, while the space launch and associated operational activity noises have not had a measurable effect on the pinniped population, it also suggests that there was a greater “disturbance level” exhibited during launch activities. There was a recommendation to continue observations for behavioral effects and to perform long-term population monitoring (Jehl and Cooper 1980).

The continued presence of single or multiple noise sources could cause marine mammals to leave a preferred habitat. However, it does not appear likely that overflights could cause migration from suitable habitats as aircraft noise over water is mobile and would not persist over any particular area. Aircraft noise, including supersonic noise, currently occurs in the overwater airspace of Eglin, Tyndall, and Langley AFBs from sorties predominantly involving jet aircraft. Survey results reported in Davis et al. (2000), indicate that cetaceans (i.e., dolphins) occur under all of the Eglin and Tyndall marine airspace. The continuing presence of dolphins indicates that aircraft noise does not discourage use of the area and apparently does not harm the locally occurring population.

In a summary by the National Park Service (1994) on the effects of noise on marine mammals, it was determined that gray whales and harbor porpoises showed no outward behavioral response to aircraft noise or overflights. Bottlenose dolphins showed no obvious reaction in a study involving helicopter overflights at 1,200 to 1,800 feet above the water. Neither did they show any reaction to survey aircraft unless the shadow of the aircraft passed over them, at which point there was some observed tendency to dive (Richardson et al. 1995). Other anthropogenic noises in the marine environment from ships and pleasure craft may have more of an effect on marine mammals than aircraft noise (U.S. Air Force 2000). The noise effects on cetaceans appear to be somewhat attenuated by the air/water interface. The cetacean fauna along the coast of California have been subjected to sonic booms from military aircraft for many years without apparent adverse effects (Tetra Tech, Inc. 1997).

Manatees appear relatively unresponsive to human-generated noise to the point that they are often suspected of being deaf to oncoming boats [although their hearing is actually similar to that of pinnipeds (Bullock et al. 1980)]. Little is known about the importance of acoustic communication to manatees, although they are known to produce at least ten different types of sounds and are thought to have sensitive hearing (Richardson et al. 1995). Manatees continue to occupy canals near Miami International Airport, which suggests that they have become habituated to human disturbance and noise (Metro-Dade County 1995). Since manatees spend most of their time below the surface and do not startle readily, no effect of aircraft overflights on manatees would be expected (Bowles et al. 1993).

Birds

Auditory research conducted on birds indicates that they fall between the reptiles and the mammals relative to hearing sensitivity. According to Dooling (1978), within the range of 1,000 to 5,000 Hz, birds show a level of hearing sensitivity similar to that of the more sensitive mammals. In contrast to mammals, bird sensitivity falls off at a greater rate to increasing and decreasing frequencies. Passive observations and studies examining aircraft bird strikes indicate that birds nest and forage near airports. Aircraft noise in the vicinity of commercial airports apparently does not inhibit bird presence and use.

High-noise events (like a low-altitude aircraft overflight) may cause birds to engage in escape or avoidance behaviors, such as flushing from perches or nests (Ellis et al. 1991). These activities impose an energy cost on the birds that, over the long term, may affect survival or growth. In addition, the birds may spend less time engaged in necessary activities like feeding, preening, or caring for their young because they spend time in noise-avoidance activity. However, the long-term significance of noise-related impacts is less clear. Several studies on nesting raptors have indicated that birds become habituated to aircraft overflights and that long-term reproductive success is not affected (Ellis et al. 1991; Grubb and King 1991). Threshold noise levels for significant responses range from 62 dB for Pacific black brant to 85 dB for crested tern (Brown 1990; Ward and Stehn 1990).

Songbirds were observed to become silent prior to the onset of a sonic boom event (F-111 jets), followed by "raucous discordant cries." There was a return to normal singing within 10 seconds after the boom (Higgins 1974 in Manci et al. 1988). Ravens responded by emitting protestation calls, flapping their wings, and soaring.

Manci et al. (1988), reported a reduction in reproductive success in some small territorial passerines (i.e., perching birds or songbirds) after exposure to low-altitude overflights. However, it has been observed that passerines are not driven any great distance from a favored food source by a nonspecific disturbance, such as aircraft overflights (U.S. Forest Service 1992). Further study may be warranted.

A cooperative study between the DoD and the U.S. Fish and Wildlife Service (USFWS), assessed the response of the red-cockaded woodpecker to a range of military training noise events, including artillery, small arms, helicopter, and maneuver noise (Pater et al. 1999). The project findings show that the red-cockaded woodpecker successfully acclimates to military noise events. Depending on the noise level that ranged from innocuous to very loud, the birds responded by flushing from their nest cavities. When the noise source was closer and the noise level was higher, the number of flushes increased proportionately. In all cases, however, the birds returned to their nests within a relatively short period of time (usually within 12 minutes). Additionally, the noise exposure did not result in any mortality or statistically detectable changes in reproductive success (Pater et al. 1999). Red-cockaded woodpeckers did not flush when artillery simulators were more than 122 m away and SELs were 70 dB.

Lynch and Speake (1978) studied the effects of both real and simulated sonic booms on the nesting and brooding eastern wild turkey in Alabama. Hens at four nest sites were subjected to between 8 and 11 combined real and simulated sonic booms. All tests elicited similar responses, including quick lifting of the head and apparent alertness for 10-20 seconds. No apparent nest failure occurred as a result of the sonic booms. Twenty-one brood groups were also subjected to simulated sonic booms. Reactions varied slightly between groups, but the largest percentage of groups reacted by standing motionless after the initial blast. Upon the sound of the boom, the hens and poults fled until reaching the edge of the woods (approximately 4-8 m). Afterward, the poults resumed feeding activities while the hens remained alert for a short period of time (approximately 15-20 seconds). In no instances were poults abandoned, nor did they scatter and become lost. Every observation group returned to normal activities within a maximum of 30 seconds after a blast.

Bald Eagle

A study by Grubb and King (1991) on the reactions of the bald eagle to human disturbances showed that terrestrial disturbances elicited the greatest response, followed by aquatic (i.e., boats) and aerial disturbances. The disturbance regime of the area where the study occurred was predominantly characterized by aircraft noise. The study found that pedestrians consistently caused responses that were greater in both frequency and duration. Helicopters elicited the highest level of aircraft-related responses. Aircraft disturbances, although the most common form of disturbance, resulted in the lowest levels of response. This low response level may have been due to habituation; however, flights less than 170 m away caused reactions similar to other disturbance types. Ellis et al. (1991) showed that eagles typically respond to the proximity of a disturbance, such as a pedestrian or aircraft within 100 m, rather than the noise level. Fleischner and Weisberg (1986) stated that reactions of bald eagles to commercial jet flights, although minor (e.g., looking), were twice as likely to occur when the jets passed at a distance of 0.5 mile or less. They also noted that helicopters were four times more likely to cause a reaction than a commercial jet and 20 times more likely to cause a reaction than a propeller plane.

The USFWS advised Cannon AFB that flights at or below 2,000 feet AGL from October 1 through March 1 could result in adverse impacts to wintering bald eagles (USFWS 1998). However, Fraser et al. (1985) suggested that raptors habituate to overflights rapidly, sometimes tolerating aircraft approaches of 65 feet or less.

Golden Eagle

In their guidelines for aerial surveys, USFWS (Pagel et al. 2010) summarized past studies by stating that most golden eagles respond to survey aircraft (fixed- and rotary-wing aircraft) by remaining on their nests, and continuing to incubate or roost. Surveys take place generally as close as 10 to 20 meters from cliffs (including hovering less than 30 seconds if necessary to count eggs) and no farther than 200 meters from cliffs depending on safety (Pagel et al. 2010).

Grubb et al. (2007) experimented with multiple exposure to two helicopter types and concluded that flights with a variety of approach distances (800, 400, 200, and 100 meters) had no effect on golden eagle nesting success or productivity rates within the same year or on rates of renewed nesting activity the following year when compared to the corresponding figures for the larger population of non-manipulated nest sites (Grubb et al. 2007). They found no significant, detrimental, or disruptive responses in 303 helicopter passes near eagles. In 227 AH-64 Apache helicopter experimental passes (considered twice as loud as a civilian helicopter also tested) at test distances of 0–800 meters from nesting golden eagles, 96 percent resulted in no more response than watching the helicopter pass. No greater reactions occurred until after hatching when individual golden eagles exhibited five flatten and three fly behaviors at three nest sites. The flight responses occurred at approach distances of 200 meters or less. No evidence was found of an effect on subsequent nesting activity or success, despite many of the helicopter flights occurring during early courtship and nest repair. None of these responding pairs failed to successfully fledge young, except for one nest that fell later in the season. Excited, startled, avoidance reactions were never observed. Non-attending eagles or those perched away from the nests were more likely to fly than attending eagles, but also with less potential consequence to nesting success (Grubb et al. 2007). Golden eagles appeared to become less responsive with successive exposures. Much of helicopter sound energy may be at a lower frequency than golden eagles can hear, thus reducing expected impacts. Grubb et al. (2007) found no relationship between helicopter sound levels and corresponding eagle ambient behaviors or limited responses, which occurred throughout recorded test levels (76.7–108.8 dB, unweighted). The authors thought that the lower than expected behavioral responses may be partially due to the fact that the golden eagles in the area appear acclimated to the current high levels of outdoor recreational, including aviation, activities. Based on the results of this study, the authors recommended reduction of existing buffers around nest sites to 100 meters (325 feet) for helicopter activity.

Richardson and Miller (1997) reviewed buffers as protection for raptors against disturbance from ground-based human activities. No consideration of aircraft activity was included. They stressed a clear line of sight as an important factor in a raptor's response to a particular disturbance, with visual screening allowing a closer approach of humans without disturbing a raptor. A GIS-assisted viewshed approach combined with a designated buffer zone distance was found to be an effective tool for reducing potential disturbance to golden eagles from ground-based activities (Richardson and Miller 1997). They summarized recommendations that included a median 0.5-mile (800-meter) buffer (range = 200-1,600 m, n = 3) to reduce human disturbances (from ground-based activities such as rock climbing, shooting, vehicular activity) around active golden eagle nests from February 1 to August 1 based on an extensive review of other studies (Richardson and Miller 1997). Physical characteristics (i.e., screening by topography or vegetation) are important variables to consider when establishing buffer zones based on raptors' visual- and auditory-detection distances (Richardson and Miller 1997).

Osprey

A study by Trimper et al. (1998), in Goose Bay, Labrador, Canada, focused on the reactions of nesting osprey to military overflights by CF-18 Hornets. Reactions varied from increased alertness and focused observation of planes to adjustments in incubation posture. No overt reactions (e.g., startle response, rapid nest departure) were observed as a result of an overflight. Young nestlings crouched as a result of any disturbance until 1 to 2 weeks prior to fledging. Helicopters, human presence, float planes, and other ospreys elicited the strongest reactions from nesting ospreys. These responses included flushing, agitation, and aggressive displays. Adult osprey showed high nest occupancy rates during incubation regardless of external influences. The osprey observed occasionally stared in the direction of the flight before it was audible to the observers. The birds may have been habituated to the noise of the flights; however, overflights were strictly controlled during the experimental period. Strong reactions to float planes and helicopter may have been due to the slower flight and therefore longer duration of visual stimuli rather than noise-related stimuli.

Red-tailed Hawk

Anderson et al. (1989), conducted a study that investigated the effects of low-level helicopter overflights on 35 red-tailed hawk nests. Some of the nests had not been flown over prior to the study. The hawks that were naïve (i.e., not previously exposed) to helicopter flights exhibited stronger avoidance behavior (9 of 17 birds flushed from their nests) than those that had experienced prior overflights. The overflights did not appear to affect nesting success in either study group. These findings were consistent with the belief that red-tailed hawks habituate to low-level air traffic, even during the nesting period.

Upland Game Birds

Greater Sage-grouse

The greater sage-grouse was recently designated as a candidate species for protection under the Endangered Species Act after many years of scrutiny and research (USFWS 2010). This species is a widespread and characteristic species of the sagebrush ecosystems in the Intermountain West. Greater sage-grouse, like most bird species, rely on auditory signals as part of mating. Sage-grouse are known to select their leks based on acoustic properties and depend on auditory communication for mating behavior (Braun 2006). Although little specific research has been completed to determine what, if any, effects aircraft overflight and sonic booms would have on the breeding behavior of this species, factors that may be important include season and time of day, altitude, frequency, and duration of overflights, and frequency and loudness of sonic booms.

Booth *et al.* (2009) found, while attempting to count sage-grouse at leks (breeding grounds) using light sport aircraft at 150 meters (492 feet) to 200 meters (650 feet) AGL, that sage-grouse flushed from leks on 12 of 14 approaches when the airplane was within 656 to 984 feet (200–300 meters) of the lek. In the other two instances, male grouse stopped exhibiting breeding behavior and crouched but stayed on the lek. The time to resumption of normal behavior after disturbance was not provided in this study. Strutting ceased around the time when observers on the ground heard the aircraft. The light sport aircraft could be safely operated at very low speed (68 kilometers/hour or 37 nautical miles/hour) and was powered by either a two-stroke or a four-stroke engine. It is unclear how the response to the slow-flying light sport aircraft used in the study would compare to overflight by military jets, operating at speeds 10 to 12 times as great as the aircraft used in the study. It is possible that response of the birds was related to the slow speed of the light sport aircraft causing it to resemble an aerial predator.

Other studies have found disturbance from energy operations and other nearby development have adversely affected breeding behavior of greater sage-grouse (Holloran 2005; Doherty 2008; Walker *et al.* 2007; Harju *et al.* 2010). These studies do not specifically address overflight and do not isolate noise disturbance from other types (e.g., visual, human presence) nor do they generally provide noise levels or qualification of the noise source (e.g., continuous or intermittent, frequency, duration).

Because so few studies have been done on greater sage-grouse response to overflights or sonic booms, research on related species may be applicable. Observations on other upland game bird species include those on the behavior of four wild turkey (Meleagris gallapavo) hens on their nests during real and simulated sonic booms (Manci *et al.* 1988). Simulated sonic booms were produced by firing 5-centimeter mortar shells, 300 to 500 feet from the nest of each hen. Recordings of pressure for both types of booms measured 0.4 to 1.0 pounds per square foot (psf) at the observer's location.

Turkey hens exhibited only a few seconds of head alert behavior at the sound of the sonic boom. No hens were flushed off the nests, and productivity estimates revealed no effect from the booms. Twenty brood groups were also subjected to simulated sonic booms. In no instance did the hens desert any poults (young birds), nor did the poults scatter or desert the rest of the brood group. In every observation, the brood group returned to normal activity within 30 seconds after a simulated sonic boom. Similarly, researchers cited in Manci *et al.* (1988) observed no difference in hatching success of bobwhite quail (*Colinus virginianus*) exposed to simulated sonic booms of 100 to 250 micronewtons per square meter.

<u>Migratory Waterfowl</u>

Fleming et al. (1996) conducted a study of caged American black ducks found that noise had negligible energetic and physiologic effects on adult waterfowl. Measurements included body weight, behavior, heart rate, and enzymatic activity. Experiments also showed that adult ducks exposed to high noise events acclimated rapidly and showed no effects.

The study also investigated the reproductive success of captive ducks, which indicated that duckling growth and survival rates at Piney Island, North Carolina, were lower than those at a background location. In contrast, observations of several other reproductive indices (i.e., pair formation, nesting, egg production, and hatching success) showed no difference between Piney Island and the background location. Potential effects on wild duck populations may vary, as wild ducks at Piney Island have presumably acclimated to aircraft overflights. It was not demonstrated that noise was the cause of adverse impacts. A variety of other factors, such as weather conditions, drinking water and food availability and variability, disease, and natural variability in reproduction, could explain the observed effects. Fleming noted that drinking water conditions (particularly at Piney Island) deteriorated during the study, which could have affected the growth of young ducks. Further research would be necessary to determine the cause of any reproductive effects (Fleming et al. 1996).

Another study by Conomy et al. (1998) exposed previously unexposed ducks to 71 noise events per day that equaled or exceeded 80 dB. It was determined that the proportion of time black ducks reacted to aircraft activity and noise decreased from 38% to 6% in 17 days and remained stable at 5.8% thereafter. In the same study, the wood duck did not appear to habituate to aircraft disturbance. This supports the notion that animal response to aircraft noise is species-specific. Because a startle response to aircraft noise can result in flushing from nests, migrants and animals living in areas with high concentrations of predators would be the most vulnerable to experiencing effects of lowered birth rates and recruitment over time. Species that are subjected to infrequent overflights do not appear to habituate to overflight disturbance as readily.

Black brant studied in the Alaska Peninsula were exposed to jets and propeller aircraft, helicopters, gunshots, people, boats, and various raptors. Jets accounted for 65% of all the disturbances. Humans, eagles, and boats caused a greater percentage of brant to take flight. There was markedly greater reaction to Bell-206-B helicopter flights than fixed-wing, single-engine aircraft (Ward et al. 1986).

The presence of humans and low-flying helicopters in the Mackenzie Valley North Slope area did not appear to affect the population density of Lapland longspurs, but the experimental group was shown to have reduced hatching and fledging success and higher nest abandonment. Human presence appeared to have a greater impact on the incubating behavior of the black brant, common eider, and Arctic tern than fixed-wing aircraft (Gunn and Livingston 1974).

Gunn and Livingston (1974) found that waterfowl and seabirds in the Mackenzie Valley and North Slope of Alaska and Canada became acclimated to float plane disturbance over the course of three days. Additionally, it was observed that potential predators (bald eagle) caused a number of birds to leave their nests. Non-breeding birds were observed to be more reactive than breeding birds. Waterfowl were affected by helicopter flights, while snow geese were disturbed by Cessna 185 flights. The geese flushed when the planes were less than 1,000 feet, compared to higher flight elevations. An overall reduction in flock sizes was observed. It was recommended that aircraft flights be reduced in the vicinity of premigratory staging areas.

Manci et al. 1988, reported that waterfowl were particularly disturbed by aircraft noise. The most sensitive appeared to be snow geese. Canada geese and snow geese were thought to be more sensitive than other animals such as turkey vultures, coyotes, and raptors (Edwards et al. 1979).

Wading and Shorebirds

Black et al. (1984), studied the effects of low-altitude (less than 500 feet AGL) military training flights with sound levels from 55 to 100 dB on wading bird colonies (i.e., great egret, snowy egret, tricolored heron, and little blue heron). The training flights involved three or four aircraft, which occurred once or twice per day. This study concluded that the reproductive activity--including nest success, nestling survival, and nestling chronology--was independent of F-16 overflights. Dependent variables were more strongly related to ecological factors, including location and physical characteristics of the colony and climatology.

Another study on the effects of circling fixed-wing aircraft and helicopter overflights on wading bird colonies found that at altitudes of 195 to 390 feet, there was no reaction in nearly 75% of the 220 observations. Approximately 90% displayed no reaction or merely looked toward the direction of the noise source. Another 6% stood up, 3% walked from the nest, and 2% flushed (but were without active nests) and returned within 5 minutes (Kushlan 1978). Apparently, non-nesting wading birds had a slightly higher incidence of reacting to overflights than nesting birds. Seagulls observed roosting near a colony of wading birds in another study remained at their roosts when subsonic aircraft flew overhead (Burger 1981). Colony distribution appeared to be most directly correlated to available wetland community types and was found to be distributed randomly with respect to military training routes. These results suggest that wading bird species presence was most closely linked to habitat availability and that they were not affected by low-level military overflights (U.S. Air Force 2000).

Burger (1986) studied the response of migrating shorebirds to human disturbance and found that shorebirds did not fly in response to aircraft overflights, but did flush in response to more localized intrusions (i.e., humans and dogs on the beach). Burger (1981) studied the effects of noise from JFK Airport in New York on herring gulls that nested less than 1 kilometer from the airport. Noise levels over the nesting colony were 85-100 dB on approach and 94-105 dB on takeoff. Generally, there did not appear to be any prominent adverse effects of subsonic aircraft on nesting, although some birds flushed when the Concorde flew overhead and, when they returned, engaged in aggressive behavior. Groups of gulls tended to loaf in the area of the nesting colony, and these birds remained at the roost when the Concorde flew overhead. Up to 208 of the loafing gulls flew when supersonic aircraft flew overhead. These birds would circle around and immediately land in the loafing flock (U.S. Air Force 2000).

In 1970, sonic booms were potentially linked to a mass hatch failure of sooty terns on the Dry Tortugas (Austin et al. 1970). The cause of the failure was not certain, but it was conjectured that sonic booms from military aircraft or an overgrowth of vegetation were factors. In the previous season, sooty terns were observed to react to sonic booms by rising in a "panic flight," circling over the island, then usually settling down on their eggs again. Hatching that year was normal. Following the 1969 hatch failure, excess vegetation was cleared and measures were taken to reduce supersonic activity. The 1970 hatch appeared to proceed normally. A colony of noddies on the same island hatched successfully in 1969, the year of the sooty tern hatch failure.

Subsequent laboratory tests of exposure of eggs to sonic booms and other impulsive noises (Cottereau 1972; Cogger and Zegarra 1980; Bowles et al. 1991, 1994) failed to show adverse effects on hatching of eggs. A structural analysis by Ting et al. (2002) showed that, even under extraordinary circumstances, sonic booms would not damage an avian egg.

Burger (1981) observed no effects of subsonic aircraft on herring gulls in the vicinity of JFK International Airport. The Concorde aircraft did cause more nesting gulls to leave their nests (especially in areas of higher density of nests), causing the breakage of eggs and the scavenging of eggs by intruder prey. Clutch sizes were observed to be smaller in areas of higher-density nesting (presumably due to the greater tendency for panic flight) than in areas where there were fewer nests.

Raptors

In a literature review of raptor responses to aircraft noise, Manci et al. (1988) found that most raptors did not show a negative response to overflights. When negative responses were observed they were predominantly associated with rotor-winged aircraft or jet aircraft that were repeatedly passing within 0.5 mile of a nest.

Ellis et al. (1991), performed a study to estimate the effects of low-level military jet aircraft and mid- to high-altitude sonic booms (both actual and simulated) on nesting peregrine falcons and seven other raptors (common black-hawk, Harris' hawk, zone-tailed hawk, red-tailed hawk, golden eagle, prairie falcon, bald eagle). They observed responses to test stimuli, determined nest success for the year of the testing, and evaluated site occupancy the following year. Both long- and short-term effects were noted in the study. The results reported the successful fledging of young in 34 of 38 nest sites (all eight species) subjected to low-level flight and/or simulated sonic booms. Twenty-two of the test sites were revisited in the following year, and observations of pairs or lone birds were made at all but one nest. Nesting attempts were underway at 19 of 20 sites that were observed long enough to be certain of breeding activity. Re-occupancy and productivity rates were within or above expected values for self-sustaining populations.

Short-term behavior responses were also noted. Overflights at a distance of 150 m or less produced few significant responses and no severe responses. Typical responses consisted of crouching or, very rarely, flushing from the perch site. Significant responses were most evident before egg laying and after young were "well grown." Incubating or brooding adults never burst from the nest, thus preventing egg breaking or knocking chicks out of the nest. Jet passes and sonic booms often caused noticeable alarm; however, significant negative responses were rare and did not appear to limit productivity or re-occupancy. Due to the locations of some of the nests, some birds may have been habituated to aircraft noise. There were some test sites located at distances far from zones of frequent military aircraft usage, and the test stimuli were often closer, louder, and more frequent than would be likely for a normal training situation (Ellis et al. 1991).

Manci et al. (1988), noted that a female northern harrier was observed hunting on a bombing range in Mississippi during bombing exercises. The harrier was apparently unfazed by the exercises, even when a bomb exploded within 200 feet. In a similar case of habituation/non-disturbance, a study on the Florida snail-kite stated the greatest reaction to overflights (approximately 98 dB) was "watching the aircraft fly by." No detrimental impacts to distribution, breeding success, or behavior were noted.

Fish and Amphibians

The effects of overflight noise on fish and amphibians have not been well studied, but conclusions regarding their expected responses have involved speculation based upon known physiologies and behavioral traits of these taxa (Gladwin *et al.* 1988). Although fish do startle in response to low-flying aircraft noise, and probably to the shadows of aircraft, they have been found to habituate to the sound and overflights. Amphibians that respond to low frequencies and those that respond to ground vibration, such as spadefoot toads, may be affected by noise.

Summary

Some physiological/behavioral responses such as increased hormonal production, increased heart rate, and reduction in milk production have been described in a small percentage of studies. A majority of the studies focusing on these types of effects have reported short-term or no effects.

The relationships between physiological effects and how species interact with their environments have not been thoroughly studied. Therefore, the larger ecological context issues regarding physiological effects of jet aircraft noise (if any) and resulting behavioral pattern changes are not well understood.

Animal species exhibit a wide variety of responses to noise. It is therefore difficult to generalize animal responses to noise disturbances or to draw inferences across species, as reactions to jet aircraft noise appear to be species-specific. Consequently, some animal species may be more sensitive than other species and/or may exhibit different forms or intensities of behavioral responses. For instance, wood ducks appear to be more sensitive and more resistant to acclimation to jet aircraft noise than Canada geese in one study. Similarly, wild ungulates seem to be more easily disturbed than domestic animals.

The literature does suggest that common responses include the “startle” or “fright” response and, ultimately, habituation. It has been reported that the intensities and durations of the startle response decrease with the numbers and frequencies of exposures, suggesting no long-term adverse effects. The majority of the literature suggests that domestic animal species (cows, horses, chickens) and wildlife species exhibit adaptation, acclimation, and habituation after repeated exposure to jet aircraft noise and sonic booms.

Animal responses to aircraft noise appear to be somewhat dependent on, or influenced by, the size, shape, speed, proximity (vertical and horizontal), engine noise, color, and flight profile of planes. Helicopters also appear to induce greater intensities and durations of disturbance behavior as compared to fixed-wing aircraft. Some studies showed that animals that had been previously exposed to jet aircraft noise exhibited greater degrees of alarm and disturbance to other objects creating noise, such as boats, people, and objects blowing across the landscape. Other factors influencing response to jet aircraft noise may include wind direction, speed, and local air turbulence; landscape structures (i.e., amount and type of vegetative cover); and, in the case of bird species, whether the animals are in the incubation/nesting phase.

C.6 References

Acoustical Society of America. 1980. San Diego Workshop on the Interaction Between Manmade Noise and Vibration and Arctic Marine Wildlife. Acoustical Society of America, Am. Inst. Physics, New York. 84 pp.

American Speech-Language-Hearing Association. 2005. Guidelines for Addressing Acoustics in Educational Settings, ASHA Working Group on Classroom Acoustics.

Ancona, C., C. Badaloni, V. Fano, T. Fabozzi, F. Forastiere and C. Perucci. 2010. “Aircraft Noise and Blood Pressure in the Populations Living Near the Ciampino Airport in Rome”, Epidemiology: November 2009 - Volume 20 - Issue 6 - pp S125-S126

Anderson, D.E., O.J. Rongstad, and W.R. Mytton. 1989. Responses of Nesting Red-tailed Hawks to Helicopter Overflights, The Condor, Vol. 91, pp. 296-299.

Andersson, H., L. Jonsson, and M. Ogren. 2013. "Benefit measures for noise abatement: calculations for road and rail traffic noise," Eur. Transp. Res. Rev. 5:135–148.

Andrus, W.S., M.E. Kerrigan, and K.T. Bird. 1975. Hearing in Para-Airport Children. Aviation, Space, and Environmental Medicine, Vol. 46, pp. 740-742.

ANR 2010. “German Airport Association Criticizes Greiser Studies for Lack of Peer Review”. Airport Noise Report Vol. 22, page 58, May 14.

ANSI. 1985. Specification for Sound Level Meters, ANSI S1.4A-1985 Amendment to ANSI S1.4-1983.

_____. 1988. Quantities and Procedures for Description and Measurement of Environmental Sound: Part 1, ANSI S12.9-1988.

_____. 1994. *ANSI S1.1-1994 (R 2004) American National Standard Acoustical Terminology*. New York, NY: The Acoustical Society of America.

_____. 1996. Quantities and Procedures for Description and Measurement of Environmental Sound: Part 4, ANSI S12.9-1996.

_____. 2002. Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, ANSI S12.60-2002.

_____. 2008. Methods for Estimation of Awakenings with Outdoor Noise Events Heard in Homes, ANSI S12.9-2008/Part6.Austin, Jr., O.L., W.B. Robertson, Jr., and G.E. Wolfenden. 1970. “Mass Hatching Failure in Dry Tortugas Sooty Terns (Sterna fuscata),” Proceedings of the XVth International Arnithological Congress, The Hague, The Netherlands, August 30 through September 5.

Babisch W. B., D. Houthuijs, G. Pershagen, K. Katsouyanni, M. Velonakis, E. Cadum and L. Jarup. 2008. “Hypertension and exposure to noise near airports - results of the HYENA study”, 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT.

Babisch W. and Kamp Iv. 2009. Exposure-response relationship of the association between aircraft noise and the risk of hypertension. Noise Health 2009;11:161-8.

Babisch, W. 2013. "Exposure-Response Curves of the Association Between Transportation Noise and Cardiovascular Diseases – An Overview":, First International Congress on Hygiene and Preventive Medicine, Belgrade, Serbia, 22-24 May 2013.

Babisch, W., G. Pershagen, J. Selander, D. Houthuijs, O. Breugelmans, E. Cadum, F. Vigna-Taglianti, K. Katsouyanni, A.S. Haralabidis, K. Dimakopoulou, P. Sourtzi, S. Floud, and A.L. Hansell. 2013. Noise annoyance – A modifier of the association between noise level and cardiovascular health? Science of the Total Environment, Volumes 452-453, pp. 50-57, May.

Basner, M., H. Buess, U. Miller, G. Platt, and A. Samuel. 2004. "Aircraft Noise Effects on Sleep: Final Results of DLR Laboratory and Field Studies of 2240 Polysomnographically Recorded Subject Nights", Internoise 2004, The 33rd International Congress and Exposition on Noise Control Engineering, August 22-25.

Basner M, U. Muller, EM. Elmenhorst. 2011. Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. Sleep 2011; 34: 11–23.

Basner, M., Clark, C., Hansell, A., Hileman, J., Janssen, S., Shepherd, K., & Sparrow, V. (2017). Aviation Noise Impacts: State of the Science. *Noise and Health*, 19(87): 41-50.

Berger, E.H., W.D. Ward, J.C. Morrill, and L.H. Royster. 1995. Noise And Hearing Conservation Manual, Fourth Edition, American Industrial Hygiene Association, Fairfax, Virginia.

Berglund, B., and T. Lindvall, eds. 1995. Community Noise, Jannes Snabbtryck, Stockholm, Sweden.

Beyer, D. 1983. "Studies of the Effects of Low-Flying Aircraft on Endocrinological and Physiological Parameters in Pregnant Cows," Veterinary College of Hannover, München, Germany.

Black D., J. Black, T. Issarayangyun, and S. Samuels, 2007. "Aircraft noise exposure and resident's stress and hypertension: A public health perspective for airport environmental management." J Air Transp Manag 2007; 13: 264-76.

Black, B., M. Collopy, H. Percivial, A. Tiller, and P. Bohall. 1984. "Effects of Low-Altitude Military Training Flights on Wading Bird Colonies in Florida," Florida Cooperative Fish and Wildlife Research Unit, Technical Report No. 7.

Booth, D.T., S.E. Cox, G.E. Simonds, and B. Elmore. 2009. Efficacy of Two Variations on an Aerial Lek-Count Method for Greater Sage-Grouse. In the Western North American Naturalist. Volume 69(3). Pgs. 413-416.

Bond, J., C.F. Winchester, L.E. Campbell, and J.C. Webb. 1963. "The Effects of Loud Sounds on the Physiology and Behavior of Swine," U.S. Department of Agriculture Agricultural Research Service Technical Bulletin 1280.

Bowles, A.E. 1995. Responses of Wildlife to Noise, In R.L. Knight and K.J. Gutzwiller, eds., "Wildlife and Recreationists: Coexistence through Management and Research," Island Press, Covelo, California, pp. 109-156.

Bowles, A.E., C. Book, and F. Bradley. 1990. "Effects of Low-Altitude Aircraft Overflights on Domestic Turkey Poults," HSD-TR-90-034.

Bowles, A.E., F.T. Awbrey, and J.R. Jehl. 1991. "The Effects of High-Amplitude Impulsive Noise On Hatching Success: A Reanalysis of the Sooty Tern Incident," HSD-TP-91-0006.

Bowles, A.E., B. Tabachnick, and S. Fidell. 1993. Review of the Effects of Aircraft Overflights on Wildlife, Volume II of III, Technical Report, National Park Service, Denver, Colorado.

Bowles, A.E., M. Knobler, M.D. Sneddon, and B.A. Kugler. 1994. "Effects of Simulated Sonic Booms on the Hatchability of White Leghorn Chicken Eggs," AL/OE-TR-1994-0179.

Bradley J.S. 1985. "Uniform Derivation of Optimum Conditions for Speech in Rooms," National Research Council, Building Research Note, BRN 239, Ottawa, Canada.

Bradley, J.S. 1993. "NRC-CNRC NEF Validation Study: Review of Aircraft Noise and its Effects," National Research Council Canada and Transport Canada, Contract Report A-1505.5.

Bronzaft, A.L. and D.P. McCarthy. 1975. "The effects of elevated train noise on reading ability" J. Environment and Behavior, 7, 517-527.

Braun, C.E. 2006. A Blueprint for Sage-grouse Conservation and Recovery. Unpublished report. Grouse Inc. Tucson, Arizona.

Brown, A.L. 1990. Measuring the Effect of Aircraft Noise on Sea Birds, Environment International, Vol. 16, pp. 587-592.

Bullock, T.H., D.P. Donning, and C.R. Best. 1980. "Evoked brain potentials demonstrate hearing in a manatee (trichechus inunguis)", Journal of Mammals, Vol. 61, No. 1, pp. 130-133.

Burger, J. 1981. Behavioral Responses of Herring Gulls (Larus argentatus) to Aircraft Noise. Environmental Pollution (Series A), Vol. 24, pp. 177-184.

Burger, J. 1986. The Effect of Human Activity on Shorebirds in Two Coastal Bays in Northeastern United States, Environmental Conservation, Vol. 13, No. 2, pp. 123-130.

Cantrell, R.W. 1974. Prolonged Exposure to Intermittent Noise: Audiometric, Biochemical, Motor, Psychological, and Sleep Effects, Laryngoscope, Supplement I, Vol. 84, No. 10, p. 2.

Casady, R.B. and R.P. Lehmann. 1967. "Response of Farm Animals to Sonic Booms", Studies at Edwards Air Force Base, June 6-30, 1966. Interim Report, U.S. Department of Agriculture, Beltsville, Maryland, p. 8.

Cawthorn, J.M., T.K. Dempsey, and R. Deloach. 1978. "Human Response to Aircraft Noise-Induced Building Vibration."

CHABA. 1977. "Guidelines for Preparing Environmental Impact Statements on Noise," The National Research Council, National Academy of Sciences.

Chen, T. and S. Chen. 1993. Effects of Aircraft Noise on Hearing and Auditory Pathway Function of School-Age Children, International Archives of Occupational and Environmental Health, Vol. 65, No. 2,
pp. 107-111.

Chen, T., S. Chen, P. Hsieh, and H. Chiang. 1997. Auditory Effects of Aircraft Noise on People Living Near an Airport, Archives of Environmental Health, Vol. 52, No. 1, pp. 45-50.

Clark, C., R. Martin, E. van Kempen, T. Alfred, J. Head, H.W. Davies, M.M. Haines, I.L. Barrio, M. Matheson, and S.A. Stansfeld. 2005. "Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: the RANCH project," American Journal of Epidemiology, 163, 27-37.

Clark, C., S.A. Stansfeld, and J. Head. 2009. "The long-term effects of aircraft noise exposure on children's cognition: findings from the UK RANCH follow-up study." In Proceedings of the Euronoise Conference. Edinburgh, Scotland, October.

Cogger, E.A. and E.G. Zegarra. 1980. "Sonic Booms and Reproductive Performance of Marine Birds: Studies on Domestic Fowl as Analogues," In Jehl, J.R., and C.F. Cogger, eds., "Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports," San Diego State University Center for Marine Studies Technical Report No. 80-1.

Cohen, S., Glass, D.C. & Singer, J. E. 1973. "Apartment noise, auditory discrimination, and reading ability in children." Journal of Experimental Social Psychology, 9, 407-422.

Cohen, S., Evans, G.W., Krantz, D. S., et al. 1980. Physiological, Motivational, and Cognitive Effects of Aircraft Noise on Children: Moving from Laboratory to Field, American Psychologist, Vol. 35, pp. 231-243.

Cohen, S., Evans, G.W., Krantz, D. S., et al. 1981. "Aircraft noise and children: longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement," Journal of Personality and Social Psychology, 40, 331-345.

Cohen, J. 1998. Statistical power analysis for the behavioral sciences (2nd ed.). New Jersey: Lawrence Erlbaum.

Conomy, J.T., J.A. Dubovsky, J.A. Collazo, and W.J. Fleming. 1998. "Do black ducks and wood ducks habituate to aircraft disturbance?," Journal of Wildlife Management, Vol. 62, No. 3, pp. 1135-1142.

Correia, A.W., J.L. Peters, J.I. Levy, S. Melly, and F. Dominici. 2013. "Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study," British Medical Journal, 2013; 347:f5561 doi: 10.1136/bmj.f5561, 8 October.

Cottereau, P. 1972. Les Incidences Du 'Bang' Des Avions Supersoniques Sur Les Productions Et La Vie Animals, Revue Medicine Veterinaire, Vol. 123, No. 11, pp. 1367-1409.

Cottereau, P. 1978. The Effect of Sonic Boom from Aircraft on Wildlife and Animal Husbandry, In "Effects of Noise on Wildlife," Academic Press, New York, New York, pp. 63-79.

Crowley, R.W. 1973. "A case study of the effects of an airport on land values," Journal of Transportation Economics and Policy, Vol. 7, May.

Davis, R.W., W.E. Evans, and B. Wursig, eds. 2000. Cetaceans, Sea Turtles, and Seabirds in the Northern Gulf of Mexico: Distribution, Abundance, and Habitat Associations, Volume II of Technical Report, prepared by Texas A&M University at Galveston and the National Marine Fisheries Service. U.S. Department of the Interior, Geological Survey, Biological Resources Division, USGS/BRD/CR-1999-0006 and Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana, OCS Study MMS 2000-003.

Deutsche Welle. 2013. "Death by aircraft noise is a real concern for people living under the flight path", interview with Deutsche Welle. September 10, 2013.

DOD. 1978. “Environmental Protection, Planning in the Noise Environment”, Air Force Manual AFM 19-10, Technical Manual TM 5-803-2, NAVFAC P-870, Departments of the Air Force, the Army and the Navy. 15 June.

_____. 2009a. “Improving Aviation Noise Planning, Analysis, and Public Communication with Supplemental Metrics,” Defense Noise Working Group Technical Bulletin, December.

_____. 2009b. “Sleep Disturbance From Aviation Noise,” Defense Noise Working Group Technical Bulletin, November.

_____. 2009c. Memorandum from the Under Secretary of Defense, Ashton B. Carter, re: “Methodology for Assessing Hearing Loss Risk and Impacts in DoD Environmental Impact Analysis,” 16 June.

_____. 2009d. “Community Annoyance Caused by Noise From Military Aircraft Operations,” Defense Noise Working Group Technical Bulletin, December.

_____. 2012. “Noise–Induced Hearing Impairment” Defense Noise Working Group Technical Bulletin, July.

Doherty, K.E. 2008. Sage-grouse and energy development: integrating science with conservation planning to reduce impacts. Presented as a dissertation to the University of Montana, Missoula, Montana. Autumn.

Dooling, R.J. 1978. “Behavior and psychophysics of hearing in birds,” J. Acoust. Soc. Am., Supplement 1, Vol. 65, p. S4.

Dufour, P.A. 1980. “Effects of Noise on Wildlife and Other Animals: Review of Research Since 1971,” U.S. Environmental Protection Agency.

Eagan, M.E., G. Anderson, B. Nicholas, R. Horonjeff, and T. Tivnan. 2004. “Relation Between Aircraft Noise Reduction in Schools and Standardized Test Scores,” Washington, DC, FICAN.

Edmonds, L.D., P.M. Layde, and J.D. Erickson. 1979. Airport Noise and Teratogenesis, Archives of Environmental Health, Vol. 34, No. 4, pp. 243-247.

Edwards, R.G., A.B. Broderson, R.W. Harbour, D.F. McCoy, and C.W. Johnson. 1979. “Assessment of the Environmental Compatibility of Differing Helicopter Noise Certification Standards,” U.S. Dept. of Transportation, Washington, D.C. 58 pp.

Eldred, K, and H. von Gierke. 1993. “Effects of Noise on People,” Noise News International, 1(2), 67-89, June.

Eller, A.I., and R.C. Cavanaugh. 2000. *Subsonic Aircraft Noise at and Beneath the Ocean Surface: Estimation of Risk for Effects on Marine Mammals.* McLean, VA: United States Air Force Research Laboratory.

Ellis, D.H., C.H. Ellis, and D.P. Mindell. 1991. Raptor Responses to Low-Level Jet Aircraft and Sonic Booms, Environmental Pollution, Vol. 74, pp. 53-83.

ENNAH. 2013. Final Report ENNAH – European Network on Noise and Health EU Project No. 226442, FP-7-ENV-2008-1.

ERCD. 2014. “Aircraft noise, sleep disturbance and health effects”, CAP 1164, Environmental Research and Consultancy Department, UK Civil Aviation Authority.

Eriksson C, G. Bluhm, A. Hilding, CG. Ostenson and C.G. Pershagen. 2010. Aircraft noise and incidence of hypertension - gender specific effects. Environ Res 2010; 110:764-72

Evans, G.W., S. Hygge, and M. Bullinger. 1995. “Chronic noise and psychological stress,” J. Psychological Science, 6, 333-338.

Evans, G.W., M. Bullinger, and S. Hygge. 1998. Chronic Noise Exposure and Physiological Response: A Prospective Study of Children Living under Environmental Stress, Psychological Science, Vol. 9, pp. 75-77.

Evrard AS, Bouaoun L, Champelovier P, Lambert J, Laumon B. 2015. Does exposure to aircraft noise increase the mortality from cardiovascular disease in the population living in the vicinity of airports? Results of an ecological study in France. Noise Health 2015; 17:328-36

FAA. 1985. Airport Improvement Program (AIP) Handbook, Order No. 100.38.

FICAN. 1997. “Effects of Aviation Noise on Awakenings from Sleep,” June.

_____. 2002. FICAN on the Findings of the Minneapolis-St. Paul International Airport (MSP) Low-Frequency Noise (LFN) Expert Panel. FICAN, Washington, DC.

_____. 2007. “Findings of the FICAN Pilot Study on the Relationship Between Aircraft Noise Reduction and Changes in Standardised Test Scores,” Washington, DC, FICAN.

_____. 2008. “FICAN Recommendation for use of ANSI Standard to Predict Awakenings from Aircraft Noise,” December.

FICON. 1992. “Federal Agency Review of Selected Airport Noise Analysis Issues,” August.

Fidell, S., L. Silvati, K. Pearsons, S. Lind, and R. Howe. 1999. "Field Study of the Annoyance of Low-Frequency Runway Sideline Noise." J Acoust Soc Am. 106(3), 1408-1415.

Fidell, S., and L. Silvati. 2004. “Parsimonious alternatives to regression analysis for characterizing prevalence rates of aircraft noise annoyance,” Noise Control Eng. J. 52, 56–68.

Fidell, S., K. Pearsons, R. Howe, B. Tabachnick, L. Silvati, and D.S. Barber. 1994. “Noise-Induced Sleep Disturbance in Residential Settings,” AL/OE-TR-1994-0131, Wright Patterson AFB, OH, Armstrong Laboratory, Occupational & Environmental Health Division.

Fidell, S., K. Pearsons, B. Tabachnick, R. Howe, L. Silvati, and D.S. Barber. 1995a. “Field study of noise-induced sleep disturbance,” Journal of the Acoustical Society of America, Vol. 98, No. 2, pp. 1025-1033.

Fidell, S., R. Howe, B. Tabachnick, K. Pearsons, and M. Sneddon. 1995b. “Noise-induced Sleep Disturbance in Residences near Two Civil Airports,” NASA Contractor Report 198252.

Fidell, S., B. Tabachnick, and L. Silvati. 1996. “Effects of Military Aircraft Noise on Residential Property Values,” BBN Systems and Technologies, BBN Report No. 8102.

Fields, J.M., and C.A. Powell. 1987. "Community Reactions to Helicopter Noise: Results From an Experimental Study." J Acoust Soc Am. 82(2), 479-492.

Finegold, L.S., C.S. Harris, and H.E. von Gierke. 1994. “Community annoyance and sleep disturbance: updated criteria for assessing the impact of general transportation noise on people,” Noise Control Engineering Journal, Vol. 42, No. 1, pp. 25-30.

Fisch, L. 1977. "Research Into Effects of Aircraft Noise on Hearing of Children in Exposed Residential Areas Around an Airport," Acoustics Letters, Vol. 1, pp. 42-43.

Fleischner, T.L. and S. Weisberg. 1986. "Effects of Jet Aircraft Activity on Bald Eagles in the Vicinity of Bellingham International Airport," Unpublished Report, DEVCO Aviation Consultants, Bellingham, WA.

Fleming, W.J., J. Dubovsky, and J. Collazo. 1996. "An Assessment of the Effects of Aircraft Activities on Waterfowl at Piney Island, North Carolina," Final Report by the North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, prepared for the Marine Corps Air Station, Cherry Point.

Floud, S. 2013. "Exposure to Aircraft and Road Traffic Noise and Associations with Heart Disease and Stroke in Six European Countries: A Cross-Sectional Study". Environmental Health 2013, 12:89.

Fraser, J.D., L.D. Franzel, and J.G. Mathiesen. 1985. "The impact of human activities on breeding bald eagles in north-central Minnesota," Journal of Wildlife Management, Vol. 49, pp. 585-592.

Frerichs, R.R., B.L. Beeman, and A.H. Coulson. 1980. "Los Angeles Airport noise and mortality: faulty analysis and public policy," Am. J. Public Health, Vol. 70, No. 4, pp. 357-362, April.

Gladwin, D.N., K.M. Manci, and R. Villella. 1988. "Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife," Bibliographic Abstracts, NERC-88/32. U.S. Fish and Wildlife Service National Ecology Research Center, Ft. Collins, Colorado.

Green, K.B., B.S. Pasternack, and R.E. Shore. 1982. Effects of Aircraft Noise on Reading Ability of School-Age Children, Archives of Environmental Health, Vol. 37, No. 1, pp. 24-31.

Griefahn, B. 1978. Research on Noise Disturbed Sleep Since 1973, Proceedings of Third Int. Cong. On Noise as a Public Health Problem, pp. 377-390 (as appears in NRC-CNRC NEF Validation Study: (2) Review of Aircraft Noise and Its Effects, A-1505.1, p. 31).

Grubb, T.G. D.K. Delaney, and W.W. Bowerman. 2007. Investigating potential effects of heli-skiing on golden eagles in the Wasatch Mountains, Utah. Final report to the Wasatch-Cache National Forest. 10 November. Grubb, T.G., and R.M. King. 1991. "Assessing human disturbance of breeding bald eagles with classification tree models," Journal of Wildlife Management, Vol. 55, No. 3, pp. 500-511.

Gunn, W.W.H., and J.A. Livingston. 1974. "Disturbance to Birds by Gas Compressor Noise Simulators, Aircraft, and Human Activity in the MacKenzie Valley and the North Slope," Chapters VI-VIII, Arctic Gas Biological Report, Series Vol. 14.

Haines, M.M., S.A. Stansfeld, R.F. Job, B. Berglund, and J. Head. 2001a. Chronic Aircraft Noise Exposure, Stress Responses, Mental Health and Cognitive Performance in School Children, Psychological Medicine, Vol. 31, pp. 265 277, February.

Haines, M.M., S.A. Stansfeld, S. Brentnall, J. Head, B. Berry, M. Jiggins, and S. Hygge. 2001b. The West London Schools Study: the Effects of Chronic Aircraft Noise Exposure on Child Health, Psychological Medicine, Vol. 31, pp. 1385-1396. November.

Haines, M.M., S.A. Stansfeld, J. Head, and R.F.S. Job. 2002. "Multilevel modelling of aircraft noise on performance tests in schools around Heathrow Airport London," Journal of Epidemiology and Community Health, 56, 139-144.

Hansell, A.L., M. Blangiardo, L. Fortunato, S. Floud, K. de Hoogh, D. Fecht, R.E. Ghosh, H.E. Laszlo, C. Pearson, L. Beale, S. Beevers, J. Gulliver, N. Best, S. Richardson, and P. Elliott. 2013. "Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study," British Medical Journal, 2013; 347:f5432 doi: 10.1136/bmj.f5432, 8 October.

Hanson, C.E., K.W. King, M.E. Eagan, and R.D. Horonjeff. 1991. "Aircraft Noise Effects on Cultural Resources: Review of Technical Literature," Report No. HMMH-290940.04-1, available as PB93-205300, sponsored by National Park Service, Denver CO.

Haralabidis, A.S., Dimakopoulou, K., Vigna-Taglianti, F., Giampaolo, M, Borgini, A., Dudley, M.-L., Pershagen, G., Bluhm, G., Houthuijs, D., Babisch, W., Velonakis, M., Katsouyanni, K., and Jarup, L., for the HYENA Consortium. 2008. "Acute effects of night-time noise exposure on blood pressure in populations living near airports," European Heart Journal, doi:10.1093/eurheartj/ehn013.

Harju, S.M., M.R. Dzialak, R.C. Taylor, L.D. Hayden-Wing, and J.B. Winstead. 2010. Thresholds and time lags in effects of energy development on greater sage-grouse populations. Journal of Wildlife Management. Volume 74, Number 3: 437–448.Harris, C.M. 1979. Handbook of Noise Control, McGraw-Hill Book Co.

Higgins, T.H. 1974. The response of songbirds to the seismic compression waves preceding sonic booms. Natl. Tech. Inf. Serv., Springfield, VA, FAA-RD-74-78. 28 pp.

Hodgdon, K., A. Atchley, and R. Bernhard. 2007. Low Frequency Noise Study. PARTNER-COE-2007-001 Federal Aviation Administration, Washington DC.

Holloran, M.J. 2005. Greater Sage-Grouse (Centrocercus urophasianus) Population Response to Natural Gas Field Development in Western Wyoming. A dissertation submitted to the Department of Zoology and Physiology and the Graduate School of the University of Wyoming, Laramie, Wyoming. December.

Huang D, Song X, Cui Q, Tian J, Wang Q, Yang K. 2015 "Is there an association between aircraft noise exposure and the incidence of hypertension? A meta-analysis of 16784 participants". Noise Health 2015; 17:93-7

Hygge, S., G.W. Evans, and M. Bullinger. 2002. A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in School Children, Psychological Science Vol. 13, pp. 469-474.

Ising, H., Z. Joachims, W. Babisch, and E. Rebentisch. 1999. Effects of Military Low-Altitude Flight Noise I Temporary Threshold Shift in Humans, Zeitschrift fur Audiologie (Germany), Vol. 38, No. 4, pp. 118-127.

ISO. 1989. "Evaluation of Human Exposure to Whole-Body Vibration – Part 2: Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz)," International Organization for Standardization, Standard 2631-2, February.

Jarup L., M.L. Dudley, W. Babisch, D. Houthuijs, W. Swart, G. Pershagen, G. Bluhm, K. Katsouyanni, M. Velonakis, E. Cadum, and F. Vigna-Taglianti for the HYENA Consortium. 2005. "Hypertension and Exposure to Noise near Airports (HYENA): Study Design and Noise Exposure Assessment," Environ Health Perspect 2005, 113: 1473–1478.

Jarup L., W. Babisch, D. Houthuijs, G. Pershagen, K. Katsouyanni, E. Cadum, M-L. Dudley, P. Savigny, I. Seiffert, W. Swart, O. Breugelmans, G. Bluhm, J. Selander, A. Haralabidis, K. Dimakopoulou, P.

Sourtzi, M. Velonakis, and F. VignaTaglianti, on behalf of the HYENA study team. 2008. “Hypertension and Exposure to Noise near Airports - the HYENA study,” Environ Health Perspect 2008, 116:329-33.

Jehl, J.R. and C.F. Cooper, eds. 1980. “Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands,” Technical Report No. 80-1, Center for Marine Studies, San Diego State University, San Diego, CA.

Jones, F.N. and J. Tauscher. 1978. “Residence Under an Airport Landing Pattern as a Factor in Teratism,” Archives of Environmental Health, pp. 10-12, January/February.

Kinsler, L.E., A.R. Frey, A.B. Coppens, and J.V. Sanders. 1982. *Fundamentals of Acoustics*) (3rd ed.). New York, NY: John Wiley & Sons.

Kovalcik, K. and J. Sottnik. 1971. Vplyv Hluku Na Mliekovú Úzitkovost Kráv [The Effect of Noise on the Milk Efficiency of Cows], Zivocisná Vyroba, Vol. 16, Nos. 10-11, pp. 795-804.

Kryter, K.D. and F. Poza. 1980. “Effects of noise on some autonomic system activities,” J. Acoust. Soc. Am., Vol. 67, No. 6, pp. 2036-2044.

Kushlan, J.A. 1978. “Effects of helicopter censuses on wading bird colonies,” Journal of Wildlife Management, Vol. 43, No. 3, pp. 756-760.

Lazarus H. 1990. “New Methods for Describing and Assessing Direct Speech Communication Under Disturbing Conditions,” Environment International, 16: 373-392.

LeBlanc, M.M., C. Lombard, S. Lieb, E. Klapstein, and R. Massey. 1991. “Physiological Responses of Horses to Simulated Aircraft Noise,” U.S. Air Force, NSBIT Program for University of Florida.

Lercher, P., G.W. Evans, M. Meis, and K. Kofler. 2002. “Ambient neighbourhood noise and children's mental health,” J. Occupational and Environmental Medicine, 59, 380-386.

Lercher, P., G.W. Evans, and M. Meis. 2003. “Ambient noise and cognitive processes among primary school children,” J. Environment and Behavior, 35, 725-735.

Lind S.J., K. Pearsons, and S. Fidell. 1998. “Sound Insulation Requirements for Mitigation of Aircraft Noise Impact on Highline School District Facilities,” Volume I, BBN Systems and Technologies, BBN Report No. 8240.

Ludlow, B. and K. Sixsmith. 1999. Long-term Effects of Military Jet Aircraft Noise Exposure during Childhood on Hearing Threshold Levels. Noise and Health 5:33-39.

Lukas, J.S. 1978. Noise and Sleep: A Literature Review and a Proposed Criterion for Assessing Effect, In Daryl N. May, ed., Handbook of Noise Assessment, Van Nostrand Reinhold Company: New York, pp. 313-334.

Lynch, T.E. and D.W. Speake. 1978. Eastern Wild Turkey Behavioral Responses Induced by Sonic Boom, In “Effects of Noise on Wildlife,” Academic Press, New York, New York, pp. 47-61.

Manci, K.M., D.N. Gladwin, R. Villella, and M.G Cavendish. 1988. “Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: A Literature Synthesis,” U.S. Fish and Wildlife Service National Ecology Research Center, Ft. Collins, CO, NERC-88/29. 88 pp.

Márki Ferenc. 2013. Outcomes of EU COSMA (Community Oriented Solutions to Minimise Aircraft Noise Annoyance) Project, Budapest University of Technology and Economics, London, May.

Matsui, T., T. Uehara, T. Miyakita, K. Hiramatsu and T. Yamamoto. 2008. "Dose-response relationship between hypertension and aircraft noise exposure around Kadena airfield in Okinawa," 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT.

Meecham, W.C., and Shaw, N. 1979. "Effects of Jet Noise on Mortality Rates," British Journal of Audiology, 77-80. August.

Metro-Dade County. 1995. "Dade County Manatee Protection Plan," DERM Technical Report 95-5, Department of Environmental Resources Management, Miami, Florida.

Miedema H.M. and H. Vos. 1998. "Exposure-response relationships for transportation noise," J. Acoust. Soc. Am., pp. 104(6): 3432–3445, December.

Michalak, R., H. Ising, and E. Rebentisch. 1990. "Acute Circulatory Effects of Military Low-Altitude Flight Noise," International Archives of Occupational and Environmental Health, Vol. 62, No. 5, pp. 365-372.

Myrberg, A.A., Jr. 1978. Ocean noise and the behavior of marine animals: relationships and implications. Pages 169-208 in J.L. Fletcher and R.G. Busnel, eds. Effects of noise on wildlife. Academic Press, New York.

National Park Service. 1994. "Report to Congress: Report on Effects of Aircraft Overflights on the National Park System," Prepared Pursuant to Public Law 100-91, The National Parks Overflights Act of 1987. 12 September.

NATO. 2000. "The Effects of Noise from Weapons and Sonic Booms, and the Impact on Humans, Wildlife, Domestic Animals and Structures," Final Report of the Working Group Study Follow-up Program to the Pilot Study on Aircraft Noise, Report No. 241, June.

Navy. 2017. *Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis.* U.S. Department of the Navy.

Navy. 2018. *Quantifying Acoustic Impacts on Marine Mammals and Sea Turtles: Methods and Analytical Approach for Phase III Training and Testing.* U.S. Department of the Navy.

Nelson, J.P. 1978. Economic Analysis of Transportation Noise Abatement, Ballenger Publishing Company, Cambridge, MA.

Nelson, J.P. 1980. "Airports and property values: a survey of recent evidence," Journal of Transport Economics and Policy, 14, 37-52.

Nelson, J.P. 2004. "Meta-analysis of airport noise and hedonic property values - problems and prospects," Journal of Transport Economics and Policy, Volume 38, Part 1, pp. 1-28, January.

Nelson, J.P. 2007. "Hedonic Property Values Studies of Transportation Noise: Aircraft and Road Traffic," in "Hedonic Methods on Housing Markets," Andrea Barazini, Jose Ramerez, Caroline Schaerer and Philippe Thalman, eds., pp. 57-82, Springer.

Newman, J.S., and K.R. Beattie. 1985. "Aviation Noise Effects," U.S. Department of Transportation, Federal Aviation Administration Report No. FAA-EE-85-2.

Nixon, C.W., D.W. West, and N.K. Allen. 1993. Human Auditory Responses to Aircraft Flyover Noise, In Vallets, M., ed., Proceedings of the 6th International Congress on Noise as a Public Problem, Vol. 2, Arcueil, France: INRETS.

Öhrström, E., Hadzibajramovic, E., Holmes, and M., H. Svensson. 2006. “Effects of road traffic noise on sleep: studies on children and adults,” Journal of Environmental Psychology, 26, 116-126.

Ollerhead, J.B., C.J. Jones, R.E. Cadoux, A. Woodley, B.J. Atkinson, J.A. Horne, F. Pankhurst, L. Reyner, K.I. Hume, F. Van, A. Watson, I.D. Diamond, P. Egger, D. Holmes, and J. McKean. 1992. “Report of a Field Study of Aircraft Noise and Sleep Disturbance,” Commissioned by the UK Department of Transport for the 36 UK Department of Safety, Environment and Engineering, London, England: Civil Aviation Authority, December.

Pagel, J.E., D.M. Whittington, and G.T. Allen. 2010. Interim Golden Eagle Inventory and Monitoring Protocols; and Other Recommendations. Division of Migratory Bird Management, U.S. Fish and Wildlife Service. February.

Parker, J.B. and N.D. Bayley. 1960. “Investigations on Effects of Aircraft Sound on Milk Production of Dairy Cattle, 1957-58,” U.S. Agricultural Research Services, U.S. Department of Agriculture, Technical Report Number ARS 44 60.

Pater, L.D., D.K. Delaney, T.J. Hayden, B. Lohr, and R. Dooling. 1999. “Assessment of Training Noise Impacts on the Red-cockaded Woodpecker: Preliminary Results – Final Report,” Technical Report 99/51, U.S. Army, Corps of Engineers, CERL, Champaign, IL.

Pearsons, K.S., D.S. Barber, and B.G. Tabachnick. 1989. “Analyses of the Predictability of Noise-Induced Sleep Disturbance,” USAF Report HSD-TR-89-029, October.

Pikilidou M.I., A. Scuteri, C. Morrell, and E.G. Lakatta. 2013. “The Burden of Obesity on Blood Pressure is Reduced in Older Persons: The Sardinia Study”, Obesity (Silver Spring), Jan 21(1).

Plotkin, K.J., B.H. Sharp, T. Connor, R. Bassarab, I. Flindell, and D. Schreckenberg. 2011. “Updating and Supplementing the Day-Night Average Sound Level (DNL),” Wyle Report 11-04, DOT/FAA/AEE/2011-03, June.

Powell, C.A. and K.P. Shepherd. 1989. "Aircraft Noise Induced Building Vibration and Effects on Human Response." InterNoise '89. Newport Beach, CA, (December 1989):567-572.

Pulles, M.P.J., W. Biesiot, and R. Stewart. 1990. Adverse Effects of Environmental Noise on Health: An Interdisciplinary Approach, Environment International, Vol. 16, pp. 437-445.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise, Academic Press, San Diego, CA.

Richardson, C.T. and C.K. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin. Volume 25, Number 3: 634-638.

Rosenblith, W.A., K.N. Stevens, and Staff of Bolt, Beranek, and Newman. 1953. “Handbook of Acoustic Noise Control, Vol. 2, Noise and Man,” USAF Report WADC TR-52-204.

Rosengren A., L. Wilhelmson and H. Wedel. 1992. “Coronary heart disease, cancer and mortality in male middle-aged light smokers”, Journal of Internal Medicine, Volume 231, Issue 4, pages 357-362, April.

Rosenlund, M., N. Berglind, G. Bluhm, L. Jarup, and G. Pershagen. 2001. “Increased Prevalence of Hypertension in a Population Exposed to Aircraft Noise,” Occupational and Environmental Medicine, Vol. 58, No. 12, pp. 769 773. December.

Shreckenberg, D. and R. Guski 2015. “Transportation Noise Effects in Communities around German Airports – Summaries of the Sub-Studies of the NORAH Project”. Summary (in English) of the study “Verkehrslärmwirkungen im Flughafenumfeld’ available at: http://www.laermstudie.de/ergebnisse/ergebnisse-studie-zu-krankheitsrisiken/ueberblick. October.

Schomer, P.D. and R.D. Neathammer. 1985. The Role of Vibration and Rattle in Human Response to Helicopter Noise. CERL N-85/14, 1-162. USA-CERL.

Schomer, P.D. and R.D. Neathammer. 1987. "The Role of Helicopter Noise-Induced Vibration and Rattle in Human Response." J Acoust Soc Am. 81(4), 966-976.

Schultz, T.J. 1978. “Synthesis of social surveys on noise annoyance,” J. Acoust. Soc. Am., Vol. 64, No. 2, pp. 377-405, August.

Sharp, B., T. Connor, D. McLaughlin, C. Clark, S. Stansfeld and J. Hervey. 2013. Assessing Aircraft Noise Conditions Affecting Student Learning, ACRP Web Document 16, http://www.trb.org/Aviation1/Blurbs/170328.aspx. Airport Cooperative Research Program, Transportation Research Board, Washington, DC.

Sharp, B.H., and K.J. Plotkin. 1984. “Selection of Noise Criteria for School Classrooms,” Wyle Research Technical Note TN 84-2 for the Port Authority of New York and New Jersey, October.

Simmons, J.A. 1983. Localization of sounds and targets in air and water by echolocating animals. (Abstract only). J. Acoust. Soc. Am. 73(Suppl.1):18.

Smith, D.G., D.H. Ellis, and T.H. Johnston. 1988. Raptors and Aircraft, In R.L Glinski, B. Gron-Pendelton, M.B. Moss, M.N. LeFranc, Jr., B.A. Millsap, and S.W. Hoffman, eds., Proceedings of the Southwest Raptor Management Symposium, National Wildlife Federation, Washington, D.C., pp. 360-367.

Stansfeld, S.A., B. Berglund, and C. Clark, I. Lopez-Barrio, P. Fischer, E. Öhrström, M.M. Haines, J. Head, S. Hygge, and I. van Kamp, B.F. Berry, on behalf of the RANCH study team. 2005. “Aircraft and road traffic noise and children's cognition and health: a cross-national study,” Lancet, 365, 1942-1949.

Stansfeld, SA., C. Clark, R.M. Cameron, T. Alfred, J. Head, M.M. Haines, I. van Kamp, E. van Kampen, and I. Lopez-Barrio. 2009. “Aircraft and road traffic noise exposure and children's mental health,” Journal of Environmental Psychology, 29, 203-207.

Stevens, K.N., W.A. Rosenblith, and R.H. Bolt. 1953. “Neighborhood Reaction to Noise: A Survey and Correlation of Case Histories (A),” J. Acoust. Soc. Am., Vol. 25, 833.

Stusnick, E., D.A. Bradley, J.A. Molino, and G. DeMiranda. 1992. “The Effect of Onset Rate on Aircraft Noise Annoyance, Volume 2: Rented Home Experiment,” Wyle Laboratories Research Report WR 92-3, March.

Sutherland, L.C., S. Fidell, and A. Harris. 2000. Finding of the Low-Frequency Noise Expert Panel, September 30, 2000.

Sutherland, L.C. 1990. “Assessment of Potential Structural Damage from Low Altitude Subsonic Aircraft,” Wyle Research Report 89-16 (R).

Tetra Tech, Inc. 1997. “Final Environmental Assessment Issuance of a Letter of Authorization for the Incidental Take of Marine Mammals for Programmatic Operations at Vandenberg Air Force Base, California,” July.

Time. 2009. “Airport Noise Increases Risk of Strokes”, Time Magazine December 15, 2009

Ting, C., J. Garrelick, and A. Bowles. 2002. “An analysis of the response of sooty tern eggs to sonic boom overpressures,” J. Acoust. Soc. Am., Vol. 111, No. 1, Pt. 2, pp. 562-568.

Trimper, P.G., N.M. Standen, L.M. Lye, D. Lemon, T.E. Chubbs, and G.W. Humphries. 1998. “Effects of low-level jet aircraft noise on the behavior of nesting osprey,” Journal of Applied Ecology, Vol. 35, pp. 122-130.

UKDfES. 2003. “Building Bulletin 93, Acoustic Design of Schools - A Design Guide,” London: The Stationary Office.

U.S. Air Force. 1993. The Impact of Low Altitude Flights on Livestock and Poultry, Air Force Handbook. Volume 8, Environmental Protection, 28 January.

_____. 1994a. “Air Force Position Paper on the Effects of Aircraft Overflights on Large Domestic Stock,” Approved by HQ USAF/CEVP, 3 October.

_____. 1994b. “Air Force Position Paper on the Effects of Aircraft Overflights on Domestic Fowl,” Approved by HQ USAF/CEVP, 3 October.

_____. 2000. “Preliminary Final Supplemental Environmental Impact Statement for Homestead Air Force Base Closure and Reuse,” Prepared by SAIC, 20 July.

U.S. Department of Labor. 1971. “Occupational Safety & Health Administration, Occupational Noise Exposure,” Standard No. 1910.95.

USEPA. 1974. “Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety,” U.S. Environmental Protection Agency Report 550/9-74-004, March.

_____. 1978. “Protective Noise Levels,” Office of Noise Abatement and Control, Washington, D.C. U.S. Environmental Protection Agency Report 550/9-79-100, November.

_____. 1982. “Guidelines for Noise Impact Analysis,” U.S. Environmental Protection Agency Report 550/9-82-105, April.

U.S. Fish and Wildlife Service (USFWS). 2010. 12-Month Findings for Petitions to List the Greater Sage-Grouse (Centrocercus urophasianus) as Threatened or Endangered. Federal Register, Volume 75, Number 55: 13910-14014. 23 March.

USFWS. 1998. “Consultation Letter #2-22-98-I-224 Explaining Restrictions on Endangered Species Required for the Proposed Force Structure and Foreign Military Sales Actions at Cannon AFB, NM,” To Alton Chavis HQ ACC/CEVP at Langley AFB from Jennifer Fowler-Propst, USFWS Field Supervisor, Albuquerque, NM, 14 December.

U.S. Forest Service. 1992. “Report to Congress: Potential Impacts of Aircraft Overflights of National Forest System Wilderness,” U.S. Government Printing Office 1992-0-685-234/61004, Washington, D.C.

Urick, R.J. 1983. *Principles of Underwater Sound* (3rd ed.). Los Altos, CA: Peninsula Publishing.

van Kempen, E.M.M, K. Hanneke, C. Hendriek, H.C. Boshuizen, C. B. Ameling, B. A. M. Staatsen, and A. E.M. de Hollander, 2002. “The Association between Noise Exposure and Blood Pressure and Ischemic Heart Disease: A Meta-analysis”, Environmental Health Perspectives, Vol. 110, No 3, March.

van Kempen. 2006. “Noise exposure and children’s blood pressure and heart rate: the RANCH project”, Occup Environ Med 2006;63:632–639

Vienneau, D., L. Perez, C. Schindler, N. Probst-Hensch and M. Röösli. 2013. “The relationship between traffic noise exposure and ischemic heart disease: a meta-analysis”, Proceedings of InterNoise 2013, September.

von Gierke, H.E. and W.D. Ward. 1991. “Criteria for Noise and Vibration Exposure”, Handbook of Acoustical Measurements and Noise Control, C.M. Harris, ed., Third Edition.

Walker, B.L., D.E. Naugle, and K.E. Doherty. 2007. Greater sage-grouse population response to energy development and habitat loss (pre-print version). Wildlife Biology Program, College of Forestry and Conservation, University of Montana. Missoula, Montana. June.

Ward, D.H. and R.A. Stehn. 1990. “Response of Brant and Other Geese to Aircraft Disturbances at Izembek Lagoon, Alaska,” Final Technical Report, Number MMS900046. Performing Org.: Alaska Fish and Wildlife Research Center, Anchorage, AK, Sponsoring Org.: Minerals Management Service, Anchorage, AK, Alaska Outer Continental Shelf Office.

Ward, D.H., E.J. Taylor, M.A. Wotawa, R.A. Stehn, D.V. Derksen, and C.J. Lensink. 1986. “Behavior of Pacific Black Brant and Other Geese in Response to Aircraft Overflights and Other Disturbances at Izembek Lagoon, Alaska,” 1986 Annual Report, p. 68.

Weisenberger, M.E., P.R. Krausman, M.C. Wallace, D.W. De Young, and O.E. Maughan. 1996. “Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates,” Journal of Wildlife Management, Vol. 60, No. 1, pp. 52-61.

Wesler, J.E. 1977. “Concorde Operations at Dulles International Airport,” NOISEXPO ’77, Chicago, IL, March.

Wesler, J.E. 1986. “Priority Selection of Schools for Soundproofing,”, Wyle Research Technical Note TN 96-8 for the Port Authority of New York and New Jersey, October.

Wever, E.G., and J.A. Vernon. 1957. “Auditory responses in the spectacled caiman,” Journal of Cellular and Comparative Physiology, Vol. 50, pp. 333-339.

WHO. 1999. “Guidelines for Community Noise,” Berglund, B., T. Lindvall, and D. Schwela, eds.

_____. 2000. “Guidelines for Community Noise”, World Health Organization

_____. 2003. “International Society of Hypertension (ISH) statement of management of hypertension,” J Hypertens 21: 1983–1992.

_____. 2011. “Burden of Disease from Environmental Noise”, World Health Organization

Wu, Trong-Neng, J.S. Lai, C.Y. Shen, T.S Yu, and P.Y. Chang. 1995. Aircraft Noise, Hearing Ability, and Annoyance, Archives of Environmental Health, Vol. 50, No. 6, pp. 452-456, November-December.

Wyle Laboratories. 1970. “Supporting Information for the Adopted Noise Regulations for California Airports,” Wyle Report WCR 70-3(R).

Young, R.W. 1973. Sound pressure in water from a source in air and vice versa. *The Journal of the Acoustical Society of America,* 53(6), 1708-1716.