Airborne LIDAR Survey Systems and Aviation Safety:
an overview of concepts, qualifications and regulations

prepared for

Federal Aviation Administration

by

The Management Association for Private Photogrammetric Surveyors (MAPPS)
(Prepared May 20, 2014)

Introduction

MAPPS

The Management Association for Private Photogrammetric Surveyors (MAPPS) is the only national association of firms in the surveying, spatial data and geographic information systems field in the United States. MAPPS member firms are engaged in surveying, photogrammetry, satellite and airborne remote sensing, aerial photography, hydrography, aerial and satellite image processing, GPS and GIS data collection and conversion services. MAPPS has been recognized by Federal Aviation Administration (FAA) as the voice of the aerial survey profession (Air Traffic Bulletin #2006-1, February 2006).

LIDAR

Light Detection and Ranging (LIDAR) Survey Systems are increasingly being defined by the states as part of the practice of surveying, requiring professional licensure. The FAA has issued Advisory Circular AC NO. 150/5300-17C – entitled Standards for Using Remote Sensing Technologies in Airport Surveys – to provide guidance on the use of remote sensing technologies, primarily LIDAR, in the collection of data describing the physical infrastructure of an airport.

The U.S. Department of Labor has identified the geospatial field as one of 14 high-growth, high-demand, and economically vital sectors of the American economy. The geospatial field is a $73 billion market that drives more than $1 trillion in economic activity. More than 500,000 American jobs are related to the collection, storage and dissemination of imagery and geospatial data, and another 5.3 million workers utilize such data.

FAA Position – Airborne LIDAR

Special Airworthiness Bulletin SW-06-68 (9/20/2006) was issued for the express purpose of alerting aircraft owners and operators of the potential hazards of installing *Forward Looking Infrared* (FLIR) systems with embedded laser capability on rotorcraft. As a result, the FAA has taken the position that no field approvals for installation of Class 3b or 4 laser systems will be issued until the agency develops a policy for installation of laser systems on aircraft.

Class 3b or 4 laser systems

According to the FAA, inclusion of a Class 3b or 4 laser imaging capability into the FLIR systems introduces the following potential hazards:

- **Eye damage** to flight crew or passengers due to inadvertent firing of the laser beam through the cabin windows or reflections off of highly polished surfaces.
- **Eye damage** to flight crew or passengers of other aircraft.
- **Eye damage** to civilians on the ground.

- **Eye damage** to ground maintenance crew or personnel.

The current FAA Order 8900.1, CHG 159 provides classification of alterations involving the installation of laser emitting devices, including LiDAR equipment, onboard aircraft. That classification requires approval via Supplemental Type Certificate (STC) and reflects the FAA's concern for airworthiness and operational safety.

Supplemental Type Certificate (STC)

An STC is required for any "major design change" to an aircraft; one that has an appreciable effect on an aircraft's weight, balance, structural strength, reliability, operational characteristics, or other characteristics affecting airworthiness. *See* 14 C.F.R. §21.93.

In a letter to MAPPS dated March 9, 2012, Peggy Gilligan, the FAA Associate Administrator for Safety, wrote "[T]he Aircraft Maintenance Division (AFS-300) will work with MAPPS and other industry representatives to facilitate FAA review, and when appropriate, the reclassification of LIDAR systems." Further, according to Ms. Gilligan, "[T]he FAA Aircraft Certification Office (ACO) **may determine that an STC is not necessary**." Lastly, she stated that "[R]eclassification is coordinated through the appropriate product Directorate and Aircraft Engineering Division (AIR-100)." *See* Letter dated March 9, 2012, from Peggy Gilligan, Associate Administrator for Safety.

Purpose

The purpose of this white paper is to provide technical background to the Federal Aviation Administration concerning the installation and use of Airborne LIDAR (Light Detection and Ranging) Survey Systems. The following information will establish how and why the installation and use of Airborne LIDAR systems does not have an appreciable effect on an aircraft's weight, balance, structural strength, reliability, operational characteristics, or other characteristics affecting airworthiness.

Furthermore, unlike a Class 3b or 4 laser contained in the FLIR systems, LIDAR does not introduce the potential hazards for eye damage to flight crew or passengers due to inadvertent firing of the laser beam through the cabin windows or reflections off of highly polished surfaces; eye damage to flight crew or passengers of other aircraft; eye damage to civilians on the ground; or eye damage to ground maintenance crew or personnel.

As such, the FAA Aircraft Certification Office (ACO), through the appropriate product Directorate and Aircraft Engineering Division (AIR-100), should determine that an STC is not necessary for the installation and use of Airborne LIDAR systems.

Executive Summary

LIDAR (Light Detection and Ranging) Survey System is an active remote sensing instrument that collects three-dimensional geospatial information. Airborne LIDAR Systems use fully-enclosed pulsing laser(s), deflected through a rotating or oscillating mirror system, to scan and record accurately the coordinates of hundreds of thousands of points per second. LIDAR is *not* a laser pointer, a FLIR system or a laser light show, but a sophisticated survey sensing device.

As this new technology has rapidly developed, LIDAR Survey Systems are fast becoming one of the primary means used for modern geo-spatial data collection, augmenting and/or replacing traditional photogrammetric methods. There are many hundreds of these systems in use around the world today.

Accurate, up to date geo-spatial information is vital for government to fulfill its mission to provide for the health and safety of its constituents. To this end, nearly all Federal and other governmental agencies presently contract with private sector firms to acquire LIDAR-generated data-sets. For example, LIDAR will be a key technology necessary to establish the geographic database required to implement the FAA's NextGen program - see FAA AC 150/5300-17C.

Because some LIDAR Survey Systems incorporate powerful lasers (Class III & IV), the FAA has become concerned that there may be a potential safety hazard. Efforts have been made to regulate these instruments by requiring a Supplemental Type Certificate (STC) application process (see FAA 8900.1 CHG 159 dated Jun 10, 2011), as well as other proposed use limitations under consideration (for example, see Proposed Policy No. PS-ASW-27, 29-06).

LIDAR Survey Systems emit safe levels of laser energy by design, as regulated by the Food and Drug Administration (FDA) and other international standards. These systems are "portable," so their installation should not constitute a major aircraft design change requiring the need for an STC. As a stakeholder, representing both operators and manufacturers of LIDAR systems, MAPPS is concerned that the creation of any new regulations or approval processes should properly address all safety concerns in the most efficient and reasonable manner.

MAPPS (www.mapps.org) is the national association of private sector firms in the remote sensing, spatial data and geographic information systems field in the United States. The MAPPS membership spans the entire spectrum of the geospatial community, including Member Firms engaged in satellite and airborne remote sensing, surveying, photogrammetry, aerial photography, LIDAR, hydrography, bathymetry, charting, aerial and satellite image processing, GPS, and GIS data collection and conversion services. MAPPS also includes Associate Member Firms, which are companies that provide hardware, software, products and services to the geospatial profession in the United States and other firms from around the world. Independent Consultant Members are sole proprietors engaged in consulting in or to the geospatial profession, or provides a consulting service of interest to the geospatial profession. MAPPS provides its member firms opportunities for networking and developing business-to-business relationships, information sharing, education, public policy advocacy, market growth, and professional development and image enhancement. MAPPS has a longstanding relationship with FAA, working with the agency to ensure air safety and efficient operation of aerial survey missions.

MAPPS is pleased to submit this whitepaper, as well as the attached PowerPoint presentation, to outline the regulatory, manufacturing and operating standards currently adhered to by LIDAR system manufacturers as suitable to meet any safety concerns. As well, included are our recommendations to ensure compliance, define what constitutes an acceptable system, and set forth suggested processes to maintain their safe operation.

1 ASSESSMENT OF POTENTIAL FOR INJURY

The purpose of this section is to review international regulations for the manufacture and use of laser products, and to distinguish between three key attributes:

- The potential hazard as defined by exposure to laser product output in very close proximity to the product
- The potential hazard, if any, at normal operating distances
- The unique differences in operation of airborne LIDAR survey systems versus other outdoor laser operations, such as laser light shows

These are discussed in Sections 1.1 through 1.3 below.

1.1 LASER CLASS

An internationally-recognized laser safety classification scheme is in operation to provide basic information regarding the potential hazards to the eye or skin associated with a specific laser product. It is the responsibility of the manufacturer of the laser product to assign the product to one of the following safety classes, Class 1 and 1M, Class 2 and 2M, Class 3R and Class 3B, and Class 4. The higher the class number, the higher the potential hazard.

The definition of the classes and the criteria that have to be fulfilled in order to assign the laser product to a certain class are contained in the international laser safety standard IEC 60825-1 (International Electrotechnical Commission). The European standardization organization has published an identical document, EN-60825-1. The IEC standard is adopted by virtually all nations publishing national laser safety standards, including Canada, Japan and Australia. However, for the U.S., there are some limited differences in the current U.S. user standard, ANSI Z136.1 and in the current U.S. manufacturer standard, which is under the responsibility of the Center for Devices and Radiological Health (CDRH) within the FDA, the U.S. Federal Laser Product Performance Standard 21 CFR 1040.10 and 1040.11. In January 2001, CDRH published an interim guidance (Laser Notice No. 50) indicating it will not object to laser products sold in the U.S. that conform to certain requirements of IEC 60825-1 in lieu of those specified in 21 CFR 1040, including the IEC system of classification and labelling.

Each laser product incorporates a laser, but the class of the laser product is not the same as the class that the laser unit itself has been assigned to by the manufacturer of the laser or laser subsystem. e.g., a laser product like a LIDAR instrument may incorporate a Class 4 laser unit, but can also correctly be assigned as a Class 1 Laser Product.

The classification of a laser product is based on the radiation emission of the product. In order to determine the class of a laser product, the energy or power passing through an aperture with a given diameter at a specific distance from the product is compared to a set of maximum allowed energy or power levels, referred to as the Accessible Emission Limits (AELs). The measurements must be taken with all parameters set in such a way that the emission is at its maximum potential value. Additionally, the classification is based on worst-case assumptions of usage and on worst-case assumptions for exposure geometry. Thus, it is possible that a laser product will be placed into a class that would indicate a certain level of hazard based purely on evaluation criteria that are not part of the normal operation scenario (e.g., at close range), although the same product may be safe in the actual and specific use.

For example, a LIDAR laser product is classified according to energy and power measurements taken in close vicinity to the exit aperture over a considerably long time. This is likely entirely different from any exposure resulting from normal operation of the sme LIDAR product, where a human may be exposed only at a considerable range for a very short period of time. Therefore, the class that the product has been assigned by the manufacturer has no immediate bearing on the safety of the cabin crew operating a LIDAR system, or the safety of a person on the ground during airborne use of the LIDAR in flight. That said, necessary precautions are still taken by ensuring proper installation and proper operation of LIDAR systems assigned to classes 3 and 4 in order to avoid exposure of the cabin crew and ground personnel.

In particular, any reflection into the aircraft cabin by either internal or external structures must always be eliminated, as any obscuration of the survey system’s optical path by either internal or external structures prevents the acquisition of range data, which is fundamental to the survey operation.

1.2 Nominal Ocular Hazard Distance (NOHD)

The Nominal Ocular Hazard Distance (NOHD) is universally recognized as the standard measure for the distance outside of which operation of a given laser product results in no potential hazard.

All laser devices output energy in a nearly-collimated pattern, meaning that all rays of the output laser energy follow a nearly parallel path to one another. This would be an idealized situation, where the laser output “footprint" would stay the same size regardless of the distance from the laser source. However, this is a condition that is essentiually impossible to achieve. As a result, all LIDAR survey systems emit laser output in a diverging pattern and the "footprint“ of the laser output increases with increasing distance from the instrument. Typical divergence angles and their effects are discussed in Section 3.1 below.

For the diverging laser beam mentioned above, the hazard for the human eye decreases with distance from the laser source. The International standard IEC 60825-1 defines the nominal occular hazard distance (NOHD) in chapter 3.62:

> *3.62 nominal ocular hazard distance*
> *NOHD*
> *distance from the output aperture at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE)*
> *If the NOHD includes the possibility of viewing through optical aids, this is termed the "extended NOHD (eNOHD)".*[1]

For an observer within a distance to the laser less than the NOHD, the laser radiation is potentially hazardous. At distances beyond the NOHD, the laser radiation it is not hazardous.

Usage of optical aids like binoculars or telescopes can increase the amount of radiation the eye is exposed to, as such optics generally collect a larger portion of the laser footprint (and thus, a larger portion of the beam energy) than the naked human eye does. The appropriate distance at which observing the laser beam gets harmless, even when using the standardized binocular with 7x50mm optics, is called the eNOHD.

When talking about potential hazard in laser products, NOHD and eNOHD are not to be confused with laser class. Laser classification uses a standardized method of power measurement at defined (and very small) distances (typically 100 mm from the output aperture) and a defined, rather long, exposure time.

In making measurements to assign a laser product to a given classification, the short distance to the source causes a large portion of the output energy to be captured by the limiting aperture used to simulate the maximum amount of radiation that can enter the human eye. LIDAR mapping systems operated on a moving aircraft at reasonable flight heights expose the observer to much less radiation than at the extremely short range used in the laser product classification test.

It is also obvious that parameters like flight height, laser pulse repetition frequency (PRF), and the scan pattern (which affect the distance between consecutive laser shots) affect the resulting NOHD and eNOHD, and these phenomena are typically documented in the User Manual for a given laser product. More on required product documentation is presented in Section 2.1.2.1.

It should be noted that NOHD and eNOHD definitions are homologated between FDA, ANSI and EC.

1.3 Airborne LIDAR versus laser light shows

The International standard IEC 60825-1:2007, defines the maximum permissible exposure MPE in chapter 3.56

> *3.56 maximum permissible exposure*
> *MPE*
> *level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects*[2]

The hazard of a laser is not only depending on the laser power, but also on the duration the human eye is exposed to the laser output.

By design, laser light shows expose the audience at close ranges and repeatedly to laser radiation. In contrast to laser light shows, a LIDAR mapping system exposes an observer to laser radiation for very short periods only. A flying aircraft with a scanning LIDAR on board exposes an observer on the ground only to a part of a single scan line. For example, this can be a single laser shot, or in the alternative, it is entirely possible that the observer on the ground is either in-between the footprints of two adjacent laser shots, resulting in no exposure at all. In the worst case, these conditions result in a very short exposure time (less than milliseconds). Additionally, LIDAR system firmware and controlling software check the measured distance against the known NOHD and inform the user or even switch off the laser source when the currently-measured distance falls below NOHD.

Operating instructions of LIDAR mapping systems require the user to follow operational workflows that ensure the laser radiation, to which an observer may be exposed, is below the maximum permissible exposure level.

2 Regulatory requirements for laser products

Laser products fall under a series of regulatory requirements. These requirements cover the manufacture and introduction of laser products into the stream of commerce, as well as use of the laser products, including those unique to use of laser products in an aircraft environment. These three topics are discussed in Sections 2.1, 2.2 and 2.3 below, respectively. Each of these sections decribes the recognized entity responsible for each aspect of the laser product and the regulating document(s) with which compliance is currently required. It can be seen from the inputs provided herein that the manufacture, use and qualification for compatibility with the aircraft environment is already adequately covered.

2.1 Requirements for manufacture of laser products

Introduction of laser products into the stream of commerce is regulated worldwide. As a term of art, introduction into commerce means the availability of a laser product for purchase, as indicated by either actual sale, or even the advertisement of the product as being for sale. In the United States, the manufacture of laser products is regulated by the U.S. Food and Drug Administration), under the provisions of 21 C.F.R. Chapter 1, Subchapter J, “U.S. Performance Standard for Laser Products“, specifically, the provisions of Section 1040 apply.

Internationally, government agencies defer to either the U.S. FDA regulations above, EN 60825-1 “Safety of Laser Products“ EU or IEC 60825-1 “Safety of Laser Products“. The provisions of all three regulatory documents are well-aligned, facilitating the manufacture and distribution of laser products to what is arguably a world-wide market.

All laser products sold in the U.S. must comply with all relevant paragraphs of 21 C.F.R. 1040 prior to being introduced into the stream of commerce. This means that all requirements must be met prior to advertisement or first offering for sale of the laser product. Compliance of products with the provisions of 21 C.F.R. is achieved through two main methods:

- Incorporation of constructional measures
- Incorporation of instructional measures

Constructional measures include the engineering of various hardware safety features into the product. Instructional measures include both documentation and labeling. These requirements are described in detail in Sections 2.1.1 and 2.1.2, respectively. Both constructional and informational measures are documented through the submission of various reports, as further described in Sections 2.1.2.2 and 2.1.2.3.

It should be noted that all major airborne LIDAR survey system manufacturers comply with the regulations put forth in 21 C.F.R., as well as EN/IEC 60825-1.

2.1.1 Required features

2.1.1.1 Laser Interlock

According to the International standard IEC 60825-1:2007, Section 4.3.1, a safety interlock is only required if there is a protective housing with an access panel which a) is intended to be opened by the user, and b) allows access to laser radiation levels exceeding (for laser products class 1, 1M, 2, and 3R) or equaling (for laser products class or 3B and 4) those of the product's laser class. The safety interlock shall prevent access to excessive accessible emission levels. Such protective housing access is typically provided only for service purposes and has no bearing on normal operation.

2.1.1.2 Remote Interlock

Pursuant to IEC 60825-1:2007, Section 4.4, each Class 3B and Class 4 laser system shall have a remote interlock connector. When the terminals of the connector are open-circuited, the accessible radiation shall not exceed the AEL for Class 1M or Class 2M, as applicable. This interlock is provided to allow remote interruption of laser operation, and is more typical for lasers operated in enclosed areas such as laboratories, where disabling of the laser is required under certain conditions (e.g., opening a door into the area where the laser is operating).

2.1.1.3 Key Lock

IEC 60825-1:2007, Section 4.6 provides that each Class 3B and Class 4 laser system shall incorporate a key-operated master control. The key shall be removable and the laser radiation shall not be accessible when the key is removed.

NOTE: In this Section, the term "key" includes any other control devices, such as magnetic cards, cipher combinations, computer passwords, etc., that provide the same effect.

2.1.1.4 Labeling

According to the IEC 60825-1:2007 and the 21 C.F.R. 1040.10, the following labels must be attached to the laser product in a permanent and legible way:

- Warning label: Triangular warning label with laser hazard symbol
- For each laser product, which is not class 1, an Explanatory label: Containing information about the laser's emission wavelength, output power, beam divergence, pulse duration, and pulse repetition rate
- For each class 3R, class 3B or class 4 laser product, an Aperture label: Indicating the laser beam aperture
- Serial number plate: Containing manufacturer and product model/part number, serial number and date of manufacture, to ensure traceability in the event specific systems need to be identified

2.1.1.5 Emission Indicator

Class 3B and class 4 laser systems, as well as class 3R laser systems with an emission wavelength below 400nm and above 700nm, shall produce an audible or visible warning signal when the laser is activated. The warning shall be fail safe, redundant, and clearly audible/visible (even through appropriate protective eyewear). Remote control units shall have individual warning systems.

According to 21 C.F.R. 1040.10, (f)(5)(ii), the emission indicator shall be activated during emission and sufficiently prior to emission of such radiation in order to allow appropriate action to avoid exposure to the laser radiation.

2.1.2 Required documentation

Both U.S. and international regulations for the manufacture of laser products require documentation of laser products introduced into the stream of commerce. The required documentation serves both the consumer and the regulator. Each laser product must be shipped with a user manual, and the specific requirements imposed on user manuals for laser products is described in Section 2.1.2.1 below. These serve to inform the consumer of the laser product. Regulatory compliance is documented through submission of reports as described in Section 2.1.2.2 and 2.1.2.3.

2.1.2.1 User Manual

Pursuant to 21 C.F.R., a user manual must be supplied with each system. From a regulatory standpoint, the main purpose of the user mannual is to ensure that adequate instructional information is present for the user to understand the nature and operational limitations of the laser product. Specifically, the user manual must include:

- specific wording in the foreword or safety section identifying the class of the laser product, including the definition of the general consequence of improper use, and
- a safety chapter that provides specific information about the laser output, which allows the user to verify the safety of the device, in addition to providing precautionary information to prevent adverse exposure to laser output.

21 C.F.R. requires specific information and, in some cases (e.g., consequences of improper use) specific wording in the safety section of the user manual.

2.1.2.2 Laser Product Report

Prior to each laser product’s introduction into the stream of commerce, the manufacturer must supply a Laser Product Report, or a Model Change Report. These reports provide the FDA with information about the design, manufacture and documentation of the laser product. Specifically, the Laser Product Report or Model Change Report:

- provides information and calculations supporting laser classification
- verifies the presence of required safety features and how they are implemented
- includes copies of relevant portions of the User Manual (particularly the safety section)
- generally includes copies of product literature, which must also contain an FDA/EN compliance statement

The Laser Product Report or Model Change Report is submitted to the FDA prior to introduction into the stream of commerce. The receipt of the report is acknowledged by the FDA via an Accession Letter. This Accession Letter contains an Accession Number that can be used to track receipt of the document by the FDA.

2.1.2.3 Annual Report

In addition to the Laser Product Report or Model Change Report, 21 C.F.R. requires an annual report from all laser manufacturers. This report shows the number of products sold by model. It also requires disclosure of any reported incidents of adverse exposure.

2.2 Requirements for use of laser products

The internationally-recognized standard for the safe use of lasers is compliant with ANSI Z136.1, "Safe Use of Lasers". This specification is recognized as the authoritative document in the field by ANSI, and is also referenced by government organizations such as the Occupational Safety & Health Administration (OSHA) for defining proper procedures for evaluation of lasers and prevention of adverse exposure to laser radiation. The Z136.1 speciification is authored by the Laser Institute of America (LIA). LIA was founded in 1968, and is the professional society for laser applications and safety. The stated mission of LIA is "to foster lasers, laser applications, and laser safety worldwide."[3]

As advocated by LIA, "ANSI Z136.1 provides guidance for the safe use of lasers and laser systems by defining control measures for each of seven laser hazard classifications. A practical means for accomplishing this is to (1) classify lasers and laser systems according to their relative hazards and to (2) specify appropriate controls for each classification. Once a laser or laser system is properly classified, there should be no need to carry out tedious measurements or calculations to meet the provisions of this standard. However, technical information on measurements, calculations and biological effects is also provided within the standard and its appendixes.[4]

Specifically, ANSI Z136.1 provides methods for calculating the Nominal Ocular Hazard Distance (NOHD) and extended Nominal Ocular Hazard Distance (eNOHD). It also defines under what circumstances the NOHD or eNOHD should be used as a basis for ensuring laser safety.

In addition to documenting methods for calculating laser class and laser exposure levels, ANSI Z136.1 also defines the organizational skills (e.g., laser safety officer) required in organizations using laser products. The assignment of a laser safety officer in using organizations is considered a foundational step in ensuring compliance with the specification.

2.3 Requirements for equipment installed in aircraft

Airborne LIDAR survey systems are, by purpose, installed in a host aircraft. It is imperative that the installed hardware have both structural integrity under the full possible operating environment (including the possibility of a crash landing) and must also not interfere with aircraft operation. This implies that the installed system must be of a design that:

- Maintains structural integrity
- Presents no undue strain on the aircraft's electrical system
- Does not cause interference with aircraft instrumentation
- Does not cause interference with aircraft communication equipment

In order to assure the above, all systems are properly qualified prior to release, using test regimens prescribed by the RTCA DO-160 specification. RTCA DO-160 is the internationally-recognized standard by which installed equipment are tested for compatibility with the airborne environment.

Depending upon the nature of the equipment to be installed, the specification level for any given test is proscribed. For instance, equipment directly related to the operation of the aircraft and communication with air traffic control must be qualified to different standards than other installed equipment such as the LIDAR survey systems described herein. A typical list of applicable standards for the LIDAR survey system is given in Table 1 below. References to ISO (International Organization for Standardization) 7137 standards are also shown.

Table 1 – Recommended RTCA qualification criteria

Reference to Standard		Description of Conducted Test	Environmental Test Index
ISO 7137	RTCA DO-160		
1.1	Section 4	Temperature and altitude	Category B1
1.2	Section 5	Temperature variation	Category B
1.3	Section 6	Humidity	Category B
2.1	Section 7	Operational shocks and crash safety level 2 for all fixed-wing aircraft types and helicopter	Category E (FAR 27.561)
2.2	Section 8	Vibration	Category S
4.1	Section 9	Explosionproofess	X
1.5	Section 10	Waterproofness	X
1.6	Section 11	Fluids susceptibility	X
1.7	Section 12	Sand and dust	X
1.8	Section 13	Fungus resistance	X
1.9	Section 14	Salt spray	X
3.1	Section 15	Magnetic effect	Category B
3.2	Section 16	Power input	Category B
3.3	Section 17	Voltage spike	Category A
3.4	Section 18	Audio frequency conducted susceptibility – power inputs	Category B
3.5	Section 19	Induced signal susceptibility	Category [BC]
3.6	Section 20	Radio frequency susceptibility (radiated and conducted)	Category [RR]
3.7	Section 21	Emission of radio frequency energy	Category M
3.8	Section 22	Lightning induced transient susceptibility	Category [A3E3X]
3.10	Section 23	Lightning direct effects (relevant for antenna only)	Category X
1.4	Section 24	Icing (relevant for antenna only)	Category X
3.9 (2678)	Section 25	Insulation resistance and high voltage	Category A
4.2 (2685)	Section 26	Fire resistance	Category X

Compliance with the appropriate provisions of Radio Technical Commission for Aeronautics RTCA DO-160 is verified by either analysis or test, as appropriate. Testing is summarized by means of an environmental qualification form indicating tests performed and test dates. A sample is shown in Figure 1 below, and mirrors the recommended RTCA qualification criteria shown in Table 1.

Figure 1 – Sample Environmental Qualification Form

Environmental Qualification Form

Equipment	**Lidar System:** ALS70 (LS70-HA, LS70-LP, SC70, SC70-CM, LC60)
Manufacturer	Leica Geosystems AG, CH-9435 Heerbrugg, Switzerland
Environmental index	**RTCA/DO-160F** Env. Cat. **B1BBESXXXXXXBBAB[BC][RR]M[A3E3X]XXAX**
TSO Number	not required

Reference on Standard		**Description of Conducted Test**	**Environmental Test index**	**Result & Date**
ISO 7137	**RTCA**			
1.1	Section 4	* Temperature and altitude	Category **B1**	**Passed 11/2010**
1.2	Section 5	Temperature variation	Category **B**	**Passed 02/2011**
1.3	Section 6	Humidity	Category **B**	**Passed 01/2011**
2.1	Section 7	Operational shocks and crash safety level 2 for all Fixed-Wing Aircraft types and Helicopter	Category **E** (FAR 27.561)	**Passed 04/2011**
2.2	Section 8	Vibration	Category **S**	**Passed 05/2009**
4.1	Section 9	Explosion proofness	**X**	no test required
1.5	Section 10	Waterproofness	**X**	no test required
1.6	Section 11	Fluids susceptibility	**X**	no test required
1.7	Section 12	Sand and dust	**X**	no test required
1.8	Section 13	Fungus resistance	**X**	no test required
1.9	Section 14	Salt spray	**X**	no test required
3.1	Section 15	Magnetic Effect	Category **B**	**Passed 10/2010**
3.2	Section 16	Power Input	Category **B**	**Passed 09/2010**
3.3	Section 17	Voltage Spike	Category **A**	**Passed 10/2010**
3.4	Section 18	Audio Frequency cond. susceptibility-Power Inputs	Category **B**	**Passed 05/2008**
3.5	Section 19	Induced Signal Susceptibility	Category **[BC]**	**Passed 09/2010**
3.6	Section 20	Radio Frequency susceptibility (Radiated and Conducted)	Category **[RR]**	**Passed 10/2010**
3.7	Section 21	Emission of Radio Frequency Energy	Category **M**	**Passed 09/2010**
3.8	Section 22	Lightning Induced Transient Susceptibility	Category **[A3E3X]**	**Passed 10/2010**
3.10	Section 23	Lightning Direct Effects (Relevant for antenna only)	Category **X**	no test required
1.4	Section 24	Icing (Relevant for antenna only)	Category **X**	no test required
3.9 (2678)	Section 25	Insulation resistance and high voltage	Category **A**	**Passed 09/2010**
4.2 (2685)	Section 26	Fire resistance	Category **X**	no test required

* Exceptions for all ALS70 System:

Referencing to RTCA/DO-160F	**Remark**
Section 4	Operating Low Temperature: 0 °C (B1: -20 °C) Operating High Temperature: +40 °C (B1: +55 °C)

Leica Geosystems AG, April 27., 2011

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- when it has to be **right**

Leica Geosystems

3 ADDITIONAL SAFETY FEATURES IN AIRBORNE LIDAR SYSTEMS

Both passive and proactive features contribute to the safe operation of airborne LIDAR survey systems. Passive features can be defined as those characteristics of the system or its operation that inherently reduce exposure levels to persons inside the survey area. Proactive safety features are ones that are designed into the system or its operational workflow that, like passive features, serve to reduce exposure levels. These are discussed below in Sections 3.1 and 3.2, respectively.

3.1 PASSIVE SAFETY FEATURES

Several characteristics of airborne LIDAR systems contribute to a reduction in exposure to laser radiation for persons on the ground and inside the survey area. These include:

- Beam divergence – The output of the LIDAR's laser is not perfectly collimated. That is to say, the laser's effective "footprint" increases in size as it leave the system. The increase in footprint size can be measured as an angle, called beam divergence. Beam divergence is typically measured in units of milliradians. Most airborne LIDAR survey systems have laser output divergence values between 0.15 and 0.50 milliradians measured at the so-called 1/e point, that is, the divergence angle within which ~65% of the total laser energy falls. For a given laser pulse energy and a given distance, the laser radiation is less intense if the laser output is spread over a larger divergence angle.

- Flying height – The measurement of laser divergence in units of milliradians results in an intuitive impression of the laser footprint size at any given distance from the survey system. For instance, the footprint diameter of a laser with an output divergence of 1.0 milliradians will increase by 1.0 meter for every 1000 meters distance from the laser output. As the laser footprint increases with flying height, the energy contained in each laser pulse is spread over a larger and larger area. As a result, the exposure level per unit area decreases as the square of the distance from the system. A system flying 2000 meters above terrain will produce ¼ the exposure at the ground of a system flying 1000 meters above terrain.

- Aircraft motion – By its very nature, an airborne LIDAR survey system depends on scanning action to allow the system to make measurements over some defined swath, and depends upon forward motion of the aircraft to make measurements along some extended path. In essence, the scanner provides one dimension of scanning and the forward motion of the aircraft supplies the second scanning dimension. The same forward motion upon which the system depends for scanning dimension, inherently prevents repeat exposure to any one particular person or object on the ground below. For this reason, airborne LIDAR survey systems can use a single-pulse exposure criteria for ensuring eye safety.

- Scanning action – Just as forward motion of the aircraft prevents repeated laser exposure of a fixed point on the ground, the scanning action of the LIDAR system also prevents repeated laser exposure to a fixed point on the ground. The scanning motion remains constant throughout operation of the airborne LIDAR system in order ensure that an effective swath is covered over the ground.

3.2 PROACTIVE SAFETY FEATURES

In addition to the passive safety features described above, manufacturers incorporate one or more of the following design and/or workflow software features to minimize exposure and ensure that the NOHD is not less than the actual flying height. These proactive features include:

- Flight planning software – Flight planning software has two general purposes: (1) determining the appropriate system settings that will result in maximum area coverage rate and (2) layout of flight lines (given the predetermined system settings) in a geometry that minimizes total flying time. Part of the optimization for determining appropriate system settings is to minimize laser output consistent with the desired flying height. In addition, other algorithms may be used to assure that laser footprints are not overlapping (e.g., by using too-low a scan rate for a given field of view).

- Scan interlocks – Scan interlocks and warning messages are provided if the scanning motion (FOV or scan rate) is not per the flight plan. These features are capable of either warning, shutting off or shuttering the laser.

- Automatic laser shutoff – Since the system is constantly measuring range, systems are equipped with a feature that shuts off or shutters the laser if aircraft flying height is approaching the NOHD. As a general rule, the trigger point of such features can be set with a margin large enough to accommodate sudden terrain discontinuities while still resulting in ground exposures less than Class 1 laser levels.

4 ENGINEERING CONSIDERATIONS

4.1 TYPICAL AIRCRAFT MODIFICATIONS TO ACCOMMODATE REMOTE SENSING EQUIPMENT

The installation of remote sensing equipment, in this case the airborne LIDAR survey equipment, consists of two main efforts:

- modification of the aircraft to provide an aperture through which the equipmment can operate with a clear view to the ground below during flight
- installation of the remote sensing hardware

This section is intended to distinguish between these two efforts, and to define the scope of the modification phase as fully separate from the hardware installed in the modified aircraft.

Nearly all modern airframe modifications that accommodate scanners, sensors, cameras and navigation sight ports are approved by the FAA via the Supplemental Type Certificate (STC) process. There are a number of legacy airframe modifications that have been accomplished via Field Approval pursuant to FAA Order 8900.1, Vol. 4, Chapter 9. The Field Approval process has been phased out due the complexity of the structural analysis required. Furthermore, the FAA has shifted its engineering analysis from the local Flight Standards Disctrict Office (FSDO) level to its DER (Designated Engineering Representative) network.

The current typical STC no longer associates any particular Remote Sensing Equipment (RSE) with the modification. Since there is no “approved remote sensing equipment“ listed in the STC, another method for approval is necessary. The burden is therefore shifted to individual operators and to the interpretation of the local FSDO. If approval is to be sought, the RSE must therefore conform with the original certification basis of the aircraft in question. This is accomplished via the DER network. See Section 4.2 below for further consideration.

Current STCs typically include approval and installation instructions for the necessary electrical components, including a power distribution panel. An electrical supply upgrade may be in order to compensate for the electrical draw created by the RSE and associated sub-systems. If the electrical approval is not in contained in the STC, separate DER electrical engineering approval data will be needed. See section 4.2 below for further consideration.

The STC normally includes a supplemental flight manual, so flight crews will need to familiarize themselves with how the STC may affect the operation of the aircraft.

Additional maintenance practices referred to as Instructions for Continued Airworthiness (ICA) will need to be incorporated into maintenance cycles as spelled out in the applicable STC.

4.2 Typical installation of remote sensing equipment in modified aircraft

As documented in Section 4.1 above, the recommended approach for installing RSE is to separate the structural and/or electrical modifications from the installation of the equipment. Section 4.2 documents the requirements for the installation of the RSE. To that end, the following must be fulfilled for each installation of RSE:

- Unless specified by the STC, the RSE that will be installed into a camera/sensor port in the aircraft must conform to the original certification basis of aircraft, and be within all parameters defined by the original Aircraft Type Certificate (TC). Appropriate analysis (DER structural approval) must be provided to assure that system mounting is crash-worthy (FAA FAR Part 23 and RTCA DO-160, Section 7).

- Support system equipment racks will be installed utilizing existing seat rails themselves or attach to structures utilized by the seat rails. DER structural analysis will be used to ensure applicable loads are within the original TC.

- DER electrical analysis will supplement the electrical installation when the STC does not support an electrical installation section in the installation instructions of the STC.

- A revised weight and balance document will be created reflecting the new configuration.

- An aircraft logbook entry will document the configuration as it currently exists.

Compliance with the above ensures installation and operation are not adversely affected by the RSE.

5 Recommendations

The following recommendations are made regarding directives or policies affecting the installation and use of airborne LIDAR survey systems in both fixed- and rotary-wing aircraft:

5.1 Compliance with 21 C.F.R. 1040

All manufacturers of airborne LIDAR survey systems must comply with regulatory requirements of laser products as provided in 21 C.F.R. 1040.10. Specifically, the manufacturer of such a laser product must submit the registration and listing to the Food and Drug Administration, Center for Devices and Radiological Health, Director, Office of Compliance, 10903 New Hampshire Ave., Bldg. 66, rm. 3521, Silver Spring, MD 20993-0002.

Such compliance will be evidenced by receipt of a letter from the FDA providing an Accession Number and acknowledging that the required laser product documentation has been received by the FDA.

5.2 Compliance with RTCA DO-160

All airborne LIDAR survey systems must be tested for compliance with the appropriate sections of RTCA (Radio Technical Commission for Aeronautics) Document DO-160, Environmental Conditions and Test Procedures for Airborne Equipment, last updated to version G issued on December 8, 2010. The specific sections concerned with aircraft safety are: Operational Shocks and Crash Safety Tests; Emission of Radio Frequency Energy (Conducted and Radiated); Flammability Test; Power Input Tests. Power input tests are included since there are tests to verify that the airborne LIDAR survey system does not have a negative influence on the aircraft power system that would be harmful or would otherwise cause degraded performance in other installed equipment. The tests regarding susceptibility of the LIDAR to the power supplied from the aircraft buss do not affect aircraft safety.

Compliance with the aircraft safety-related tests enumerated above would be evidenced by an Environmental Qualification Form, which indicates the tests that had been performed and the LIDAR system successfully complied.

5.3 SEPARATION OF AIRCRAFT MODIFICATION FROM SYSTEM INSTALLATION

Modification of an aircraft to permit the installation of a downward-looking payload, such as an airborne LIDAR survey system, should be covered by an STC. This STC should also provide limits on the power, weight and size of the payload that can be installed in the aircraft to which the STC applies.

For installation/de-installation of the LIDAR payload, Field Approval pursuant to FAA Order 8900.1, Vol. 4, Chapter 9 should suffice, as long as the weight, power and balance limits as specified under the STC for the aircraft are not exceeded..

5.4 USE OF NOHD OR ENOHD AS BASIS FOR DETERMIING SAFE OPERATION

Operation of the LIDAR survey system in the aircraft should be governed by compliance with operation at flying heights greater than the NOHD or eNOHD (as applicable) and not by laser class. NOHD is the recognized criteria for determining whether exposure to the output of the laser instrument is considered non-hazardous. Conditions for use of NOHD versus eNOHD should follow the criteria set forth in IEC 60825-1 and/or ANSI Z136.1

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[1] IEC 80625-1
[2] IEC 80625-1
[3] Laser Institute of America (LIA) Homepage www.lia.org
[4] Laser Institute of America (LIA) website www.lia.org/ANSI/106

Conclusion

Based upon the foregoing information, the FAA Aircraft Certification Office (ACO), through the appropriate product Directorate and Aircraft Engineering Division (AIR-100), should determine that an STC is not necessary for installation and use of Airborne LIDAR systems.