Use of Aircraft Spotters for Keck II Laser Safety

1.0 Introduction

1.1 Document History

This document is an update of the Keck Adaptive Optics Note #213. The KAON 213 version from October 2002 has been updated and converted into a new KAON 360 to reflect some changes. The main modifications include:

- Add reference to FAA AC 70-1 (Section 2)
- Provide additional details on the role & responsibilities of personnel for laser safety (Section 3)
- Provide additional details on operational procedures (Section 4)

1.2 Background and Purpose of the Document:

The Keck Laser Guide Star (LGS) system is used to generate artificial guide stars for the Adaptive Optics (AO) system. The laser is propagated into the sky in the same direction as the telescope is pointing. The light from this laser will excite sodium atoms in a mesospheric layer of the atmosphere (~90km altitude). These sodium atoms will begin to fluoresce and effectively create what appears to the telescope systems as an artificial star. This artificial star will then be used by the AO system to correct optical aberrations introduced by the atmospheric turbulence into the science images.

Emitting bright lights such as our laser into the night sky presents a potential risk to passing aircraft. In particular, the FAA recognizes the risk of distraction, disruption, disorientation and incapacitation of flight crews exposed to these light sources. It is our responsibility to insure that the use of our laser will not present a hazard to aircraft flying around Mauna Kea.

We have plans for a multi-tier, redundant safety system to protect aircraft. These plans include the use of a mosaic radar display, a wide-field CCD camera and a boresight IR camera. All of these systems could detect aircraft and be integrated into the laser safety system to ensure that our laser does not accidentally illuminate them. The mosaic radar and wide-field camera systems are still in development. The boresight camera is in use during laser propagation. Until such time as our multi-tier aircraft safety system has been successfully integrated and approved by the FAA, we will need to continue to use human observers stationed outdoors to look for aircraft while the laser is being used. These “aircraft spotters” or “safety observers” will communicate with laser safety personnel to insure that the laser does not illuminate air traffic in our area.

The purpose of this document is to present the plan for use of aircraft spotters as part of our laser safety program.

2.0 Requirements and Standards

2.1 Applicable Standards Documents

There are several different standards documents in existence describing safe use of lasers outdoors in navigable airspace.

- ANSI Z136.6 *Standard for Safe Use of Lasers Outdoors*
- FAA Order 7400.2D, Chapter 34, *Outdoor Laser / High Intensity Light Demonstrations*
- SAE Aerospace Standard AS4970 *Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace.*
- Advisory Circular 70-1, *Outdoor Laser Operations*.

2.2 What the standards say about aircraft spotters

Some documents refer to aircraft spotters by the phrase Safety Spotters or Laser Safety Observers. In this document, these two titles together with Aircraft Spotters are intended to mean the same thing. Along these lines, following are some references regarding what the standards documents say about aircraft spotters.

2.2.1 From FAA Order 7400.2D on the subject of spotters:

> ***34-17. CONTROL MEASURES***
>
> ***Physical, procedural, and automated control measures which meet FAA standards can be used to insure that aircraft flying within specific flight zones will not be exposed to levels of illumination greater than the respective maximum irradiance levels. Such controls include but are not limited to: . . .***
>
> ***. . . d. Manual operation of a shutter or beam termination system can be used in conjunction with airspace observers. Observers shall be able to see all airspace surrounding beam paths to a distance appropriate to the affected airspace.***

2.2.2 From FAA AC 70-1 that provides information to those planning to conduct outdoor laser operations

> ***Appendix 1, item 3: Brief description of control measures: Describe the method use to protect aircraft space: for example the use of observers [..]. The more the operations relies on control measures to ensure safety, the more detailed the description should be.***

2.2.3 ANSI Z136.6 - 2000 Section 4.8.1 states:

> ***4.8.1 Laser Safety Observers. Safety observers may be employed to observe airspace for aircraft when visible laser irradiance levels exceed visual interference levels. Safety observers shall be properly trained (See 5.2.6). Observation times should be limited (perhaps one hour on and one hour off or a ten minute break every hour). The safety observer shall have the responsibility, capability, and authority to terminate laser beams immediately when an aircraft approaches, and before a potential hazard occurs.***
>
> ***The safety observer shall only be relied upon when conditions permit the visual detection of aircraft. The safety observer shall not be expected to see aircraft at a distance of more than 3 miles, except in remote locations. For multiple beams, multiple observers may be necessary.***

The issue mentioned above concerning "*observer shall not be expected to see aircraft at a distance of more than 3 miles, except in remote locations*" is significant for Keck Observatory operations and deserves comment.

The Keck Observatory is situated at the summit of a dormant volcano -- Mauna Kea -- located on the island of Hawaii in the middle of the relatively thermally stable

Pacific Ocean. The observatory was built in this location to take advantage of the 13,600-ft. elevation with no mountain ranges to disrupt the upper atmosphere with light-reflecting dust. Mauna Kea is a remote and rural location with few people other than astronomers staying in the area, so there are few lights. The same conditions that make Mauna Kea ideal for conducting astronomical research also provide excellent conditions for aircraft safety observers.

We should certainly qualify as a "*remote location*" where observers can routinely be expected to see aircraft at night at distances far exceeding 3 miles. While we have not done any quantifiable tests to determine the distance at which observers can easily see aircraft, there is qualitative evidence to support this statement. At night, it is normal for observers at the summit to be able to see aircraft in the area of the Kona or Hilo airports, distances of approximately 38 and 27 miles, respectively.

2.2.4 ANSI Z136.6 - 2000 Section 5.2.6 states:

5.2.6 Safety Observer. Safety observers shall
(1) Have distant visual acuity corrected to 20/20, normal visual fields, no pathology of the eye
(2) Have the capability of terminating laser emission when a hazardous condition is identified
(3) identify and report potential conflicts within visual detection range to the LSO
(4) take into account visual fatigue. The LSO shall provide for regular rotation, e.g. a 10-minute break for every hour of observation, or one hour of observing and then an hour off.
(5) have an unobstructed view of the laser beam paths and buffer zones, or a view that overlaps with additional observers.

2.2.5 Regarding spotter viewing aids, SAE AS4970, section 7 states:

7. Preventive Methods
7.1 Aircraft Detection
Following are some examples of preventive measures that have been successfully used to protect airspace
Observer
Authorized Laser Operator - Control of access to beam by operator (operator located outdoors)
Aircraft Spotter - Dedicated person looking for aircraft outdoors
Aircraft Spotter Team - Multiple Persons with communications looking for aircraft outdoors
Vision Enhancement - Vision aids to enhance detection range:
(a) night Vision (light amplifiers)
(b) Infrared vision (8-12 um)

This excerpt hints that use of light amplifiers or IR vision aids could be used to allow aircraft spotters to be effective at ranges greater than the 3 miles mentioned in ANSI Z136.6 - 2000 Section 4.8.1. Unfortunately, we believe that the narrow field of view of these devices, combined with the fact that our remote and dark site makes spotting aircraft possible at distances much greater than 3 miles leads us to decide not to plan for our spotters to use binoculars, light amplifiers or IR aids.

2.2.6 Regarding training of spotters, ANSI Z136.6 - 2000 appendix F, section 7, states that:

Appendix F, Training Requirements . . .

. . . F7. Safety Observers
Personnel shall receive training on specific hazards of lasers used, methods of communications with appropriate control centers and authorized laser operators, emergency laser shutdown, applicable laser SOP's and pertinent regulations. In addition, this person should receive training in:
(1) Assigned duties and responsibilities
(2) local safety procedures
(3) local emergency laser termination procedures
(4) laser hazard identification
(5) local air traffic patterns
(6) visual scanning techniques
(7) limitations of the observing location

3.0 Aircraft Safety Personnel

3.1 Laser Safety Lead:

The Keck laser is a class 4 device, requiring that a LaserSafety Officer be assigned. We will have a qualified person on staff at all times to perform the duties of the laser safety officer. The Laser Safety Officer will be trained as per appendix F of the ANSI Z136.6 standards. This person will be responsible for recommending company laser policy, laser safety procedures, preparing instructions and training for users, insuring proper barriers and warning signs are in place, investigating and reporting on incidents, emergency procedures and record keeping.

The Laser Safety Officer (LSO) is not required to be on site whenever the laser is being used. The LSO has designated qualified Lead Laser Safety persons who will be on site during laser use. Our policy will be that any time the laser is to be used, there will be a Lead Laser Safety person designated. This Lead Laser Safety person will be responsible for insuring that all procedures and policies are followed during laser operations.

In addition, the laser technical tasks are only perfomed by authorized personnels that have been trained for operations and safety by the Laser Engineer.

- The observing assistant (OA) on duty during laser operations will be the Lead Laser Safety (see Sect. 3.2). This person is responsible for directing and supervising the aircraft spotter personnel.
- During day preparation for operation or engineering, the Lead Laser Safety person is the authorized laser engineer or technician present at the summit.

3.2 The Observing Assistants

The observing assistants at Keck Observatory are responsible for coordinating the safe use of the telescope and instruments. Again, the observing assistant (OA) on duty during laser operations will be the Lead Laser Safety. The OA will be in constant intercom communication with aircraft spotters, laser operators, and lead safety person. The OA will insure that aircraft spotters are always informed about laser operations and directions of laser propagation prior to the laser shutters being opened. The OA will also ensure that the aircraft spotters take their stations and stand down at appropriate times. The OA will be kept informed by all personnel on the summit of the status of any and all laser and safety systems as well as weather and sky transparency conditions.

3.3 Visual Aircraft Spotters or Laser Safety Observers

Much of this information comes from the standard document ANSI Z136.6 section 5.2, and some of it comes from example procedures provided by colleagues at Maui Space Surveillance Systems.

3.3.1 Aircraft spotters are temporary personnel hired at the Observatory. They will be required to pass the visual exam (see 3.3.2). They will be trained for the tasks and responsibilities (see 3.3.3 and later) and receive an hourly rate.

3.3.2 According to the standards documents, the aircraft spotters must have at least 20/20 corrected vision, normal visual fields and no pathology of the eye. We also insist that aircraft spotters have normal color perception, at least to the extent that they can make use of the red and green lights on aircraft to determine the direction of travel. Keck aircraft spotters undergo the following tests during eye exams prior to working at the summit: Check for 20/20 Corrected Vision, Entrance Visual Acuity, Pathology

Exam, Ophthalmoscopy Exam (interior), Slit Lamp Exam (exterior), Normal Visual Fields Exam, Normal Color Perception Exam, Amsler Grid Test, Refraction Exam, and Intraocular Pressure Exam.

3.3.3 Spotters will need to be trained regarding applicable responsibilities and procedures.

ANSI Z136.6 - 2000 appendix F, section 7, states that:

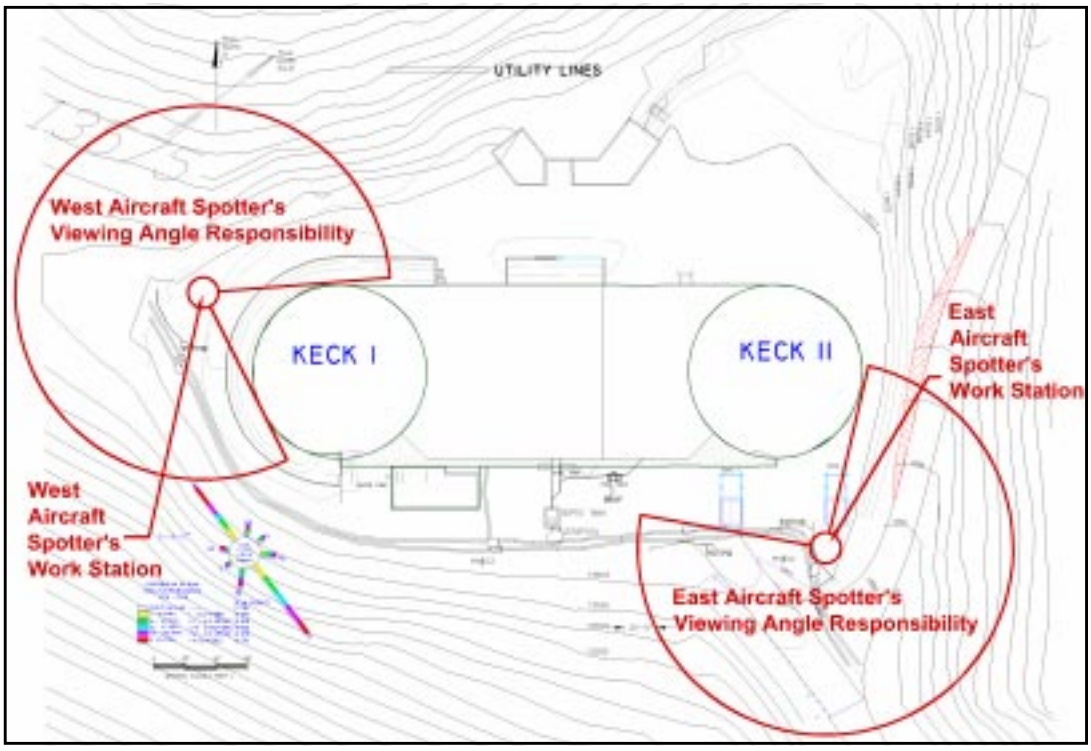
Appendix F, Training Requirements. . .

. . . F7. Safety Observers
Personnel shall receive training on specific hazards of lasers used, methods of communications with appropriate control centers and authorized laser operators, emergency laser shutdown, applicable laser SOP's and pertinent regulations. In addition, this person should receive training in:
(1) Assigned duties and responsibilities
(2) local safety procedures
(3) local emergency laser termination procedures
(4) laser hazard identification
(5) local air traffic patterns
(6) visual scanning techniques
(7) limitations of the observing location

3.3.4 To visually cover an adequate buffer zone around the laser we should employ at least two spotters at all times when the laser is emitting to the sky.

3.3.5 Spotters will be positioned to have an overlapping field of view, such that at least one spotter will have clear, unobstructed view in all directions in order to include the laser beam and sufficient buffer zone. Spotters will be stationed on the ground in specific predetermined areas.

Figure 1: Diagram of assigned spotter stations.



3.3.6 Spotters will be allowed to stand or walk around within their designated station. They will also be allowed to make use of swiveling stools.

3.3.7 While we have considered providing aircraft spotters with a small hut or shelter to protect them from the harsh conditions on Mauna Kea, for a number of reasons, we have decided against this option. So, in order to protect spotters from the harsh conditions, spotters will be provided with adequate cold weather gear. This gear will

probably include shared parkas and cold weather pants. Individual boots, hats and gloves will be provided.

3.3.8 We will have Keck vehicle stationned in proximity to the spotter's work station. Spotters will be allowed to sit in these vehicle while their eyes accomodate to the dark (Sect. 3.3.10) as well as when spotters are requested to stay outside during the stand down time (Sect. 3.3.15). They will not be allowed to sit in cars during spotting.

3.3.9 Prior to evening operations, the spotters will be briefed by the designated lead safety person. The subject of this briefing may include things like observing plans, weather forecasts, work schedules and coordination of shift changes, as well as any changes in operating procedures.

3.3.10 Spotters will take their work stations 10 minutes before they are needed in order to get their eyes adjusted to the dark. This includes shift changes during the night as well as the first shift of the night.

3.3.11 To account for visual fatigue, spotters will work outside watching for aircraft one hour on/one hour off, with staggered shifts so one fresh observer goes outside each half hour.

3.3.12 During those hours that the spotters are not outside watching for aircraft, they will be given other duties which can be performed indoors.

3.3.13 At the beginning of the night, or when laser emission is about to continue after a period of non-use, the following exchange will take place:

- At least 10 minutes prior to laser emission, the observing assistant (OA) will announce over the PA system "Aircraft spotters to their stations," at which time aircraft spotter personnel will proceed to their assigned stations.
- Upon arriving at their stations, aircraft spotters will connect their communication devices and announce "West Aircraft Spotter on station" or "East Aircraft Spotter on station"

3.3.14 During laser down time, the lead safety person will make a decision whether to have the aircraft spotters come inside or not. If the down time is expected to be short (less than 15 minutes) it may be more efficient to decide to have them remain outside during the down time to avoid the need to dark adapt their eyes again.

3.3.15 In the event the aircraft spotters are called in, the OA will announce via the spotter communication system:

- "Aircraft spotters stand down for XX minutes," or
- "Aircraft spotters stand down. We are done for the evening."

3.3.16 The Keck Observatory already has policies and procedures in place for addressing a case of spotter illness or weather conditions that could require the spotter (s) to evacuate the summit. The Observing Assistant is the lead responsible personnel for such emergency situation.

4.0 Aircraft Safety Operational Procedures

4.1 Communication Setup:

4.1.1 Each spotter is in voice contact with the lead safety person, the observing assistant and the laser operator by means of an intercom. Each spotter work station will have a predetermined "call sign" for use in communications. Call signs based on the predetermined spotter work stations around the observatory are "West Aircraft Spotter" and "East Aircraft Spotter."

4.1.2 Prior to evening operations, each spotter will test their communication devices to insure that they are fully functional.

4.1.3 Each spotter has a kill switch, and is authorized to terminate laser emission when a hazardous condition is identified.

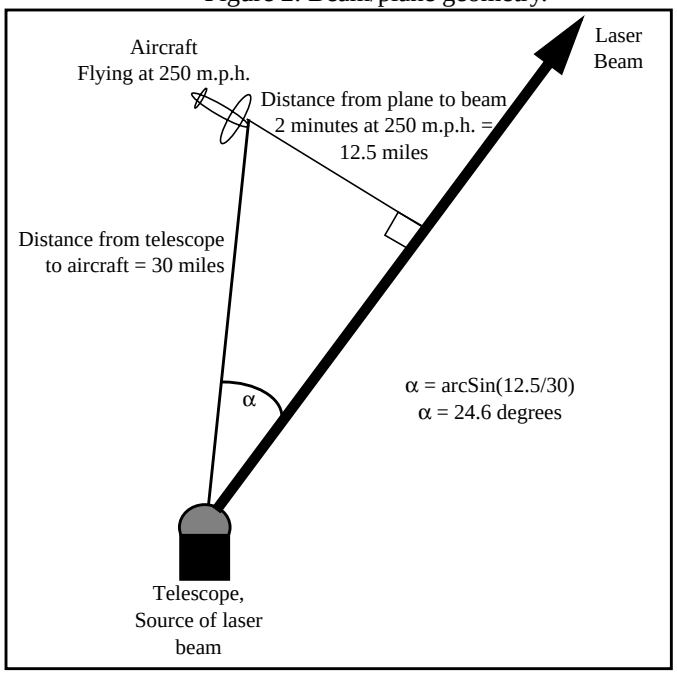
4.1.4 Prior to evening operations, each spotter will test their kill switch to insure that it is fully functional. This test will be performed in coordination with the designated safety officer.

4.2 Conditions for Aircraft Safety

4.2.1 Spotters will report potential hazards of any kind within visual range to a designated safety officer.

4.2.2 The relative risk of our laser operations to an aircraft varies with the distance from the plane to the laser beam, and with the aircraft speed. Obviously, planes close to the beam are at greatest risk and the beam should be terminated in order to protect them. In order for all aircraft spotters to perform in a consistent manner, we would like to quantify the angles between aircraft and laser beam that should result in beam termination.

Figure 2: Beam/plane geometry.



What we really want to do is to terminate the beam if an aircraft is within 2 minutes (for example) of intersecting the beam.

In order to convert that 2-minute safety zone to an angular measure we need to make some assumptions.

-Assume a plane traveling 250 miles an hour, toward the closest part of the laser beam

-Assume the plane is 30 miles away.

This leads us to conclude that we should terminate the beam for any plane within 25 degrees of the beam path. Of course some planes travel faster than 250 m.p.h., and some may be closer or farther away than 30 miles, so these are guidelines. Aircraft spotters are advised to terminate the beam even when planes are at angles greater than 25 degrees to the beam if in their opinion it is prudent to do so.

Note: Our colleagues at Maui Space Surveillance Systems also use 25 degrees as the angle at which spotters terminate their laser beams.

4.2.3 Spotters will report ALL visible aircraft using the spotter/safety intercom. These aircraft will be in one of three categories. Spotters will use the following language to report aircraft in each category.

- Planes greater than 50 degrees from the beam.

  "This is the West Aircraft Spotter. We have an aircraft in the area. Not a factor at this time."

- Planes within 50 degrees of the beam.

  "This is the East Aircraft Spotter. We have an aircraft in the area, nearing the beam. Not a factor at this time. I will keep you posted."

- Planes within 25 degrees of the beam.

  "This is the West Aircraft Spotter. I have shuttered the laser because of an aircraft near the beam path. I will re-enable when the aircraft clears the area."

- When a previously reported aircraft leaves the 25-degree safety buffer

  "This is the East Aircraft Spotter. The beam path is clear. Enabling laser."

4.2.4 Spotters will report weather conditions that prevent effectively spotting aircraft visually, using the following language.

- If there are thick clouds greater than 25 degrees from the beam

  "This is the East Aircraft Spotter. Clouds are threatening to obstruct my view. I will keep you posted."

- If thick clouds are within 25 degrees of the beam, preventing the spotter from seeing beyond the clouds

  "This is the West Aircraft Spotter. I have shuttered the laser due to cloud cover. I will re-enable when clouds clear and beam path is clear."

From the experience of the Keck Observing Assistants, a "thick cloud" that would prevent from spotting aircraft would produce at least 2 magnitude of stellar extinction. In addition to the spotters noticing the disappearance of many stars, the vicinity of a thick cloud would be immediately noticed by the adaptive optics system looking at the laser, as it would increase the level of scattered light and reduce the light level on the wavefront sensor by up to a factor 6.

4.2.5 When desiring to propagate the laser, the Observing Assistant will poll the East and West spotters giving the direction of expected propagation:

"East and West spotters, we request permission to propagate at altitude 60 degrees, azimuth 180 degrees."

If no aircraft or clouds that would prevent spotting aircrafts are within the angle of the requested propagation direction, the spotters should verify that they enable the laser and answer in turn:

"This is East Spotter: you are clear to propagate in that direction"

From this moment on, the spotters must watch the direction stated and report any aircraft and clouds whether or not the laser is propagating.

4.2.6 If the laser is being shuttered for more than 2 minutes, the Observing Assistant should consider the permission to propagate “stale” and again request permission to propagate to the spotters.

4.2.7 Spotters should be informed anytime the laser is being shuttered for very short period of time, as the operations of the adaptive optics system may require.

4.2.8 Spotters will also report thin clouds in the beam path that could be illuminated by our laser and adversely effect other observatories’ astronomical science. Such an event will be reported with the following language

- “This is the West Aircraft Spotter. Clouds are in the area of the laser beam. I will keep you posted.”