Outdoor Laser Operations: Experiences and Safety Considerations

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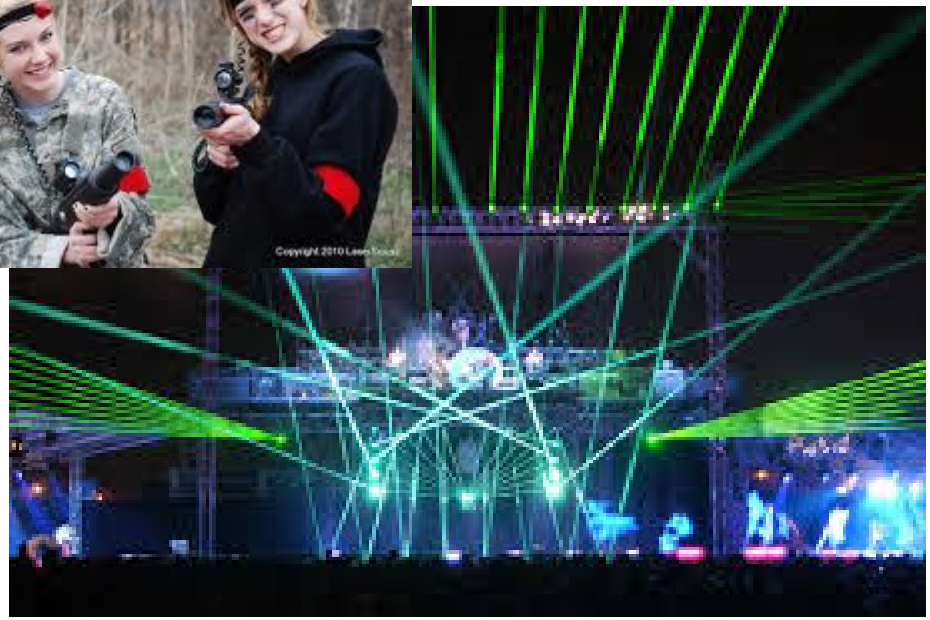
Introduction

- Ball has a long history of safe outdoor laser operations
- Started in earnest with the Remote Mirror Experiment (RME) in early 90s
- Continued with high energy laser (HEL) system development and testing
- Continued with atmospheric scintillation compensation experiments
- Continued with terrestrial, airborne and space laser communications
- Real commitments to outdoor laser testing started with the CALIPSO LIDAR
- Continues to the present day with a variety of LIDAR technologies
  - Systems use swept beams, multiple beams and diffused divergent beams
  - Many different wavelengths and formats, pulsed and CW
- Goal of exceeding the requirements of “Aided NOHD” by 1.5X to 2X
- Solid record of extraordinary safety in field testing and far safer than most outdoor laser entertainment events

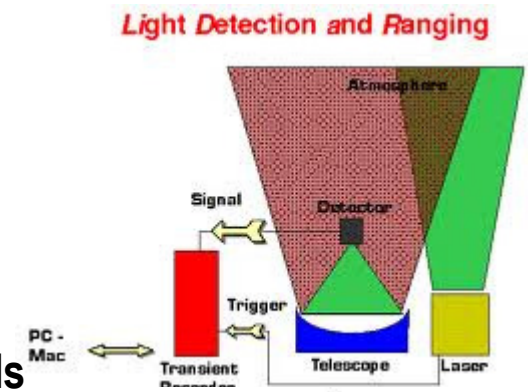
Not the Outdoor Laser Operations We Have in Mind…

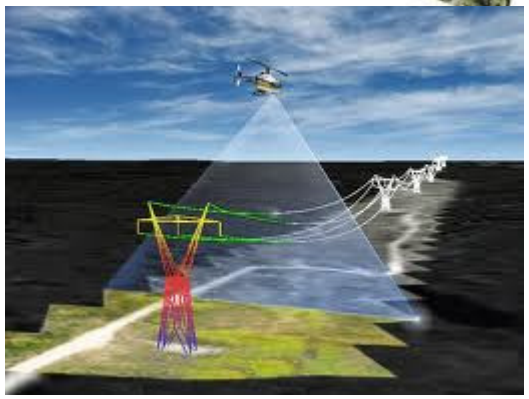


More Like the Outdoor Operations We Had in Mind…

An Example of Outdoor Laser Operations: LIDAR

- What is LIDAR?
  - Stands for "LIght Detection And Ranging"
    - (or – in the photogrammetric world)
  - "Laser Image Detection and Ranging"
- LIDAR is used for both profiling and imaging
  - Profiling aerosols such as smoke plumes, clouds
  - 3D topographic imaging (some in real-time)
- Most common form is direct pulse return
  - Time of flight directly related to range
- Many firms including Ball Aerospace build various kinds of LIDAR systems for space and airborne applications
- All of these systems require outdoor laser operations for development and testing





Laser Risks Associated With LIDAR

- Lasers in LIDARs come in a variety of wavelengths and formats (pulsed & CW) at energies and powers sufficient to provide a high SNR
- VIS /NIR pulsed LIDAR systems merit particular attention
  - Potential skin and eye exposure from high peak and average powers
- Imaging with LIDAR cameras requires a large energy per pulse
  - Energies increase linearly with the number of pixels
- Camera based imaging lasers are typically diffused to fill a field of view (FOV) but still may not be eye-safe at the aperture
- Eye-safety is, however, ensured within, perhaps, meters to tens of meters and well above flight altitudes
- These systems are typically scanned so exposure is generally a single pulse per unit area of ground track
- Systems are extensively interlocked to prevent accidental exposure and baffled to prevent stray light
- Gimbals, if used, must also be interlocked to prevent pilot/operator exposure

Outdoor Ground Level Operations

- Ground level operations are necessary during development
  - Validates system performance and control
- Ground operations must be conducted in approved ranges
  - Extensive measures for public and operator eye-safety must be taken
- The Front Range is well suited to ground operations
  - Relatively unobstructed views of the foothills from tall buildings and either private property or open spaces with natural and/or manmade restrictions
- If an open space area is contemplated
  - Suitable baffling is easily installed to prevent any ground level exposure below seven or eight feet since foothill targets allow upward sloping beam paths
- A well planned security perimeter
  - Perimeter tape and manned with goggled personnel as a precaution.
- Be cognizant of local air traffic routes
  - Be well outside of those and the prohibited zones around airports
- Google Earth™ is a useful tool for organizing ground and aerial operations

Outdoor Aerial Operations

- Aerial operations are the next step in the life of LIDAR development
  - For space platforms, airborne testing is usually the next step in validation.
- Platforms include both fixed and rotary wing aircraft
  - Both have tradeoffs from a safety, cost and efficiency standpoint
- Fixed wing aircraft are typically more suited to larger systems
  - When more developmental in nature and perhaps require more support personnel
  - Also tend to be a bit safer from the standpoint of operators and pilots due to downward only beam path pointing
- Rotary wing platforms (helicopters) are sometimes more versatile
  - Availability of camera gimbals that are common in the movie industry and survey work
  - Versatility comes at the expense of risk of pilot/operator exposure requiring additional interlocking of both the hardware and software
- Diversity of interlocking is important
  - Manual and software interlocks prevent hangar, crew and runway exposure
  - Air pressure interlocks provide additional safety and only release at altitude

General Outdoor Safety Requirements

- Obvious here but easy access to goggles is crucial.
  - Particularly true for unexpected visitors to the site. We always maintain sets of goggles at the perimeter
- Communication between the operator(s) and security crew are typically handled by preexisting protocols involving hand signals and radio gear
- Weather can be a factor
  - A sudden gust of wind or flash of lightning can cause distractions and accidents
  - Tripods and other important hardware must be tied down. Typically, we operate under some sort of canopy and so must also ensure that that is tied down as well
- Monitor the forecast and be aware of developing storms
  - Shutdown and exit the area well ahead of any storm activity
  - Especially true along the Front Range where bad weather can develop quickly
- Public safety is always paramount
  - Have multiple margins of safety on power, interlocks, perimeters and baffling

Specific Outdoor Safety Requirements

- Safety plans must be drawn up and approved.
  - Typically more involved than those for indoor work
- Goggle density must be > OD 6 at wavelengths of use
  - Ensures safety in case of direct exposure to interior beams
- Software tools include the standard LIA software for exposure estimation as well as custom Excel sheets that adapt the ANSI standards to specific situations
- Safety margins of up to 2X
  - Accounts for scene "hot spots" Hot spots are localized deviations from smooth intensity profiles over a FOV
- Custom baffling constructed for each application
  - Common material is black foam-board that is easily adapted to any situation
- Check all interlocks, hardware and software for prior to arriving at field site
- Use co-boresighted video cameras and monitors
  - View intended target scene prior to initiating lasing operations
- Make sure all regulatory authority is signed-off
  - Local NOTAMs issued if necessary

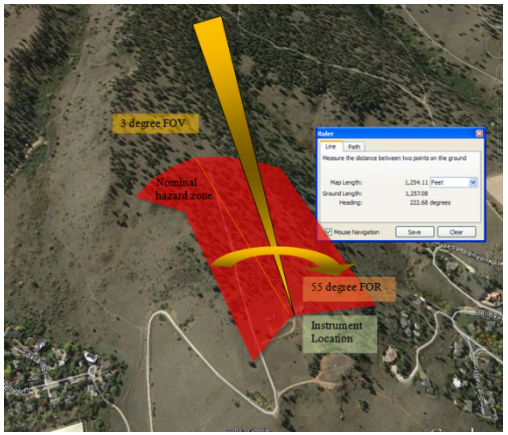
Safety Planning Issues

- Factors that influence the location of ground testing sites include:
  - Local topography: do natural and manmade features provide protection?
  - Relative isolation from nearby public involvement?
  - Relative ease of securing the immediate testing area?
  - Relative absence of regulatory or legal impediments to plan approval?
  - Informed and supportive site managers or owners?
  - Local access to power and internet is often helpful
- Factors that influence choice of aerial routes and operators
  - Relative isolation from nearby public involvement?
  - Relative absence of regulatory or legal impediments to plan approval?
  - Informed and supportive regulatory authorities and law enforcement?
  - Relative ease of aircraft modification, power and interlocking?
  - Experience with maintaining accurate ground tracks with GPS?
  - Experience with mechanical safety margins, particularly hardware racks?
  - Clean and well maintained aircraft

Major Elements of an Outdoor Safety Plan

- Scope, Purpose, Rationale and Duration
  - Include specific arguments and field of regard
  - Follow internal laser safety standards
- Laser Safety Personnel and Laser Description
- Eyesafety Hazard Calculations
  - Follow ANSI standard Z-136.1-2007 "Safe Use of Lasers" and ANSI Z136.6 (2005) "Safe Use Of Lasers Outdoors"
- Test Area Access Control Requirements
- Laser Operational Restrictions and Weather Safety
- Test Layout and General Safety Precautions
- Master Key Switch, Beam Path Control and Protective Eyewear
- Posted Signs, Standard Procedures and Training Requirements
- Eye Exam Requirements, Exposure Reporting , Visitor Control
- FAA and Air Traffic Control Notifications and Clearances
- Chemical Hazard Control and Electrical Hazard Control

	Embedded laser	System	
		3°x1° output	3°x3° output
Pulse Energy	80 mJ	70 mJ	
Beam Diameter	4 mm	16 mm	
Wavelength	1064 nm		
Maximum PRF	30 Hz		
Beam Divergence	0.75 mrad	51 x 17 mrad	51 x 51 mrad
Exposure Duration Assumed	10 s		
MPE (unaided)[1]	0.6 $\mu J/cm^2$		
MPE (aided)[1]	0.017 $\mu J/cm^2$		
Eyeglass OD (unaided[2])	5.3[3]	**4.8**	
Safety factor	2		
NOHD (unaided)	**N/A**	**370'**	**220'**
NOHD (aided)	**N/A**	**2220'**	**1280'**
Laser Hazard Classification	Class 3b	Class 4	Class 4



Possible Management Concerns

- Ensure that relevant safety plans have bee approved by internal authority
- Ensure that all operator and public safety concerns have been addressed
- Ensure that all local authorities that have specific interest and jurisdiction have been notified in case of public interest or concern or possible accident
- Ensure that the FAA paperwork is signed off and available if necessary
- Ensure that public perception is not adversely affected by outdoor operations
- Look for opportunities to enhance public perception through demonstrations
- Look for opportunities to improve communication with local and federal authority
- Look for opportunities to generate informational and promotional material
- Maintain cost and schedule

Government and Regulatory Entities

- Local law enforcement with jurisdiction over test range and flight path
  - Typically local Sherriff's and Police departments
- Local, state and federal agencies charged with oversight of particular areas
  - Typically entities in charge of parks and forests
- Federal Aviation Administration branch for the region (Western or Eastern)
- Local air traffic control with jurisdiction over flight paths
  - Local air traffic control may wish to issue NOTAM's

Summary - Anecdotes and Final Thoughts

- Goal is to dispel the myth that outdoor laser operations are inherently risky
  - This is a common misconception and easily refuted
  - We do this by constructing a comprehensive safety plan and executing it
  - Net result is greater safety than most lecture rooms with laser pointers!
- Our finding is that most public agencies and entities, properly engaged and informed, are helpful and supportive
  - Likewise, considerable internal education is often necessary to dispel common concerns of management over exposure risk but a record of success leads to long term support
- Other helpful experiences
- In summary, after many hours of successful operation, we've shown this myth is easily dismissed and that an effective and enlightened approach to laser safety leads to an appreciation of these remarkable instruments.