SR-22-003

Range Commanders Council

Optical Systems Group

METHODOLOGY FOR TESTING METRIC ZOOM LENSES

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METHODOLOGY FOR TESTING METRIC ZOOM LENSES

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Preface

This report was generated for members in the test range community to provide recommended guidance on addressing methods to successfully characterize metric zoom lenses (MZLs). It does not provide characterization of any zoom lens but does offer recommendations in establishing the facilities and methodologies to obtain successful characterization of MZLs.

It is important for the test range community to begin to address MZL characterization as more test ranges are in the process of acquiring and implementing MZLs for obtaining optical data of test events.

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Acronyms

ARTIS	Advanced Range Tracking and Imaging System
MISB	Motion Imagery Standards Board
MITS	Multispectral Imaging and Tracking System
MRTFB	Major Range and Test Facility Base
MZL	metric zoom lens
OSG	Optical Systems Group
RCC	Range Commanders Council
SME	subject matter expert
TSPI	time-space-position information

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1. Introduction

Throughout the Department of Defense and Major Range and Test Facility Bases (MRTFBs), digital camera sensors are used extensively to determine time-space-position information (TSPI) when evaluating various weapon systems and targets involved in testing activities. This can be accomplished by using properly calibrated camera lens combinations at appropriate determined line-of-sight locations relative to the test event in combination with software solutions to calculate "XYZ" coordinates of the object(s) of interest. The traditional convention employed at the MRTFBs is to use fixed focal length lenses. As technology has progressed in optical test instrumentation, various ranges have shown interest in employing metric zoom lenses (MZLs) to help in improving image quality and increasing system flexibility, while retaining TSPI accuracy.

Due to increased interest in emerging technology associated with MZLs, the Range Commanders Council (RCC) Optical Systems Group (OSG) has sanctioned the solicitation of a study geared around documenting a methodology for testing nonideal behaviors of MZL systems and how they can affect the measurement uncertainty of TSPI calculations. It is the intent of this published study to establish a baseline starting point for MRTFBs and other test ranges to address testing and characterization of MZLs. In addition, there is a need for TSPI test ranges to address MZLs to meet Advanced Range Tracking and Imaging System (ARTIS) use cases and specifications.

The primary purpose for this portion of the study is to consider the nonideal effects of MZLs and how these factors can affect TSPI accuracy. Given the scope of this effort and the resources required to accomplish this, there is a point of diminishing return associated with this portion of the study. Since MZLs have not been deployed in any significant manner on MRTFBs or test ranges, there is a lack of experience and associated documentation regarding the nonideal behavior of MZLs. To achieve the desired results of fully characterizing MZLs there will need to be concerted efforts related to gathering relevant test data and characterizing performance when these MZL systems are fielded.

Part of this study was conducted in conjunction with physical testing of an MZL at China Lake. The project staff was dependent on test results provided by Mr. David O'Connor of the Naval Air Warfare Center and his evaluation of the Canon CN20X50 MZL.[1] In addition, subject matter experts (SMEs) in industry were interviewed to obtain relevant information for this portion of the study. Some of the SMEs interviewed currently manufacture MZLs that will be delivered to test ranges on the Multispectral Imaging and Tracking System (MITS).

Given the budgetary constraints of this project, this is not an exhaustive study. Further research and characterization of this new technology will need to continue when first-article units are delivered under the ARTIS/MITS project.

[1] Range Commanders Council. *Evaluation of Canon CN20X50 Zoom Lens*. SR-21-006. July 2022. Retrieved 20 July 2022. Available to RCC members with private page access at https://www.trmc.osd.mil/wiki/display/RCC/Special+and+Technical+Reports.

2. Consideration Factors Applied to Metric Zoom Lenses

2.1 Product Use Cases

For this study, several use cases were considered for the deployment and use of capturing optical data for TSPI calculations. Most of these use cases correspond with the defined use case scenarios outlined in the ARTIS use case requirements and match what is commonly performed at the MRTFBs. These common scenarios are intercept, launch, impact, and high-speed events.

2.1.1 Intercept Events

Most common intercept events on test ranges occur at higher altitudes, which proves to be challenging for optical instrumentation systems on most ranges. Given the altitude where most intercept events occur, there is typically a larger amount of atmosphere or slant angle that the photons must traverse. This can induce nonideal viewing scenarios with a high amount of distortion of imagery. Figure 1 shows some of these scenarios at which intercept events occur.

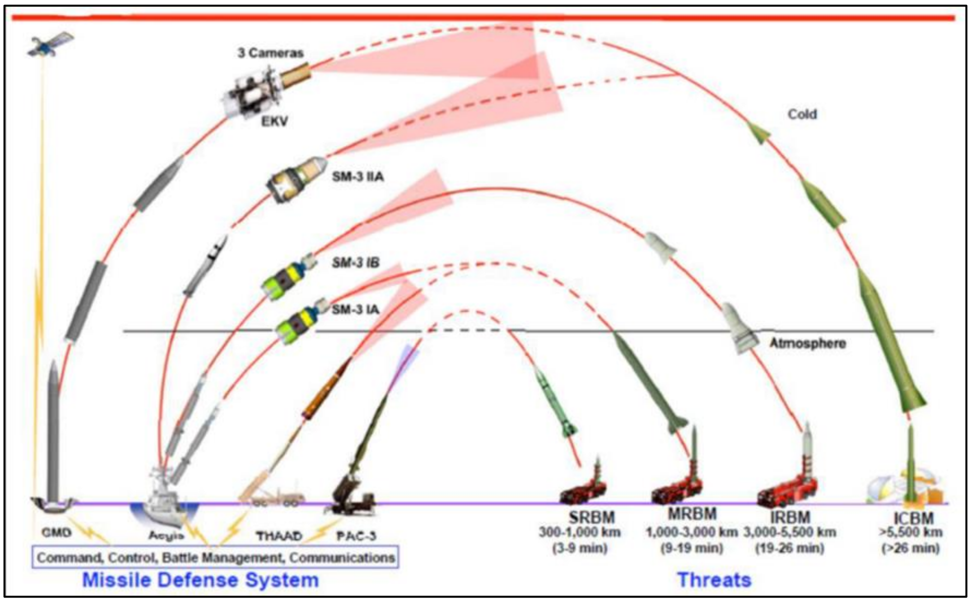

Figure 1. Missile Defense Intercept Event Scenarios

With intercept events being a common use case, MZLs need to have a method of sending out appropriate focal lengths and other associated metadata for ingestion into optical tracking systems. This is necessary for proper TSPI calculations.

2.1.2 Launch

In this use case there are important considerations as to whether you are using a fixed camera system or a tracking gimbal. Each scenario at launch poses its own unique challenges associated with the required field of view for each test.

Applied to tracking, both visible and infrared MZLs are required to maintain a fixed focus on the weapon system launch platform and then transition into a variable zoom as the item traverses its trajectory path. During this process the MZLs need to produce the lens position at a sufficiently high rate, which is determined by the required dynamics as the field of view changes. Depending on the velocity of the item being tracked, the MZLs need to be able to keep up and maintain proper focus. Figure 2 illustrates an Army launch system.

Figure 2. PAC-3 Missile Launch System

Fixed-position MZLs need to maintain the fixed focal length as applied to the field of view of the test event. This in turn makes things simpler as applied to TSPI calculations. This variable is required to be clearly defined within the readout of the lens so it can be properly inserted into delivered data products from the field. One concept is to have the MZL produce this information for ingest into the desired camera so it can be inserted with the other associated metadata, such as an image frame time stamp, exposure time, etc.

2.1.3 **Impact**

Impact scenarios provide their own unique aspects of test scenarios with varying regions of interest in the frame and can vary greatly on what each test project wants to see. One example is a count of debris that is generated, or the effects experienced by the intended target. Another could be what the weapon system being tested does prior to impact. In either case MZLs need to be able to perform properly to meet the desired outcome of the data product for proper TSPI calculations. Similar to launch events, fixed and tracking aspects apply to this use case also. In many cases there are other factors to consider during this use case. One of the primary aspects is sudden change in scene content. Figure 3 is an example of an impact and the many aspects that may need to be tracked.


Figure 3. Impact with Debris

In terms of tracking, each MZL needs to be able to zoom out as the test item gets closer to the target and maintain proper focus. This aspect of tracking as applied to MZLs is not properly characterized and will not be until adequate data is collected.

With fixed-camera impact events, MZLs need to be able to maintain their focus on the item(s) of interest as the event unfolds. Another key aspect that is commonly overlooked is the inherent shock wave during impact that some fixed camera sensor/lens combinations will experience dependent on their position relative to the event. The MZL will need to be able to maintain proper focus when a scenario like this unfolds, and this is going to be highly dependent on the construction of the lens.

2.1.4 **High-Speed Events**

High-speed events described in the portion of this study directly relate to the test scenarios where scene content changes at a high rate of speed. One example of this is tests that are conducted on rocket sleds where the tracked item can traverse the field of view in velocities many times the speed of sound. The MZLs are required to maintain proper focus during these types of events. This can be a significant challenge depending on the rate of speed and time varying change in scene content. Figure 4 captures an event at the Holloman Air Force Base High Speed Test Track.

Figure 4. High Speed Test Track Test Scenario

2.2 Boresight Wander

Typical zoom lens construction consists of multiple fixed optical elements, along with multiple movable elements required to vary the focal length and focal point all contained inside an overall housing structure. An MZL design needs to be implemented that maintains the location of each individual optical surface to a very tight tolerance. This mandates a physical structure that holds each element and can move throughout a range of locations that achieve the design goals for the specific lens. Since the movement of a lens element in any translation or rotation manner will change the path of light rays traveling through it, the consistency and repeatability of this movement dictates the ultimate capabilities and utility of the lens. A primary effect of this movement and shifting of light rays is the apparent change in location of a defined point that resides at the optical boresight of the lens. In an ideal MZL, this point will reside at a static location in the image plane while the lens is zoomed in and out. For nonideal systems, this point will “wander” across the image sensor plane. It is the amount and deterministic behavior of this wander that is of interest. It is desirable to be small enough to not create angular measurement errors for a feature point in an image that is above some use case-dependent threshold. If the feature point does wander but does so in a manner that is consistent, then a calibration process may be achievable to eliminate the effect of the wander. If the wander is not deterministic, then this sets a higher boundary for the measurement uncertainty using the lens, which is undesirable.

There are several factors that contribute to and induce boresight wander in an MZL. One of these factors can be the variance of the optical axis due to loose tolerances in the manufacturing process and another can be attributed to harsh physical conditions, such as temperature variation. To meet specifications outlined in ARTIS, any visible MZL is required to maintain boresight at the optical sensor plane when zooming or focusing to within 30 µm for close-in events and 10 µm for distant events.

2.2.1 **Manufacturing**

Part of the focus on this part of the study was to identify the manufacturers of MZLs that have created lenses that are being integrated into MITS. One of the companies selected to provide the visible and infrared MZLs, Optec, was accommodating and participated in an interview regarding their fabrication efforts for the MZLs that are being used on the MITS system. As a background, Optec has been working with MZL technology for nearly 20 years. They are currently building both short-wave infrared and visible MZLs. Some of their technology comes from the machine vision field, robotics, and laser welders. One of the debates as to how to approach the manufacturing of MZLs was to use either a cam or linear rails. According to Optec representatives, there is no noted benefit to employing a cam design in an MZL except when using an electronic cam that is more flexible in its capacity. With this they stated that there is much more granular design effort associated with taking this approach.

Another manufacturer that was identified was FLIR Systems. They are delivering the mid-wave infrared sensor that has the MZL integrated with the sensor as a complete system. FLIR stressed the importance of having precise accuracy when machining of all components inside the zoom lens. They stated that this can directly affect the behavior of lens performance in relation to boresight wander. These representatives mentioned that their lens sensor combination (RS-8500 series) will have a certain amount of wander when zooming in and out on a distant object, but it does remain consistent to a very high degree. One of the important factors to note is that according to FLIR, there is an inherent difference that can be measured from lens to lens. There is a means with their sensor lens combination to adjust the boresight at the end of the zoom range but not at any of the intermediate positions during zoom transversal. Part of this inconstancy in boresight drift can vary due to lens construction.

2.2.2 **Temperature Variations**

Multiple manufacturers have expressed that variations in temperature can directly affect the performance of MZLs. This has been stated as one of the main factors other than precise machining that cause one of the biggest impacts in relation to boresight shift. It is important to consider the types of materials used in construction of MZLs and how each material is subject to variations in temperature gradients. Some manufactures like Optec test their MZLs in the most extreme environmental conditions related to real-world temperature ranges to ensure functionality of each lens. These are cross-referenced with the defined military specifications in relation to temperature tolerance to ensure functionality. One of the best methods of minimizing the uncertainty due to temperature variation is to isolate MZL sensor combinations in self-contained housings where environmental conditions can be regulated. In addition, each lens enclosure should be pressurized with nitrogen to prevent unwanted contaminants. Both Optec and FLIR Systems have taken this approach with regards to their enclosure housing.

Optec has committed to providing a maintenance kit (see Figure 5) with each delivered MZL to help keep each of their lenses properly pressurized with nitrogen.

Figure 5. Optec Nitrogen Maintenance Kit

2.3 Lens Clunk

Lens clunk can be described as the effect of shifting of internal components inside a lens that can directly affect the overall optical view through each lens. This condition can be induced by moving the lens into different orientations. One example applied to current deployed instrumentation at MRTFBs is placing a Kineto Tracking Mount into a position called “dump” where the instrument is moved in elevation a full 180 degrees until the sensor lens package is upside down in orientation. In situations like this, the components of an MZL would be fully inverted and operating upside down, which, depending on the lens design, opens the possibility of having internal components shift, which then causes the boresight to shift. This is highly undesirable.

2.4 Atmospherics

One special consideration as applied to MZLs is the presence of atmospheric phenomena while collecting optical data. The information capacity of optical instrumentation is often skewed by the presence of turbulence in the lower atmosphere. Turbulence-induced random motions of the optical imagery can diminish desired results of accuracy of the pointing data. This factor has proven to be a challenge for decades on test ranges. One contributing factor applied to this is the desired slant angle at which the optical instrument is pointed to collect the desired imagery. The longer the slant angle the more atmosphere the photons have to traverse, subjecting them to higher probability of being refracted from atmospheric turbulence. There have been many published studies throughout the years highlighting this phenomenology and it is not the intent of this study to go into detail on this proven observed problem as applied to optics.

This issue has created challenges with generating the desired results as it affects the data, in a detrimental manner, that contribute to TSPI solutions. This issue was directly observed during portions of this overall study while examining collected data at White Sands Missile Range. During the compression portion of the study, it was observed that there was significant skewing of the imagery while traversing layers of the atmosphere. Figure 6 shows some of these observed effects of the lower atmosphere.


Figure 6. Effects of Atmospherics on Imagery

It appears that the tip of the missile splits in two. This is just one of many effects that various elevations in the atmosphere can directly affect the perception of optical imagery. The important fact to note is that not all effects that are shown in optical imagery are due to the lens or compression.

2.5 Lens Metadata

A primary consideration when selecting or testing an MZL is the importance of metadata generated by the lens. To perform metric analysis on captured video, it is a requirement to capture all pertinent lens system metadata so analysis processes can properly measure and extract information from frames of motion imagery. The most important aspect of this with an MZL is the time-varying focal length. Because it is time-varying, this information needs to be time stamped with a sufficiently high accuracy (typically less than 50 microseconds) to support TSPI measurement requirements. This information is required to be ingested by optical instrumentation systems for proper compiling with the end data package. As stated in the ARTIS requirements documents, "Metadata capture and dissemination are central to the automation and efficient operation of the system and system of systems."[2] With this requirement it is important to note that all MZLs must be able to produce this metadata in the proper format using designated key-length-value determined by the Motion Industry Standards Board (MISB).

Some of the lenses discussed in this paper have different methods for how metadata is produced and exported from the lens. To improve interoperability, it is important that optical systems at test ranges be configured to properly ingest MZL metadata in an MISB-compliant manner to meet interoperability goals and desired TSPI performance results.

3. Facility Recommendations

One of the factors considered during this study was the state of current optical testing facilities on test ranges that service and maintain lenses. Considerations were given to what

[2] WSMR Systems Engineering Directorate. *ARTIS Use Case General Operations*. Version 1.0. 4 September 2014. Available to members of the DoD and their contractors on request to the RCC Secretariat.

primary equipment would be required to successfully maintain and properly characterize these lenses. Most of the information derived for this study was compiled from common best practices and the approach that MZL manufacturers are using.

Figure 7 shows an ideal lab set up for testing and initial characterization of MZLs. Some of the equipment will be shown and described in further detail.

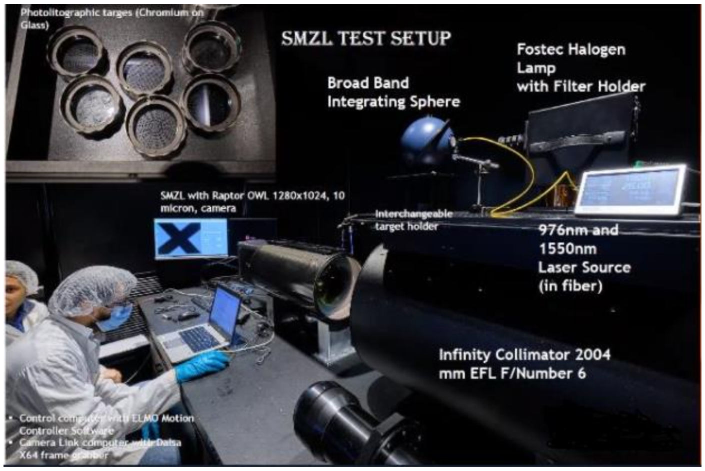

Figure 7. Optical Lens Lab (Courtesy Optec)

3.1 Dark Room

Dark rooms were originally built for the purpose of developing film products from various cameras. As we have transitioned into the digital world, the use of dark room film development has gradually dissipated. Despite the change in optical technology, dark rooms still provide an excellent environment for evaluating digital sensors and evaluating lenses. The main contributing factor to their effectiveness is the ability to avoid undesired stray light sources. Consideration needs to be given to designing or planning a dark room to perform the evaluation of MZLs. The first and most obvious is the ability to make sure that all areas of the room are sealed to prevent light pollution. In addition, special considerations should be given to temperature regulation so recorded offsets and other calibration measures can be maintained as constant as possible. As mentioned earlier in this paper and discussed with the manufacturers, variations in temperature gradients are one of the largest contributing factors to uncertainty in MZL performance.

3.2 Floating Table

A floating table or optical bench is necessary for characterizing MZLs due to very specific requirements. The surface of the table must be flat and large enough to hold various sensor lens combinations that can make good contact with the surface while remaining stable. This will help with proper alignment of lens and sensor combinations, and this alignment is critical to ensuring that the best desired accuracy can be achieved. A floating table provides an ability to minimize undesirable vibrations caused by external sources. This will help with evaluation of MZLs to determine if vibrations are caused by internal lens components while focusing or zooming. The optical tables that are required to properly characterize MZLs are not a common resource when considering current facilities at test ranges. This is primarily due to cost, including the continued maintenance cost associated with this equipment.

3.3 Infinity Collimator

Collimators are a necessary piece of equipment for MZL evaluation and characterization. Figure 8 shows an example of this type of equipment. Infinity collimators are required to be able to replicate targets at infinity zoom with minimal to no parallax. This will help when trying to determine repeatability of zooming in and out with MZLs. This can be achieved with keeping temperature variation at a constant in a lab environment rather than focusing in and out on a distant target on the horizon or stars. This provides the ability to characterize all necessary critical lens parameters, such as boresight wander, focal length accuracy and repeatability, focus, etc. over extended temperature ranges of need.

Figure 8. Infinity Collimator

3.4 Broadband Integrating Sphere

One of the manufacturers interviewed during this study recommended the use of an integrating light sphere as an additional tool to aid in characterization of MZLs. Figure 9 shows an example of such equipment. An integrating sphere provides a Lambertian light source by diffusing external light sources on the inside walls of the sphere. The uniformity of the Lambertian source ensures reproducible conditions for the characterization of MZLs.

Figure 9. Broadband Light Sphere

3.5 Recommended Targets

When evaluating MZLs it is important to select the appropriate targets for the test environment being used. When evaluating lenses in a lab environment, Optec recommended the use of photolithographic targets, such as the one in Figure 10, that can be swapped out with ease on an interchangeable target holder. Other types of targets that would provide benefit are high-resolution targets that can be used to measure the image and the focal length output of the encoder.

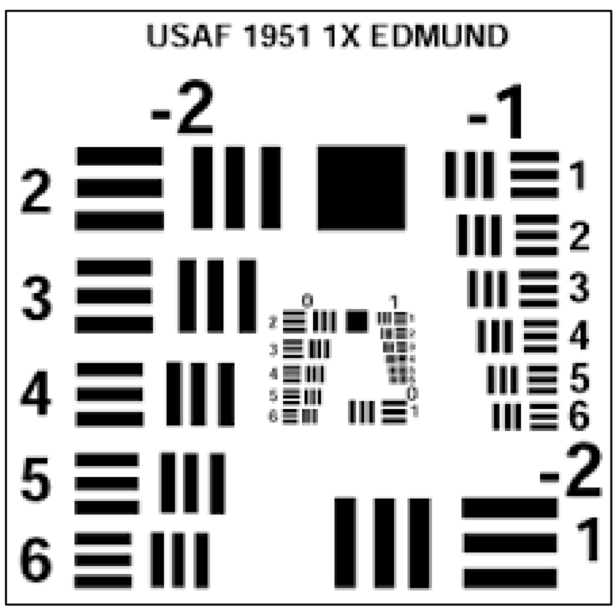

Figure 10. U.S. Air Force Optical Target

4. Calibration and Characterization

During this study, consideration has been given on the best approach to provide recommended calibration and characterization of MZLs. This section of the study will aid in providing considerations for a potential path forward for proper characterization of the nonideal effects of MZLs and how to calibrate those errors out. Figure 11 illustrates the approach taken.

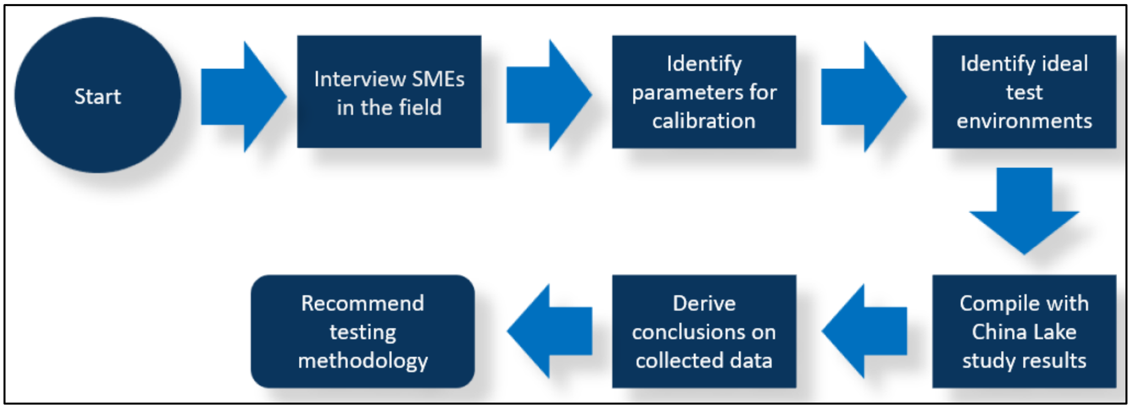

Figure 11. Process for Deriving MZL Testing Methodology

4.1 Recommended Criteria for Evaluation

There are several key parameters of MZL that are important for proper calibration and characterization.

- Focal length repeatability and accuracy
- Boresight precision that traverses the full zoom range
- Mechanical stress attributes
- Focus accuracy at various stand-off ranges

The criteria for testing listed above need to be performed a number of times (to be determined) to provide statistical relevance during acceptance testing and for the purpose of calibration.

4.2 Testing Procedures

Testing of MZLs should be conducted in multiple environments to properly obtain characterization. Some of these ideal test environments are in a controlled lab and on the system intended to facilitate the MZL. Susceptibility to temperature variation is a significant cause for inducing nonideal behavior. As such, these parameters need to be properly measured and characterized, which may require special testing facilities and capabilities that do not exist today at the ranges that will operate these systems. In addition, MZLs should be tested for boresight and focal length at various gravitational orientations. This will help address observed attributes of MZL performance induced by mechanical stress. Another approach that should be considered is using individual stars or known star fields.

5. Conclusion

This portion of the study yielded some interesting facts related to the evaluation of MZLs and was also supported by the corresponding evaluation from Mr. O’Connor. A great focus was on what is currently being used by test ranges and the types of MZLs that are slated to be delivered for MITS. In this study there were great limitations on the amount of testing and characterization that could be performed. As a result, the OSG recommends that further studies take place with the delivered MITS system to characterize the visible and infrared MZLs in a controlled lab environment. The lab environment would be the most ideal in developing a standard reference model to work from. The OSG also recommends evaluating other potential MZL candidates for test range applications by using this standard lab reference model prior to consideration for collection of TSPI optical data.

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APPENDIX A

Citations

Range Commanders Council. *Evaluation of Canon CN20X50 Zoom Lens*. SR-21-006. July 2022. Retrieved 20 July 2022. Available to RCC members with private page access at https://www.trmc.osd.mil/wiki/display/RCC/Special+and+Technical+Reports.

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