Characterization of Small-Arms Muzzle Flash Using High-Speed Thermal Infrared Imaging

Muzzle flash analysis refers to the collection and exploitation of signatures generated by the expulsion of combustion gases from the muzzle produced during the discharge of a firearm. Muzzle flash characteristics are highly dependent upon attributes of both the firearm and ammunition including firearm make and model, barrel length, ammunition caliber and grain. Characterization of small arms muzzle flash is an important first step in the development of muzzle flash suppression systems, hostile small arms fire detection, and other critical defense technologies. Technical challenges for collection of muzzle flash signatures include the short duration of the flash (millisecond timescales) and its high variability in space and time. Imaging techniques are ideally suited for this type of analysis provided the spatial and temporal resolution are sufficient to capture the dynamics of the muzzle flash event. In this work, we present high-speed thermal infrared imaging data collected on muzzle flashes generated from a variety of small arms configurations.

Introduction

Analysis of muzzle flash behavior in the thermal infrared spectrum is attractive because the in-band signature generated in the mid-wave (MW) infrared region is much stronger than the signature generated in the visible region. Additionally, due to the short time-frames over which the muzzle flash occurs, high-speed imagery is necessary for a thorough characterization of the progression of the muzzle flash phenomenon [1].

Figure 1 shows a diagram depicting the major characteristics of thermal muzzle flash behavior. After the firearm discharge, a primary flash is generated ejecting the top part of the bullet within the main gas flow. The MW-infrared signature of the primary flash is very pronounced and is produced by high temperature and pressure gases leaking between the projectile and the barrel inner diameter. The intermediate

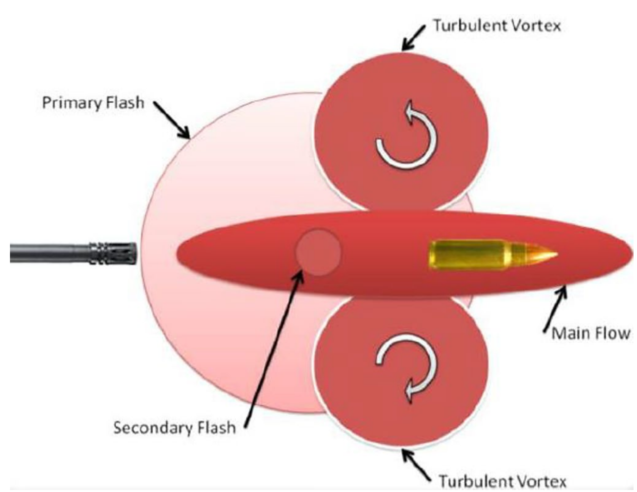

Figure 1. Major characteristics of thermal muzzle flash behavior

flash stage (not shown in Figure 1) is characterized by the expansion of primary flash gases into a triangular shape and the presence of a turbulent vortex appearing behind the projectile and resulting from the motion of the projectile through the primary flash combustion gases. Following the intermediate flash stage, secondary flashes are observed as a result of the mixture of the ejected combustion gases with the oxygen-rich environment by the turbulent vortex [2-3].

In this work, high-speed thermal infrared imaging data collected using the Telops M3k camera is presented for muzzle flashes generated from a variety of small arms configurations.

Experimental information

Telops Camera

Data collection was carried out at the indoor shooting range of Governor's Gun Club in Marietta, Georgia as shown in Figure 2. All infrared video sequences were acquired with the Telops FAST M3k thermal infrared camera equipped with a 50mm Janos foreoptic lens. The FAST M3k features a Stirling-cooled 320 x 256-pixel indium antimonide (InSb) focal plane array (FPA) detector which is sensitive over the 1.5 – 5.4 µm spectral range. The camera was factory calibrated with Telops permanent radiometric calibration [4] which allows access to calibrated pixel quantities including radiometric temperature, in-band radiance, and in-band irradiance. All infrared video sequences analyzed were collected at 1200 frame per second (fps) and 20 µs exposure time. Video sequences were recorded directly to the high-speed internal memory buffer.

Stationary shooters were located at the designated shooting station and discharged the firearms downrange as needed for data collection. The camera was placed perpendicular to the line of fire at a distance of 4.2 meters. The field of view was configured so that the tip of the firearm is just in view at the edge of the image to ensure that as much of the muzzle flash region of interest was captured by the camera as possible.

Figure 2. Muzzle flash test environment with Telops FAST M3k camera and shooter position

Given the 50 mm lens and the FPA detector pixel pitch of 30 µm, the 320 x 256 detector array yields a 10.85° x 8.69° field of view. At 4.2 meters distance from camera to target, this field of view covers an area 0.85 m horizontal and 0.68 m vertical.

Results

Figure 3 shows a frame-by-frame progression of a muzzle flash event generated by the firing of 9 mm Aguila 124 grain ammunition with a Glock 34 long barrel pistol. The temporal resolution achieved by the camera during data recording is

833 us (frame rate of 1200 fps). The progression from the primary flash to the establishment of the secondary flash stage occurs over 7 consecutive frames representing approximately 4 ms. This illustrates the requirement for high frame rate data acquisition for thermal analysis of muzzle flash.

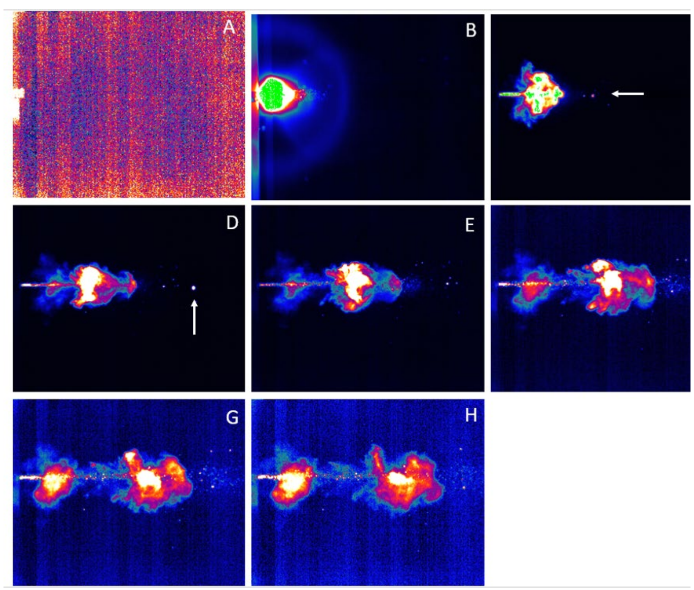

Figure 3. Selected frames from the muzzle flash event recorded by the Fast M3k camera

Frame A shows the thermal image immediately prior to discharge. The far-end of the gun barrel can be seen on the left-hand side of the image as a bright, rectangular object. In this frame the gun and its surrounding are at thermal equilibrium, yielding relatively low thermal contrast. The lack of significant thermal contrast along with the low exposure time (20us) explains the relatively low signal-to-noise ratio seen in this frame.

Frame B clearly shows the primary flash resulting from the leakage of high temperature and pressure combustion gasses out of the barrel prior to ejection of the projectile. The primary flash typically has a rounded-ellipsoid shape propagating directly from the front of the barrel and is much smaller in overall size than the resulting secondary flashes. Although the primary flash is short lived, progressing to the intermediate flash stage in Frame C after approximately 833 µs, the primary flash generates a significant fraction of the total radiance generated by the flash. Frame B also reveals the presence of thermal variations resulting from the propagation of a high-velocity shock wave emanating from the barrel.

In Frame C, the ejected projectile is indicated by a white arrow and is clearly visible as a bright spot in the center of the frame. Ejection of the projectile from the barrel leads to a sharp decrease in barrel pressure, allowing the escape of hot combustion gases. As the shock wave observed in Frame B propagates, a turbulent vortex of air currents is left in its wake, causing the entrainment and expansion of hot combustion gases. Intermediate flash often occurs in the frame immediately following the primary flash, and is characterized by its triangular shape and distance from the barrel.

Frames D-H show the progression of the intermediate flash towards the secondary flash stage. Frame D shows the continued expansion of combustion gases as a result of the turbulent vortex generated by the over-pressure wave shown in Frame B. These entrained gases reignite as they mix with the oxygen-rich environment leading to the development of secondary flashes as seen in Frames E and F. The secondary flashes are fully visible by Frames G and H. The radiance generated in the secondary flash stage is significantly less than the radiance generated during the primary and intermediate flash stages, typically by about a factor of 10. Additional hot spots away from the main flash area in Frames E-H likely represent hot particulate matter ejected during discharge.

Conclusion

This work demonstrates the utility of high-speed thermal infrared imaging in the analysis of small arms muzzle flash. The Telops M3k infrared camera was used to collect thermal imagery at 1200 Hz, allowing for a detailed analysis of typical thermal behavior of a muzzle flash progression. The collected high-speed imagery was used to characterize the progression of the muzzle flash through well-established stages. This analysis illustrates the utility of high-speed infrared imaging for analysis of highly dynamic phenomena such as small-arms muzzle flash.

References

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