SAFETY MANAGEMENT OF NATIONAL DAY PARADE FIREWORKS DISPLAY

SIM Gim Young, LEE Chung Kiat, OEI Su Cheok, ME5 ONG Woei Leng

ABSTRACT

The fireworks display is a highlight of every National Day Parade (NDP) in Singapore. The drive for a more spectacular and intimate fireworks experience increases the importance placed on the safety of performers and spectators. This article describes the challenges in managing the safety of fireworks. It starts by introducing the characteristics of fireworks and its safety management approaches, followed by an explanation of how safety is addressed through the fireworks life cycle – from product design to transportation, storage, installation, initiation and disposal. Finally, the article shares innovative solutions used to control the safety distance of fireworks. The eventual outcome of these approaches is a safe and spectacular fireworks display for NDP.

Keywords: fireworks, safety, National Day Parade, NDP

INTRODUCTION

Figure 1. NDP Fireworks Display, 2014

On 9 August each year, Singaporeans come together to celebrate the nation's independence. The National Day Parade (NDP) features mass performances, a ceremonial parade and multimedia displays that depict Singapore's cultures and values. The fireworks display is a highlight of the NDP (see Figure 1).

At every NDP, a Fireworks Committee comprising personnel from the Singapore Armed Forces Ammunition Command is formed under the NDP Executive Committee to organise the fireworks display. This committee specifies the performance and safety requirements to be implemented by the fireworks contractor.

While the displays are highly entertaining, fireworks are explosives and need to be treated with the appropriate safety protocol. As such, the Fireworks System Safety Team comprising members from the Fireworks Committee and DSTA's armament safety specialists work together to review and ensure fireworks safety during NDPs. The team adopts a system safety perspective[1] to assess the hazards of each firework activity and recommends safety measures to minimise the risks. This concept was initiated in the early 1960s in the aerospace industry and is an effective way of analysing and managing safety risks holistically.

FUNDAMENTALS OF FIREWORKS

Fireworks were invented in China in the seventh century. Its applications have since spread to other parts of the world and have been integral in many celebrations. Despite its long history, fundamentals of fireworks displays have remained largely the same over time. Aerial shells, mines, comets and variants form the main display components. Fireworks can be classified broadly into two main groups.

The first group, aerial shells, is built with a time fuse, lifting charge, bursting charge and pyrotechnic chemicals. Aerial shells are launched from mortar tubes into the sky using gunpowder as a lifting charge before bursting into displays of brilliant and colourful lights. The brilliant colours are created from the combustion of metallic powders. The appearance, component and effects of an aerial shell are illustrated in Figure 2.

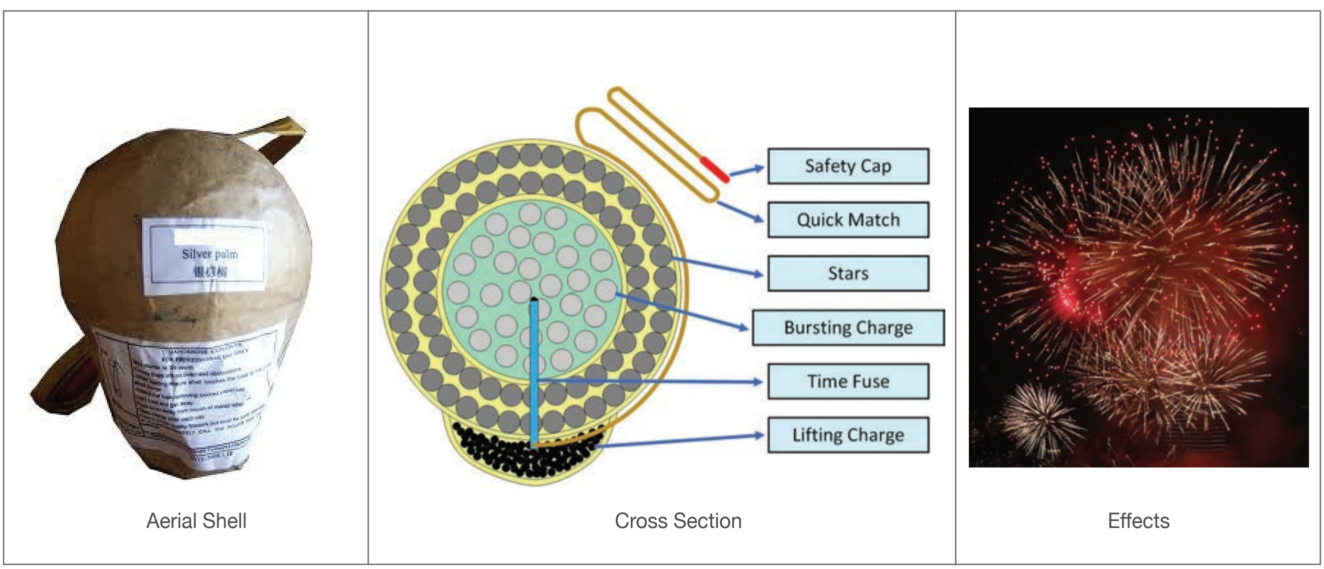

Figure 2. Aerial shell

Comets and Mines

Effects of Comet

Effects of Mine

Figure 3. Comets and mines

The second group comprises only lifting charge and pyrotechnic chemicals. The effects are ejected from the ground upon ignition. Examples are comets and mines as shown in Figure 3. Both types of fireworks can be customised to produce different colours, patterns and brilliance.

CHALLENGES

The NDP fireworks display is the largest fireworks event in Singapore and an important component of the parade's choreography. There are several rehearsals leading up to the final event, and any mishaps would have significant impact due to the fireworks' proximity to performers and spectators. Therefore, the safety review of NDP fireworks display is important to ensure safety of the public, performers and fireworks technicians while meeting the demands of the parade. The numerous stakeholders, regulations and site constraints (including weather conditions) add to the complexity. From the start, the team addresses the intrinsic safety of the fireworks product and its compliance with regulatory requirements. The team reviews the industry safety practices constantly during the preparation, setup and display of the fireworks. The established safety codes of the *US National Fire Protection Association for Display of Fireworks and British Pyrotechnic Association* serve as baseline safety requirements. The Singapore Armed Forces (SAF) and DSTA also engage established practitioners to provide training to reinforce understanding and ensure alignment with best practices.

ENSURING PRODUCT SAFETY

Fireworks must be designed and constructed to be safe during handling, transportation and use. In May 2000, a fatal explosion occurred during a fireworks display at Bray Park, Australia. Three ground fireworks exploded and ruptured the steel launcher tube, leading to one fatality and seven injuries. The investigation concluded that the fireworks malfunctioned. The explosion effect was worsened by its confinement within the steel tubes.

The team ensures product safety by sourcing fireworks from reputable manufacturers with strong safety track records of supplying fireworks to major international events. The team also requires the manufacturer to be certified by their local authority and registered with a US based independent auditor – the *American Fireworks Standards Laboratory* (American Fireworks Standards Laboratory, 2011). The manufacturer must also be ISO 9001 Quality Management System compliant. Furthermore, the team conducts factory assessments to observe the production process and test the product performance and safety features of the fireworks.

HAZARD CLASSIFICATION OF FIREWORKS

In 2000, the Netherlands had a major fireworks accident within the city of Enschede. The fireworks explosions were equivalent to 4000kg to 5000kg of high explosives[2]. It resulted in damage amounting to more than €450 million. This incident was a stark reminder that fireworks could behave like high explosives, and resulted in a review of the hazard classification of fireworks. The use of correct hazard classification enables appropriate safety protocols to be enforced during storage and transportation. In 2005, the United Nations (UN) published a method to determine the hazard classification of fireworks based on chemical composition.

The fireworks classification system assigns the hazard category of fireworks based on two key criteria: the diameter of the fireworks and the proportion of flash composition used in the fireworks. Flash composition is a mixture of pyrotechnics chemicals that reacts more vigorously to produce a bursting or explosion effect. It typically consists of an oxidiser, a non-metallic fuel and a metallic fuel. An excessive proportion of flash composition in fireworks will result in a violent explosion in the event of an accident. The diameter of fireworks determines the mass of pyrotechnics chemical that will combust instantaneously. As the diameter increases, the combustion effect becomes greater and can increase the likelihood of a violent explosion.

Using the UN fireworks classification system, the team reviewed the chemical composition of all fireworks used in NDP and identified those which can potentially explode if an accident occurred during storage or transportation (Russell, 2009). These items were isolated and stored with sufficient safety distances to the surrounding sites. They were also transported separately and prepared to prevent sympathetic explosions[3] should an accident occur. At the firing site, they were installed into the launching tubes at the earliest opportunity so that accidental ignition would launch the fireworks into the sky instead of causing an explosion of stacked fireworks (see Figure 4).

SAFE DEPLOYMENT

Fireworks are stored in licensed explosive storehouses in Singapore. Before each display, the fireworks are unpacked, inspected and moved to the firing locations. The firing circuits are then installed and tested. Since NDP 2011, fireworks have been launched from a barge in Marina Bay and around the floating platform. There were also fireworks launched from performers' personal equipment like motorcycles and torches. Figure 5 illustrates the setting up of aerial shells at the barge. The surroundings are checked after each display for fireworks that have failed to launch or dropped prematurely. The cause of each defect is investigated and the faulty fireworks are disposed of.

Figure 4. Barge for firing aerial fireworks, 2014

Figure 5. Workflow of aerial shells at barge

SPECTATORS SAFETY

Fireworks produce debris that could hurt people within the vicinity (see Figure 6).

There could also be fallout hazards from malfunctioning fireworks such as the bursting of aerial shells on the ground after they fail to ignite in the air and the improper mounting of fireworks leading to the wrong orientation when fired.

Cardboard Base of Shell | Plastic Whistling Component | Cardboard Debris of Comet

Figure 6. Examples of debris from fireworks

The team reviewed international best practices to determine the optimal safety distance and adopted the UK approach which calculates the safety distance based on various factors at each fireworks display scenario (Smith, 2011). The aerial shell safety distance considers the size of fireworks, firing angle and wind conditions. The size of an aerial shell determines the launch velocity and air-burst diameter. The firing angle, wind direction and wind speed would determine the trajectory of the aerial shell during the initial flight and the dispersion of debris after the air-burst.

The team also developed a wind chart to help the Fireworks Committee address the impact of different wind conditions on the safety distance (see Figure 7). The wind chart shows the maximum wind speed in each direction for different sizes of fireworks shells (see Figure 8). The wind conditions are monitored in real time and the committee can inhibit selected fireworks if the wind speed and direction threaten to exceed the safe limits. This ensures that fireworks displays remain safe for the performers and spectators around the barge at all times.

In addition, the team ensures that all materials used in the construction of the aerial shell are combustible. Most of the material will be burned to ashes during the bursting of the aerial shell, minimising the amount of debris falling to the ground. The installation and positioning of fireworks mortar tubes are also scrutinised to mitigate the hazard of launching the shells into the spectators.

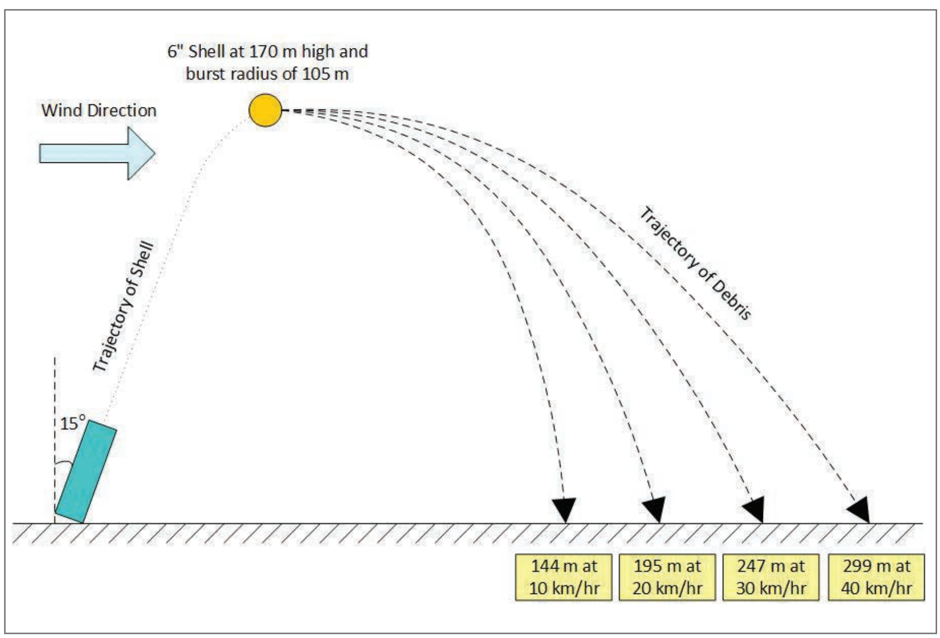

Figure 7. Possible fallout distance at various wind speeds

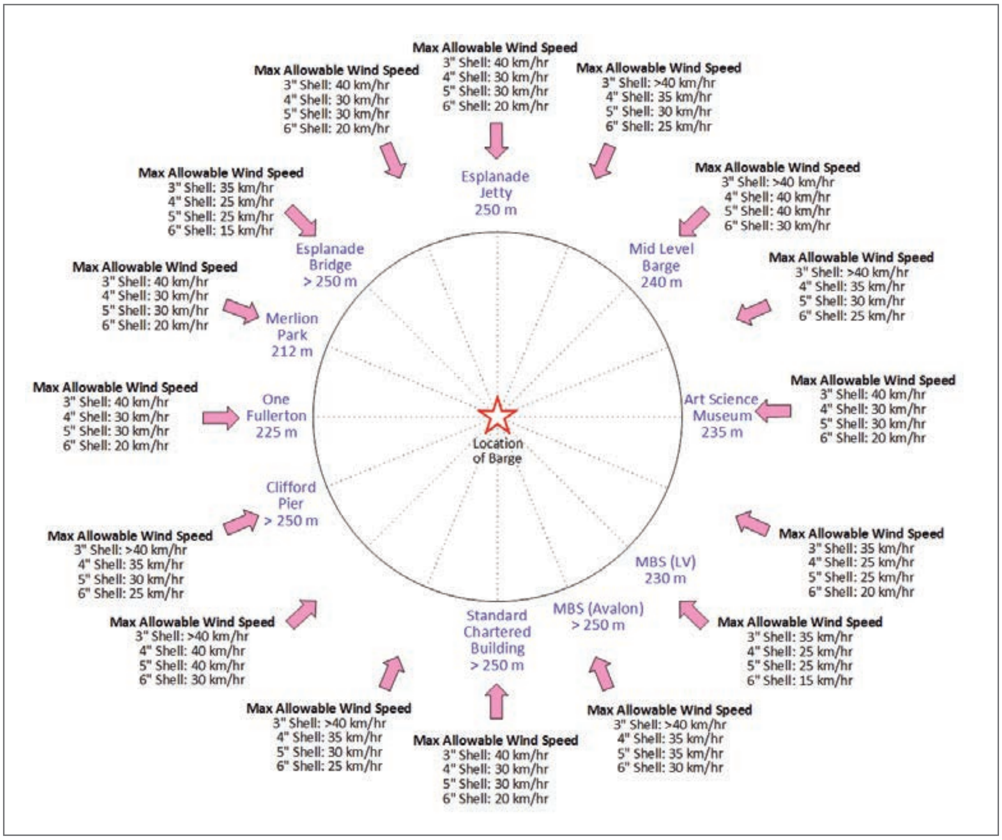

Figure 8. Wind chart around high level barge in Marina Bay, 2014

PERFORMERS SAFETY

Fireworks are used by performers in several segments of the NDP as pyrotechnic props. In 2012, these segments included the Singapore Soka Association performance, SAF Military Police precision drills and motorbikes ride-past. To ensure performers' safety, the team participated actively in the choreographies so that the fundamental safety principle of maintaining safety distance is integrated into the performances.

For performances that require hand-held pyrotechnic torches, fireworks that do not ignite clothing are used. The performers are equipped with protective eyewear, headgear and fire-resistant clothing to further mitigate the risk of burns. The team also worked with the show choreographer to ensure that the amount of fireworks required to meet performance requirements was kept to a minimum.

The pyrotechnics torch was designed to ensure that its parts do not hurt performers. The firing circuit for the pyrotechnics torch incorporated master and safety switches. This design required the performer to make two simultaneous actions to ignite the fireworks effect so as to avoid accidental ignition.

SYSTEM SAFETY APPROACH

The team took a system safety approach to ensure and enhance safety in dealing with the fireworks effectively. The priority was to use safe configurations (through appropriate safety design protocols) before providing protective devices, warning devices and relying on procedures. Some of the considerations taken during the NDP illustrate this approach.

a) Display Design and Configuration – During the grand finale which takes place at the platform and spectator stand, mines and comets are fired away from spectators and performers. Only fireworks without hazardous debris are used on stage. Performers are allowed to use only fireworks which produce harmless sparks.

b) Protection - Performers put on goggles and fire-resistant costumes to further mitigate the risks of burns. Parts of the stage which are affected by smouldering debris are constructed with fire-resistant materials.

c) Warning - A monitoring device is used to measure the wind speed and direction throughout the show. When wind conditions exceed safe limits, the firing of select aerial shells would be curbed.

d) Procedures - Fireworks safety distances are integral to the choreography of the show. The control tower monitors performers' compliance and can cease firing in the event of deviation.

The four levels of risk mitigation are standard observations of the system safety approach.

RISK ENDORSEMENT AND ACCEPTANCE

A Ministry of Defence Safety Board assesses the risks posed by NDP fireworks in accordance with the risk management framework established for NDP fireworks display. The residual risks, which are reduced to as low as reasonably practicable, are then accepted by the NDP Executive Committee. Subsequently, the team monitors the fireworks performance during each rehearsal and on the actual parade to ensure that the control measures are effective.

CONCLUSION

The team recognises the benefits of the systematic hazard identification and risk management approach in managing the complex demands of the NDP fireworks display. It has adapted safety knowledge on military explosives for fireworks display successfully. The safety controls imposed on military explosives are used when applicable to enhance the safety of storage, transportation, preparation, firing and disposal of commercial fireworks.

The system safety approach enables the team to identify possible hazards that are beyond product safety and regulations. It allows the team to prescribe measures to minimise risks to the public, performers and fireworks technicians. This ensures safe fireworks displays during all NDPs, from rehearsals to the grand finale on National Day.

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ENDNOTES

[1] System safety perspective means the safety review of the interfaces among the fireworks products, display sites, display operators, equipment, installation, weather, NDP performers and the general public.

[2] High explosives are substances or mixture of substances which can detonate under normal conditions.

[3] Sympathetic explosion is the simultaneous initiation of an explosive charge by a nearby explosion.

BIOGRAPHY

SIM Gim Young is a System Manager (Systems Management) managing the operations and support for explosives and pyrotechnics in the Singapore Armed Forces (SAF). In 2013 and 2014, he led the DSTA team supporting the National Day Parade (NDP) Fireworks Committee in assessing the safety of fireworks display. He also conducts quantitative risk assessments on explosive sites and advises on the risk mitigation measures. Gim Young graduated with a Bachelor of Engineering (Mechanical Engineering) degree from Nanyang Technological University in 2008.

LEE Chung Kiat is Head Explosives Safety (Systems Management). He is a licensed authority on military explosive facilities and advises the SAF on explosives storage and transport safety. He is also the Chairman of the Explosives Safety Technical Sub-Committee of Explosives Fire and Chemical Safety Committee. Chung Kiat graduated with a Master of Science (Explosive Ordnance Engineering) degree from Cranfield University, UK in 2005.

OEI Su Cheok is a Senior Principal Engineer (Systems Management). He develops and implements the safety management system for DSTA and the Ministry of Defence (MINDEF). He also supports system safety analysis efforts to enhance safety through risk mitigation. Su Cheok extends his safety management competence beyond DSTA in his roles as secretariat of MINDEF's Weapon Systems Safety Advisory Board as well as an executive committee member of the International System Safety Society (Singapore Chapter). He graduated with a Bachelor of Engineering (Chemical Engineering) degree from the National University of Singapore in 1985.

ME5 ONG Woei Leng is one of the Commanding Officers of SAF Ammunition Command. He is responsible for the safe storage and maintenance of ammunitions kept in the depot as well as the daily operations of the depot. He was previously a staff officer in the Explosive Safety Branch in the SAF Ammunition Command. As the Deputy Chief Safety Officer and Chief Safety Officer for NDP 2011 and 2012 respectively, Woei Leng ensured the safe conduct of the fireworks display during the shows. In NDP 2014, he served as the Deputy Chairman of the Fireworks Committee. Woei Leng graduated with a Bachelor of Arts (Psychology) degree from the Edith Cowan University, Australia, in 2010.