

KIMBOLTON FIREWORKS LTD

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A Study of Shell Failures and Mortar Rack Construction Methods

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METHODOLOGY

1. Shell burst patterns, 75mm to 200mm
2. Shell Failures inside mortar tube, 75mm to 150mm
3. Separation distances between tubes
4. Mortar Tube Racking Methods
5. Recommendations /Conclusions



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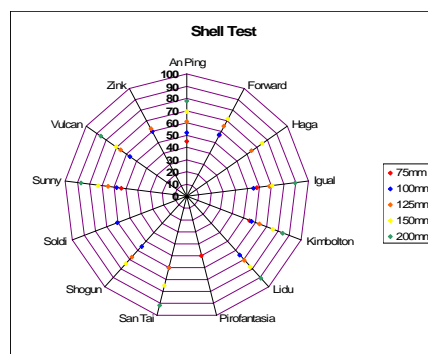
SHELL BURST PATTERNS

- The first test involved the ignition of various shell sizes on the ground to establish the distance the stars travelled.
- We tested a wide range of shell types from 75mm up to 200mm.
- Each shell size tested included a selection of various types of effects from the following manufacturers, An Ping, Forward, Haga Premium Brand, Igual, Kimbolton, Lidu, Panzera, Pirofantasia, San Tai, Shogun, Soldi, Sunny, Vulcan and Zink.
- The effects tested ranged from chrysanthemum and peony shell bursts to pattern effects, palm shells and polyp shells containing large comets.



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SHELL DEBRIS PATTERN DIAGRAM



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SHELL FAILURES INSIDE MORTAR TUBE

- Shell Failure was achieved by testing a single detonation of a shell whilst still in the mortar tube.
- The test was conducted by firing a single shell loaded in the mortar tube with the lifting charge removed. The shell was ignited remotely.
- Shell sizes tested ranged from 75mm to 150mm
- The mortar tube was attached to an upright wooden stake at our airfield test ground.
- We tested various shell types and sizes from all manufacturers which Kimbolton Fireworks stock.
- The test also included various mortar tube, including Paper or Card, HDPE and Fibreglass. (Steel mortar tubes were discounted due to the widely held view that they are not a suitable construction method for mortar tubes because of possible fragmentation).



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OBSERVATIONS

We observed the following results:

- No 75mm shell tested breached the mortar tube (flower potted). Maroon shells were tested and a full breach of the mortar tube resulted.
- Most 100mm shells tested did not breach the mortar tube (flower potted). Some shell types did breach the mortar tube, in particular multi break report shells from Soldi and some Lidu shells.
- Most 125mm shells resulted in a mortar tube breach but not all. Not all the failures resulted in a complete destructive breach.
- Most 150mm shells failed resulting in a full breach of the mortar tube, in some cases a full destructive breach was recorded.
- HDPE tubes were regarded as the strongest construction, however breaches were recorded by some shell types at 100mm, 125mm and 150mm.
- Card mortar tubes were found to be most likely to breach in premature detonation.



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RECOMMENDATIONS & CONCLUSIONS

The following conclusions were made from these tests.

- 75mm shells fired from fibreglass or HDPE mortar tubes did not result in a breach of the tube.
- 75mm maroons did breach all types of mortar tube to varying degrees. It is Kimbolton Fireworks policy to bury all mortar tubes containing maroons of any size in the ground or in steel drums filled with sand.
- 100mm round shells did not result in a significant breach of the mortar tubes made from fibreglass and HDPE. It is Kimbolton Fireworks policy to fire any cylindrical shell or any shell with report effects from HDPE mortar tubes.
- Due to the fact that 125mm and 150mm shells recorded a higher rate of mortar tube breach it was concluded that further tests should be conducted to establish the effects of these breaches on adjacent tubes and more importantly the racks which hold them.
- Card mortar tubes were regarded as the least reliable and resulted in the most destructive breaches. Kimbolton Fireworks are phasing out card mortar tubes.



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SEPARATION DISTANCES BETWEEN TUBES

After further tests we established that prematurely detonating 125mm and 150mm shells posed a risk to adjacent tubes and the rack construction. We conducted further tests to establish what separation distances should be incorporated to prevent a shell failure in a mortar tube from igniting a shell loaded in an adjacent Mortar tube.

- This test was conducted using our oldest fibreglass mortar tubes. The donor shell was ignited and detonated in the base of the tube by removing the lifting charge (as opposed to putting the shell in upside down).
- The tests were conducted on both 125mm and 150mm shell sizes of varying types and effects.
- The tests involved three mortar tubes each secured to a wooden stake. The donor shell was ignited in the centre mortar tube. The two tubes adjacent on either side were loaded with live shells of normal construction with the leader fuse coming up to the top of the mortar tube.
- The first test was conducted by placing the two test mortar tubes up against the donor tube with no separation distance. The test was then repeated a number of times by increasing the distance between each tube by a factor of 25mm each time.



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OBSERVATIONS

- 125mm shells did not always breach the mortar tube and the effects simply flower potted.
- When a breach did occur occasional communication to the adjacent tube was recorded. A separation distance of 100mm reduced the frequency of communication to the adjacent tube.
- Most 150mm shells breached the mortar tube.
- Some breaches with 150mm shells resulted in communication to the adjacent shell when there was no separation. A separation distance of 150mm significantly reduced the frequency of communication to the adjacent shell.



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RECOMMENDATIONS & CONCLUSIONS

- A separation distance between 75mm shells and 100mm shells was not a requirement, however it would be advantageous. Kimbolton Fireworks have a policy of introducing a separation distance equal to the half the shell diameter in all our 75mm and 100mm racks, especially due to the high frequency of firing these size of shells in bouquet's matched in pairs or 3's.
- 125mm shells rarely resulted in communication to the adjacent tube, however the frequency is high enough to require some sort of separation. Kimbolton Fireworks policy has been to introduce a separation distance of 175mm between tubes.
- 150mm shells did result in communication to the adjacent tube where no separation existed, but not in all cases. Kimbolton Fireworks policy has been to introduce a separation distance of 200mm between 150mm tubes.
- The separation distance between tubes achieves two results; firstly the likelihood of adjacent tube being disrupted is significantly reduced, secondly the likelihood of communication to an adjacent tube is significantly reduced.
- While the frequency of communication was high it is important to note that the frequency of a shell detonating in the tube is very rare, Tom will cover this later on.



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TRADITIONAL RACKING METHODS 100mm



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TRADITIONAL RACKING METHODS 150mm



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MORTAR TUBE RACKING METHODS

- The first test involved an assessment of the more traditional type of racking system, firstly a wooden crate consisting of 5 x 150mm fibreglass tubes side by side.
- We then tried the similar test using the same style of crate containing three mortar tubes offering separation distances of 200mm between tubes.



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MORTAR TUBE BREACH



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MORTAR TUBE SQUARE RACK STEEL

- The second style of racking tested was a square rack containing 9 tubes in a 3 x 3 configuration.
- The rack consisted of a plywood top with 150mm holes drilled through it allowing the mortar tubes to be dropped through from the top. The base of the frame was made of a steel grid structure which allowed for the separation of the tubes at 200mm distance.



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MORTAR TUBE SQUARE RACK STEEL



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MORTAR TUBE SQUARE RACK WOOD

- The third method of racking tested was similar to the second but consisted of wooden racks top and bottom rather than a steel frame for the base.
- Each tube is separated by 200mm in any direction and contains a total of 9 tubes.
- The rationale for this style of rack was to eliminate the steel element and thus avoid the risk of metallic fragmentation.



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MORTAR TUBE SQUARE RACK WOOD



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LADDER RACK CONSTRUCTION

- The fourth style of racking tested is what we refer to as the ladder rack. The rack consists of two rows of 8 tubes separated by 200mm distances between tubes.
- Two racks side by side total 32 tubes which is the number of cues of a Fireone module.
- The rack is relatively light weight and can be transported flat packed, the length fits in to the rear of a standard transit van.



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LADDER RACK DAMAGE



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LADDER RACK DAMAGE



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MORTAR TUBE CATCHING METHODS

- Kimbolton Fireworks have also conducted a number of tests to establish what type of catchers can be introduced to further reduce the risk of hazard from a displaced mortar tube.
- This type of arrangement is only used on certain types of displays where for example on large displays, the finale sequence may consist of large bouquets of shells fired in quick succession from one position.
- In this instance a herras fence surrounding the firing position where the audience are orientated can reduce any hazard. The use of a catcher and the type or construction must be assessed individually by each company.



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RECOMMENDATIONS

- Fibreglass mortar tubes are believed to be of sufficient strength to perform the task required for firing mortar shells.
- All maroons should be fired from single mortar tubes, preferably buried and not racked with other shells, especially other maroons.
- It is recommended to use stronger HDPE tubes for multi break and cylindrical shells and shells with flash or report effects.
- 75mm and 100mm shells do not significantly breach the mortar tube and during testing did not drastically affect the rack they were contained in.
- 125mm and 150mm shells which are contained in racks should contain separation distances between tubes.
- Open styles of racks similar to the ladder rack which effectively hold each tube individually allow the forces involved to dissipate and significantly reduce the risk of adjacent tubes being affected from a mortar failure.
- Traditional style mortar racks for 125mm and 150mm shells are flawed and will largely result in a failure of the rack affecting the trajectory of adjacent mortar tubes.
- It is recommended that 200mm plus mortar tubes should be individually buried and separated by a reasonable distance.



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CONCLUSIONS

- There is little any of us can do to prevent a shell failure, or indeed the frequency of a shell which detonates inside the mortar tube. What we are trying to achieve is to minimise the impact of a premature detonation and therefore reduce the risk that such an event might affect adjacent tubes and the racking system.
- In conclusion we believe the ladder rack is a suitable solution to minimising the risk of a shell failure in a mortar tube causing a destructive failure of the mortar rack affecting the stability of adjacent tubes.
- The ladder rack design effectively introduces two separate methods of support for the mortar tubes, with the top section and bottom section.
- The tests demonstrated that in the event of a shell failure and destructive breach, only one section is likely to be significantly damaged, not both, i.e. the bottom section may be destroyed in part but the top section will largely remain intact.
- In this instance, even in the unlikely event of major destruction to one section of the ladder rack, the remaining section will provide significant support for the mortar tubes to remain almost vertical.



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CONCLUSIONS

- The design and construction of the rack has (to the best of our research capability) proven that even with a significant destructive breach the structure of the ladder rack remains in tact and the remaining tubes will remain upright and significantly supported.
- The separation distance reduces the risk of communication of one shell failure propagating to an adjacent tube leading to multiple shell detonations, which could lead to a higher risk of some or all of the tubes in the rack being affected, where their trajectory could compromise the safety of operators or the audience.
- The separation distances introduced also reduces the risk of a live shell contained in a disrupted tube actually being ignited. Even in the unlikely event that an adjacent tube is knocked over the forces and flames will not breach the tube igniting the shell contained in the disrupted tube. (this is not the case for shell chains linked using pyrotechnic delays or shells independently fired by an automated firing sequencer or computer fired display).



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