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# Floating Dud Aerial Shells

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## Introduction

Over the past 25 years, the percentage of spherical aerial shells that fall to the ground as duds after firing has substantially decreased. (This is especially true for shells from China.) Obviously this is a good thing, and it is a result of such things as improvements in the quality of the time fuses being used and the methods of their priming, and because of the near universal adoption of redundant fusing techniques.[1] However, the improvement has not been so great as to reduce the percentage of dud shells to zero. Nonetheless, the reduction in the number of dud shells, in conjunction with the use of substantially increased separation distances introduced approximately 15 years ago,[2] combine to afford a high level of spectator protection from dud shells during typical displays.[3,4] Further, the increased attention to dud searches both immediately following and at first light on the morning after land-based displays has mostly eliminated accidents resulting from dud shells left behind to be found by children.

With the reduction in the number of dud shells and the virtual absence of accidents from unrecovered dud shells from displays fired over water, it is appropriate to ask why a study of floating dud shells was undertaken. In part the answer is that: nearly all dud shells do float for a period of time after landing in water; dud searches are essentially never done for displays fired over water; most dud shells are virtually impossible to find in water at night, and by the next morning they will have drifted some distance from where they fell; and even after a shell eventually sinks, its pyrotechnic contents will generally remain viable or will become viable again after minimal drying. Thus, in part the answer is that there is potential for a serious accident resulting from unrecovered dud shells from displays fired over water, and it is hoped that this study and article will raise awareness of this potential.

However, it must be acknowledged that a significant impetus for this study was simple curiosity. It was of interest to determine, for typical non-plastic spherical aerial shells: the percentage of shells that initially float; for those floating shells, how much of their volume remains above the water's surface and how long before they eventually sink; and even after sinking, how likely is it that their contents have remained pyrotechnically viable? According, a brief study was undertaken in an attempt to satisfy this curiosity.

## Results

A collection of 26 aerial shells (3 inch through 6 inch) were devoted to this study, none of which had a plastic casing. Of these 26 shells, only one sank immediately (i.e., was initially more dense than water). For those shells that initially floated, the percentage of each shell's volume above water was determined by comparing its volume, as calculated by its average diameter, with its measured mass. The result was that the 25 shells floated with 1 to 34 percent of their volume above the water's surface. The average volume above water was 17 percent, with a one-sigma standard deviation of 10 percentage points. Accordingly, with relatively little of the shells' volume above the water, such floating shells will be difficult to spot, even in completely calm water.

The first group of 19 shells to be tested had their time fuses intact, as though their time fuses had failed to ignite when the shells were fired, or had only burned for a short portion of their length before extinguishing. These shells were placed in water in an environmental chamber held at 70 °F, a temperature thought to be reasonably representative of northern lakes in early to mid summer. In this study, for the most part, the shells were not agitated during the period of their floating, contrary to what would typically occur because of wave action on real bodies of

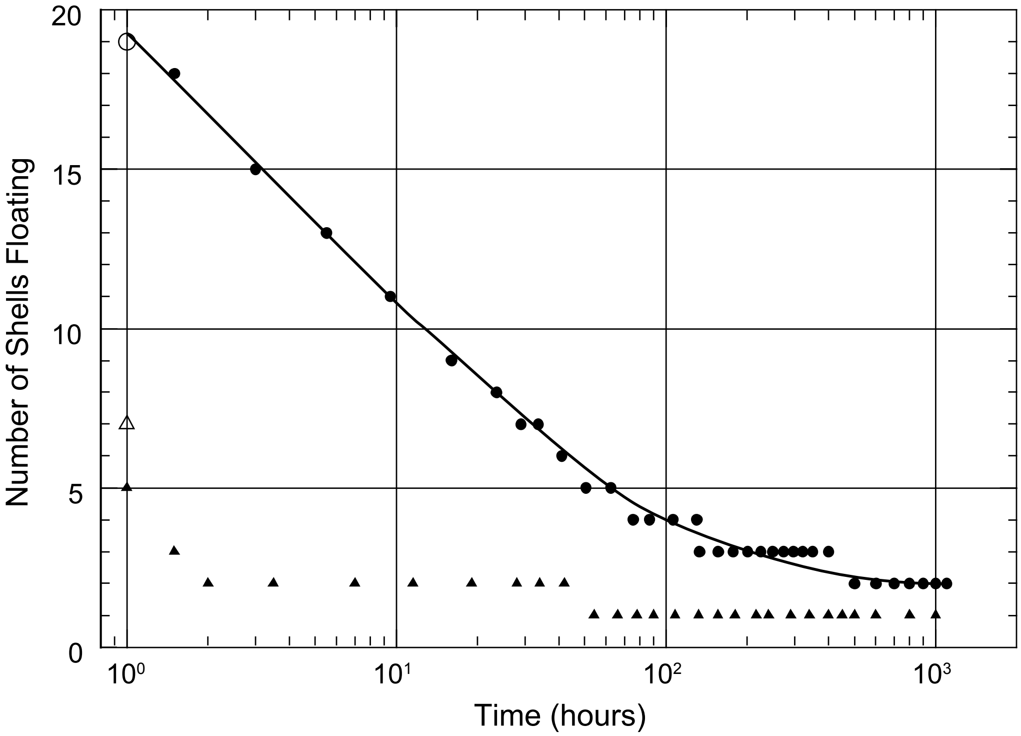


*Figure 1. Number of shells floating as time progressed. (Note that time is plotted using a logarithmic scale.)*

water. However, at the time of each shell inspection, each floating shell was momentarily submerged a few times using simple hand pressure. For the most part this bobbing of the shells was to confirm that they were still freely floating, but it was also done to introduce a minimal amount of agitation. It must be expected that the near total lack of agitation slowed the process leading to the shells' sinking. Further, for these tests, the total volume of water used was approximately 4 times that of the shells being tested. Although not as significant as the lack of agitation, this too must have slowed the process of sinking, because of a slightly reduced rate of glue dissolution. Finally, the relative humidity in the chamber was 100 percent. This, combined with the occasional dunking of the shells, possibly hastened their sinking slightly. While it is unfortunate that the conditions in this study were not those for shells actually floating in large bodies of water, this was mostly necessitated for practical reasons. Nonetheless, the results from this study still provide a useful approximation of typical shell float times, albeit somewhat of an upper limit.

The float times found for these test shells, under the conditions of this study, are presented in Figure 1 (solid dots). However, since the shells were not being monitored continuously, the precise times of their sinking are not known. The times reported in Figure 1 are for the midpoint between pairs of observations. Accordingly, when 18 shells were found to be floating one hour into the test, but only 17 were floating at two hours, the sinking was reported as happening at 1.5 hours into the test. Also in Figure 1, as a matter of convenience, the number of shells at the start of the test is plotted as an open dot at a time of one hour ($10^0$), even though one shell sank immediately. During the first couple of days of the testing, the number of floating shells decreases logarithmically. Also note that approximately 10 percent of the shells never did sink, even after 48 days at which time the test was ended.

In general, the shells that sank within the first day or two, more-or-less came totally apart, with the pasted wraps coming completely free from the inner hemispherical casing. Those shells that floated longer, for at least a couple of days, generally stayed mostly intact and seemed to have sunk because of moisture penetrating to their interior and accumulating there. A few of these shells appeared to have been coated with a water resistant coating, but most seemed to have been made using a somewhat water resistant adhesive for the pasted wraps.

Not shown in Figure 1 is the fact that one shell, which sank approximately 500 hours into the test, surfaced again within approximately another 100 hours. The resurfacing of the shell seemed to be fairly obviously the result of gas production within the shell as evidenced by the appearance of tiny bubbles. Also the two shells that never did sink appeared to be producing gas internally. For several of the floating and sunken aerial shells, gas production seemed to be the result of biologic activity, presumably from bacterial growth within the paste wraps of the shell. While not confirmed, this is consistent with previous electron microscope observations of what appeared to be several forms of microbial entities, frequently seen associated with the paste on completed aerial shells. In other cases, gas production seemed to be the result of water reactions with metal fuels in the stars of the shells.

A second smaller set of 7 aerial shells was also tested. These shells had the powder core of their time fuses carefully drilled out, in an attempt to simulate dud shells for which their time fuses had burned completely, but the fuse had failed to successfully ignite the contents of the shell. Other than the drilling of their time fuses, the remaining test conditions were not changed from those reported above. The results of this second test are also reported in Figure 1, this time as solid triangular points. As expected, these shells seemed to sink at a faster rate than those with intact time fuses. However, because the number of shells tested was rather small, how much faster the sinking would typically occur it is not clear. Nonetheless, one clear result is that, as for the first series of tests, some shells must still be expected to float for extended periods of time.

The condition of the pyrotechnic content of several shells was inspected after their sinking, and the contents were tested for viability. The inspections took place anywhere from a few hours to 4 days after the shell's sinking. In essentially all cases, the contents remained pyrotechnically viable, either immediately or after a relatively short interval of drying. The viability test consisted of attempting to ignite the stars or break charge with a propane torch. In a few cases, the contents were readily ignitable (ignited after less than one second of exposure to the flame). In other cases the contents failed to ignite within a second but ignited within a few seconds. Even when the contents would not initially ignite, they returned to a viable state after a day of air drying. The above observations were for stars were made using a water-soluble binder. In a few cases, it appeared that the stars had been made using a nonaqueous binder. Of course, the viability of these stars was not significantly affected by their exposure to moisture.

## Conclusion

Thankfully, it cannot be said that the failure to search for and retrieve dud shells from fireworks displays fired over water, represents a major safety problem. Because so little of the shells remain above water, it cannot be seriously argued that a nighttime marine search is likely to find many (any?) dud shells. Further, those dud shells that do not sink overnight are likely to be relocated some distance from the fallout area of the display as a result of wind and water currents. Thus, a first light search the morning after a display is also not likely to find many (any?) dud shells in the fallout area. Nonetheless, because there is potential for a problem with non-sinking dud shells, it is difficult to argue that absolutely nothing should be done.

One possibility, at least for non-river fired displays, is to search the shoreline in the downwind direction on the morning after the display. (For ocean-fired displays, consideration will need to be given to the direction of any along shore currents.) At least, such a search could be performed fairly quickly, because any dud shells will tend to be concentrated immediately along the shore and because of the relatively limited length of shore line needing inspection. For river-fired displays, there seems to be little that might be done to locate floating duds. However, one potential solution for any over-water display would be to only use shells that can be expected to sink well before dawn. Accordingly, any shells with a painted or varnished exterior would not be suitable. Further, shells that are pasted with water resistant adhesives would not be suitable. Unfortunately, the only sure way to identify rapidly sinking shells is to test the shells (or fragments from their exploded casings) by soaking them in water for a few hours and observing the result.

## References


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