An Evaluation of Lightning Thermo Tube™ As a Pyrotechnic Ignition System

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Abstract: *Lightning Thermo Tube (LTT) is a recently introduced type of shock tube with characteristics that make it highly suitable for use with common pyrotechnics. LTT is reliably initiated by reasonably energetic electric matches and reliably ignites most pyrotechnic compositions. LTT is physically strong, easily spliced and branched, and highly weather resistant. LTT produces a bright flash of light upon functioning, which may be useful in itself. This paper presents the results of a series of tests performed to determine some of the more important capabilities and characteristics of LTT as it relates to use with pyrotechnics in general and fireworks in particular.*

Keywords: *thermo tube, shock tube, pyrotechnic ignition system*

Introduction

Lightning Thermo Tube™ (LTT)[1,2] has recently been introduced to the US fireworks trade. The product is very similar in appearance to conventional shock tube.[3–5] However, because of the pyrotechnic used in its manufacture, it does not require the flame-to-shock and shock-to-flame converters that regular shock tube needs when used with typical pyrotechnics.[6] This makes it more convenient and cost effective to use with pyrotechnics than conventional shock tube. Fortunately, LTT retains the safety characteristics and the ease of splicing and branching of conventional shock tube.

This article reports on an initial brief evaluation of LTT for use with pyrotechnics, specifically fireworks and proximate audience pyrotechnics. However, because of the limited scope of this study, for the most part reliability issues are not thoroughly addressed. For example, LTT was definitely found to have the capability of being initiated with commonly used electric matches and with small exploding charges. A reasonably high level of reliability was found in ignition trials with one type of electric match, where 35 of 35 attempts were successful. However, because only a limited number of trials were run, it is not possible to state with confidence how reliably such initiation can be accomplished. In many other cases, because even fewer trials were conducted, the results are not statistically significant. Finally, all trials were conducted only under moderate environmental conditions (i.e., at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%); therefore, it is possible that the performance of LTT under more extreme conditions may be different.

The Product

A small coil of Lightning Thermo Tube (LTT) is shown in Figure 1. It is a thick-walled strong (high tensile strength) plastic tube, approximately 3 mm (0.12 in) in outside diameter and approximately 1.2 mm (0.05 in) in inside diameter. The inside of the tubing has been coated with a thin layer of pyrotechnic composition, which propagates an energetic chemical reaction and can ignite various other pyrotechnic materials. Also shown in Figure 1 are three short lengths of rubber tubing

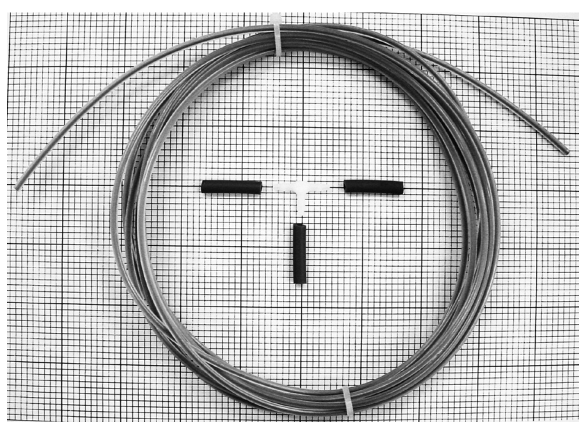

Figure 1 *A photo of a small coil of LTT and items used in coupling and splitting LTT. [Each small square is 2.5 mm (0.1 in).]*

and a small plastic tee that can be used to couple and branch the LTT.

The stable propagation rate of LTT was measured and found to be approximately 1100 m s^{-1} (3600 ft s^{-1}), which is reasonably consistent with its reported propagation rate of 1200 m s^{-1}.[7] This measurement was accomplished by video recording the propagation of a length LTT at the rate of 20,000 frames per second (see Figure 2).[8] (In Figure 2 and other figures of reacting LTT, the intensity of the light produced by the propagating LTT reaction in relation to the video camera settings was so intense as to give the false appearance that the diameter of the flash reaction greatly exceeds the diameter of the LTT tube.) Using these same video images, it was also determined that approximately 0.2 ms and approximately the first 200 mm (8 in) of propagation in the LTT were required before the propagation rate stabilized and the full intensity

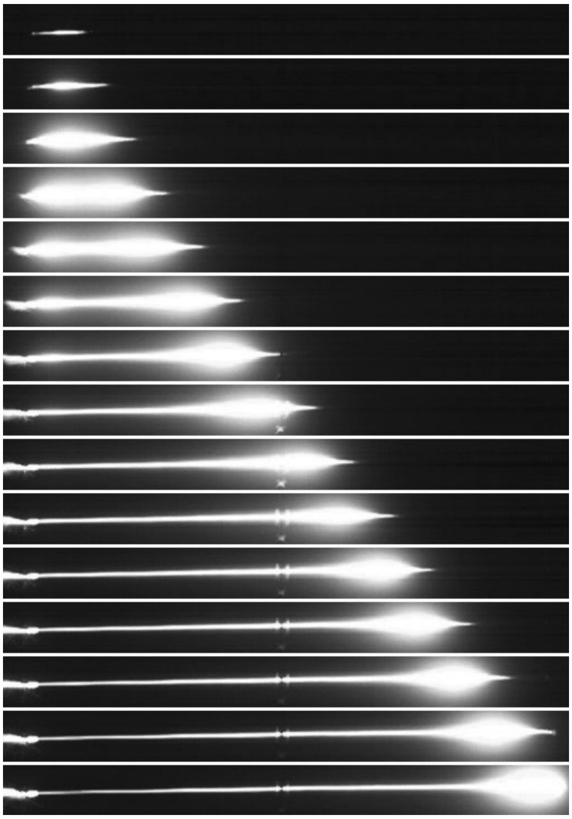

Figure 2 *A collection of 15 images of the propagation of LTT after initiation with an electric match. The elapsed time between images is 0.00005 s. (The image width is approximately 800 mm, 32 in.)*

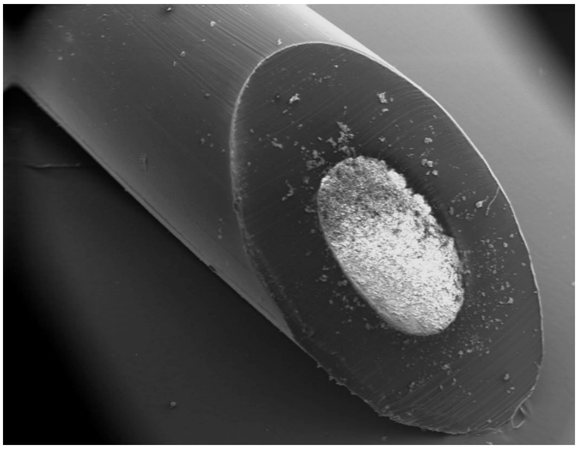

Figure 3 *An electron micrograph of a small segment of LTT cut at an angle of approximately 45° to better expose the powder coating on its interior wall.*

of the propagation was established when initiated with an electric match (Martinez Specialties' E-Max electric match[9]) using an 8 J capacitive discharge firing set. It is likely that the initiation method may affect the run-up distance but almost certainly not the steady state propagation rate.

Figure 3 is an electron micrograph of the end of a piece of LTT cut at a slight angle to better expose its interior for imaging. (Unfortunately in this two-dimensional image, the thin coating on the inside wall of the tubing somewhat gives the appearance that the inner bore of the tube is completely filled with composition.) The Material Safety Data Sheet for LTT[10] lists as its hazardous ingredients

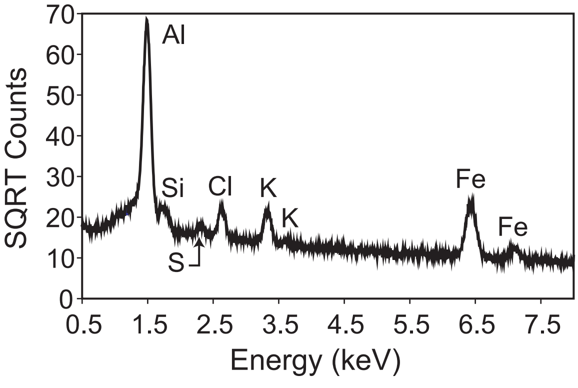

Figure 4 *The energy dispersive X-ray spectrum of a sample of LTT's interior powder coating. (SQRT Counts is the square root of the number of counts per energy channel.)*

Table 1 *Apparent chemical formulation of the internal powder coating used in LTT.*

Ingredient	Percentage
Aluminum	50
Iron(II–III) oxide	24.5
Potassium perchlorate	24.5
Talc	1

potassium perchlorate and aluminum. The energy dispersive X-ray spectrum (above an energy of 0.5 keV) of a sample of the powder coating (see Figure 4) also includes substantial peaks for iron. In comparing this information, the measured propagation rate for the LTT of approximately 1100 m s^{-1} (3600 ft s^{-1}), and information given in the US Patent upon which the LTT is apparently based,[2] suggest that the pyrotechnic composition of the interior wall coating is that given in Table 1.

Because the reported amount of pyrotechnic content is so low (8 mg m^{-1})[10] Lightning Thermo Tube is classed by the US Department of Transportation as "not regulated as an explosive" and can be shipped as non-hazardous material,[11] which is the same classification as for the plastic tubing without the pyrotechnic coating on its interior wall. Nonetheless, the US Bureau of Alcohol, Tobacco, Firearms and Explosives is requiring that LTT be sold only to licensees and that it be stored as a regulated material, including a requirement for record keeping.[7]

Figure 5 is one frame from a standard (NTSC) frame-rate video that demonstrates the projection of fire and sparks emanating from the end of LTT as it functions. The functioning thermo tube is seen as the narrow bright band at the extreme left in the image. The fire output from the LTT is seen to expand to a diameter of approximately 25 mm (1 in) and to extend to approximately 100 mm (4 in) to the right. The spray of sparks from the LTT, although not clearly visible in Figure 5, also projects to a distance of at least 200 mm (8 in) from the end of the thermo tube.

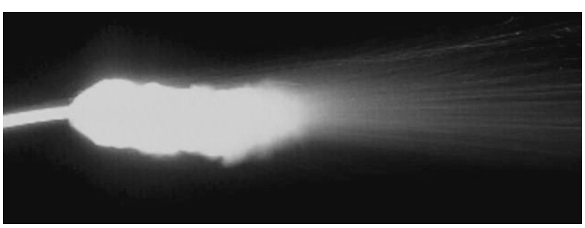

Figure 5 *A standard (NTSC) frame-rate video image of functioning LTT, where the total width of the image is approximately 250 mm (10 in).*

When conventional shock tube (charged with explosive composition) functions, the pressure developed within the tube will occasionally cause the tube to burst. (It will fairly reliably burst the tube when two nearly simultaneous shock waves are propagated from both ends of the shock tube to collide along its length.) This type of tube bursting was not observed for LTT during the trials that were conducted, even when opposing shocks were caused to collide within the tubing. (However, based on the limited testing being reported, it should not be assumed that LTT will never burst its tube.)

Similar to shock tube, the functioning of LTT can produce moderately loud sound. The sound pressure level (SPL) produced by the emerging shock front is approximately 145 dB (free field – peak – linear) measured at 1.2 m (4 ft) directly in line with the end of the LTT (i.e., at 0° to the axis of the LTT). Under the same conditions, but measured at 90° to the end of the LTT, the SPL was reduced to approximately 135 dB. The output (blast) from the end of the LTT is the primary source of the sound, as opposed to the sound radiating outward through the walls of the tube. Thus, when the ends of the LTT were sealed (or well muffled) the SPL did not exceed the background sound level in the laboratory at the time (i.e., approximately 90 dB).

Initiation Trials

A series of trials were conducted to determine what common stimuli tend to be capable of initiating Lightning Thermo Tube. In many cases only a limited number of individual trials were performed; thus one should not infer much about the reliability of the various methods. See Table 2 for a summary of the LTT initiation tests that were performed. (The order of the information in Table 2 is not the same as the order in which the trials were conducted.) Table 2 begins with three methods that were unsuccessful in producing initiations of LTT on every attempt, then two

Table 2 *Lightning Thermo Tube initiation test results.*

Test Conditions[a]	Initiations / Trials
Fall-hammer impact (5 kg hammer from a height of 1 m, 39.4 in)	0 / 10
Propane torch flame applied for five seconds (flame temperature was approximately 1900 ºC)	0 / 3
Fire spit from visco fuse coupled using inert tubing[b]	0 / 5
LTT installed into the wall of a discharging consumer fireworks mortar	2 / 4
Luna Tech BGZD electric match[12] coupled using tubing[c]	30 / 35[d]
Martinez Specialties E-Max electric match[9] coupled using tubing[c]	35 / 35
Spark gap using an 8 J capacitive discharge firing unit	30 / 30
Martinez Specialties E-Max electric match coupled using a Martinez Specialties Quick Fire VF Clip[13,c]	3 / 3
Martinez Specialties Exploding-Bridge-Wire initiator coupled using its attached inert tube and an 8 J capacitive discharge firing unit	3 / 3
Bare electric match tip (without any pyrotechnic composition) using an 8 J capacitive discharge firing unit	3 / 3
Approximately 50 mg of flash powder in coupling tube, ignited with visco fuse	3 / 3
CCI #209M shot shell primers in a shock tube firing apparatus[d]	3 / 3
Functioning shock tube coupled using tubing	2 / 2

[a] Trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. [b] Visco fuse is a thread wrapped black powder fuse approximately 2.5 mm (0.1 in) in diameter and is also called hobby, cannon and fireworks safety fuse. [c] The electric matches were fired using either an 8 J capacitive discharge firing set or one using a 5 V power supply. [d] The US distributor of LTT reports that this is the manufacturer's recommend method of initiation for LTT.

methods that worked with less than complete reliability, and finishes with a number of methods that were successful on every attempt.

The trials using fall-hammer impacts (0 initiations in 10 trials), the flame from a propane torch (0 initiations in 3 trials) and the fire spit from visco fuse (0 initiations in 5 trials) were all unsuccessful in initiating the LTT. The next stronger impetus tried was to mount the end of LTT through the side of a consumer fireworks mortar to fire a small aerial shell. The combined flame and modest pressure effect that was produced worked occasionally (2 initiations in 4 trials), but only when the aerial shell was propelled with significant force.

In the setup used to determine the capacity for initiation of LTT by electric matches and fuse, approximately 18 mm (0.75 in) of 3 mm (0.12 in) ID inert tubing was used to connect the initiation source to the LTT. The initiation source and the LTT were inserted into opposite ends of the tubing until contact was made between them. (See the upper two illustrations in Figure 6.) In the case where the initiation source was visco fuse augmented with a small flash powder charge, the coupling method was similar, except that the length of tubing was extended to approximately 32 mm (1.25 in) in length and a small amount (approximately 50 mg) of flash powder was added to the tubing between the initiation source and the LTT. (See the lower illustration in Figure 6.) The flash powder used in these trials was 70 : 30 potassium perchlorate and dark pyro aluminum (400 mesh).

The next stronger impetus tried was to use fairly mildly functioning electric matches (Luna Tech's BGZD electric matches.[12] The first 25 trials using these electric matches produced 25 successful initiations of the LTT. However, the last 10 trials only produced 5 successful initiations. At this time it is not known what the reason for this was (e.g., statistical chance or some difference in the electric matches or in the LTT). However, the

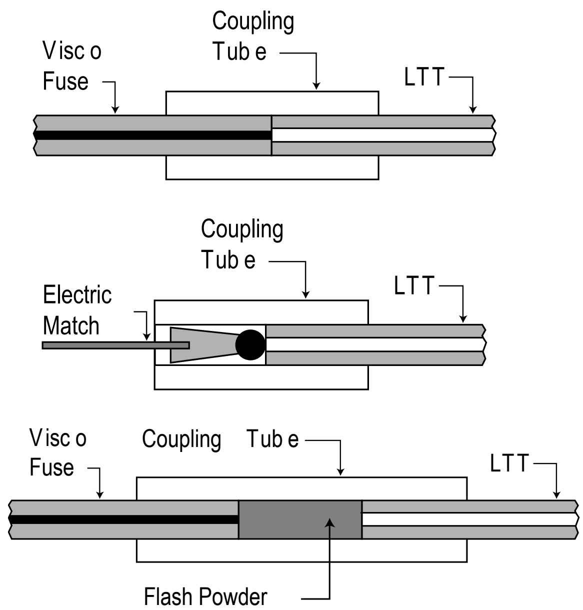

Figure 6 *An illustration of some of the methods used in trials for initiating LTT. Top, visco fuse coupled to LTT. Middle, electric match coupled to LTT. Bottom, visco fuse coupled to flash powder that is then coupled to LTT.*

Luna Tech electric matches are noticeably more mild in their functioning than are the Martinez Specialties matches that were also used.

The trials using various stronger initiation sources were all successful. These methods included the use of a more powerfully functioning electric match (Martinez Specialties E-Max electric match[9]) (35 initiations in 35 trials); capacitive discharge spark gaps[14] using an 8 J capacitive discharge firing set (30 initiations in 30 trials); an E-Max electric match coupled to the LTT using a Martinez Specialties Quick-Fire VF clip[13] (3 initiations in 3 trials); commercial exploding bridgewire initiators (Martinez Specialties) using an 8 J capacitive discharge firing set (3 initiations in 3 trials); hand-made exploding bridgewire initiators (a bare electric match tip, without any pyrotechnic composition) using an 8 J capacitive discharge firing set (3 initiations in 3 trials), small charges of fireworks flash powder (3 initiations in 3 trials), CCI #209M shot shell primers using a commercial shock tube firing appliance (3 initiations in 3 trials) and functioning commercial shock tube (2 initiations in 2 trials).

LTT Coupling Methods

One of the standard (and effective) methods used to couple lengths of shock tube is to insert the ends to be joined into a short length of inert tubing. (This coupling method is demonstrated in the top photograph of Figure 7.) Providing the two ends are reasonably close together inside the coupling tube, communication of the shock reaction seems

Table 3 *A summary of the results from the testing of LTT coupling methods.*

Test Conditions[a]	Successes / Trials
Direct contact, end to end coupling using inert tubing[b]	30 / 30
Coupled using metal compression fittings[c]	1 / 1
Coupled using plastic compression fittings	5 / 5
Coupled through ≈ 18 mm (0.75 in) inert tubing gap[d,e]	2 / 2
Coupled through ≈ 38 mm (1.5 in) inert tubing gap[d,f]	10 / 10
Coupled through ≈ 51 mm (2 in) inert tubing gap[d]	3 / 7
Coupled through ≈ 76 mm (3 in) inert tubing gap[d]	0 / 3
Propagating through very tight bend[g]	2 / 4

[a] Unless otherwise stated, to allow for the full development of LTT's propagating reaction, approximately 300 mm (12 in) of LTT was allowed before attachment to a coupling tube. This allowed for the full strength of the LTT propagation reaction to be fully established. Trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. [b] See the upper photograph in Figure 7. [c] See the upper middle photograph in Figure 7. [d] See the lower middle photograph in Figure 7. [e] See Figure 8 for a composite series of photographs of the propagation the LTT reaction through an approximately 18 mm (0.75 in) gap. [f] See Figure 9 for a composite series of photographs of the propagation the LTT reaction through an approximately 38 mm (1.5 in) gap. [g] See the lower photograph in Figure 7 for just how tight a bend was attempted.

assured. However, because the coupling tube is inert, there is a limited gap length between the two shock tube ends that will still provide reasonably assured communication of the shock reaction.[15] The testing of LTT took two forms, (1) to verify that LTT can be effectively coupled using the same general end-to-end method that is effective for conventional shock tube, and (2) to establish the approximate maximum gap that will provide reasonably assured propagation of LTT's pyrotechnic reaction. A summary of the test results is presented in Table 3. In each case, the length of LTT before the coupling was approximately 300 mm (12 in), to allow for the full development of LTT's propagating reaction.

In the coupling trials with the ends of two lengths of LTT in direct contact inside a short length of slightly larger inert tubing (upper photograph in Figure 7) a total of at least 30 trials were attempted and all successfully propagated the LTT reaction. In addition to these direct coupling trials, trials were also conducted using metal (upper middle photograph in Figure 7) and reusable plastic compression fittings. By design, these fittings operate with a short gap between the ends of the tubing being coupled. In the metal fitting the gap was approximately 5 mm (0.2 in) and in the plastic fitting the gap was approximately 12 mm (0.5 in). While the fittings could have been drilled out to allow the end of the LTT to be in close end-to-end contact, this would have been an inconvenience and was anticipated to be unnecessary because LTT should be capable of propagating through a short length of an inert coupler. In a limited number of trials (1 using a metal fitting and 5 using plastic fittings), all were successful.

Next a series of trials were conducted to determine the approximate maximum gap that would provide reasonably reliable propagation of the LTT reaction. In these trials, the ends of

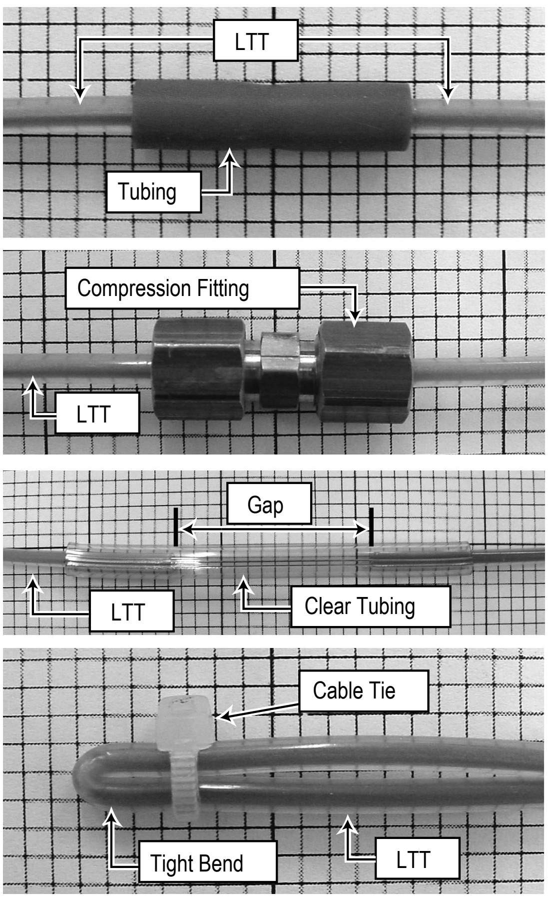

Figure 7 *A photograph demonstrating the LTT "direct contact" in inert tubing (top), "compression fitting" (upper middle), and "gap" (lower middle) coupling methods. Also shown is the "very tight bend"(bottom) used in a propagation test [2.5mm (0.1 in) per division].*

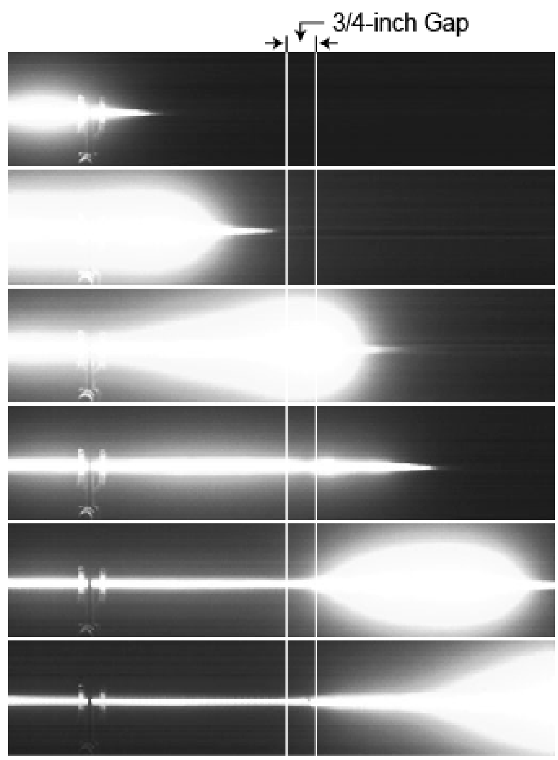

Figure 8 *A collection of 6 images of the propagation of LTT through an approximately 18 mm (¾ in) gap. The elapsed time between images is 0.0001 s.*[16]

two lengths of LTT were inserted into a length of inert tubing with an inside diameter the same as the outside diameter of the LTT (see the lower middle photograph in Figure 7). The two ends of the LTT were left separated within the larger diameter tubing by distances of approximately 18, 38, 51 and 76 mm (0.75, 1.5, 2, and 3 in). All of the trials using the approximately 18 and 38 mm (0.75 and 1.5 in) gaps were successful in propagating the LTT reaction. However, in viewing the propagation using high frame-rate video[16] it seemed apparent that the approximately 38 mm (1.5 in) gap was near the maximum gap that could be tolerated. This can be seen by comparing Figures 8 and 9 of the propagation through approximately 18 and 38 mm (0.75 and 1.5 in) gaps, respectively. For the approximately 18 mm (0.75 in) gap (Figure 8) there is only a single image in the sequence of images before the propagation of the LTT reaction was reasonably fully reestablished after reaching the gap. In contrast, for the approximately 38 mm (1.5 in) gap (Figure 9) eight images lapsed before the propagation is reasonably fully reestablished after reaching the gap. Note in Table 3 that when the gap was increased to approximately 51 mm (2 in), propagation was only successful in three of seven trials, and when the gap was further increased to approximately 76 mm (3 in), none of three trials was successful.

Tight Bend Propagation Test

The ability of LTT to propagate through an extremely tight bend was briefly investigated. The tightness of the bend is documented in the bottom photograph of Figure 7, and it approximates the very tightest bend imaginable. It was found that two of four trials were successful; however, the number of tests was so small as not to be definitive. (This information is only offered for the sake of complete reporting of the trials that were conducted.)

LTT Branching Methods

A series of trials were performed to help establish the ability of LTT to successfully branch (one line split into two or more lines). The results are summarized in Table 4 and discussed in more detail below.

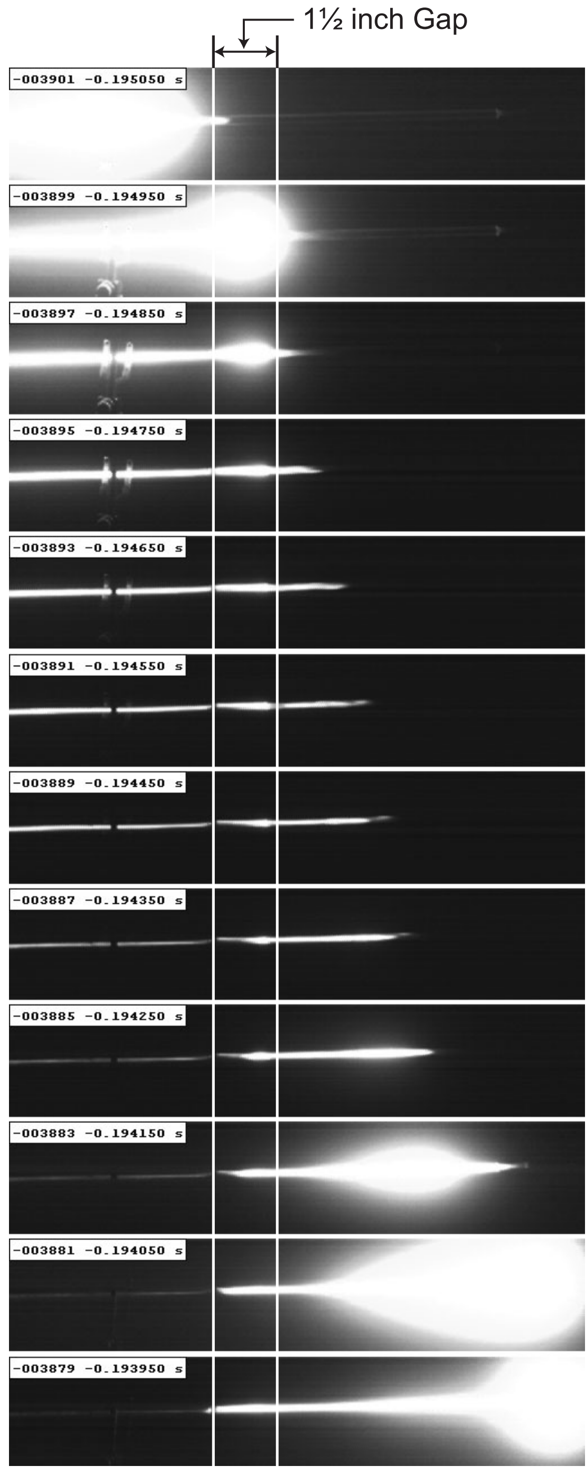

Figure 9 *A collection of 12 images of the propagation of LTT through an approximately 38 mm (1.5 in) gap. The elapsed time between images is 0.0001 s.*[16]

Table 4 *A summary of the results from the testing of LTT branching methods.*

Test Conditions[a]	Ignitions / Trials
Into the middle branch of a single tubing tee[b,c]	10 / 10
Into a side branch of a single tubing tee[b,d]	4 / 4
Through a tubing tee into two additional tubing tees[b,e]	10 / 10
Through a tubing tee with only ≈ 76 mm (3 in) of LTT leading to two additional tees[b,e]	9 / 10
Through a tubing tee directly (no LTT) into two additional tubing tees[b]	0 / 4
Through a reusable plastic compression fitting tee[f]	3 / 3
Through a single use metal compression fitting tee	1 / 1
Propagating through a notched LTT[g]	8 / 8
Split into three lines by coupling a pair of notches[h]	2 / 2
Split into seven lines by coupling inside inert tubing[i]	2 / 2

[a] Unless otherwise stated, to allow for the full development of LTT's propagating reaction, approximately 300 mm (12 in) of LTT was allowed before attachment to a tee or the first notch. This allowed the full strength of the LTT reaction to be established before branching. Trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. [b] See the upper photo in Figure 10. [c] See the left-hand illustration in Figure 11 for the orientation of the tubing tee in these trials. [d] See the right-hand illustration in Figure 11 for the orientation of the tubing tee in these trials. [e] This arrangement is illustrated in Figure 12. [f] See the middle photo in Figure 10. [g] See the lower photo in Figure 10 and see the lower photo in Figure 13 for the fire output from notches in a LTT line being fired. [h] See Figure 14. [i] See Figure 15.

Three of the methods used to branch LTT are documented in Figure 10. The first method used standard tubing tees coupled as shown in the upper photo. The attachment of LTT to the tubing tees was accomplished using short lengths of inert tubing. In the first trials, the LTT propagating reaction entered the middle branch of the tee, after traversing a total gap length of approximately 24 mm (0.95 in) of inert tubing tee plus having negotiated a 90° bend (see the left drawing in Figure 11). Ten of ten trials of this branching method successfully propagated the LTT reaction. Further testing was performed using a slight modification of this tubing tee method, where the LTT propagation reaction entered one of the side branches of the tee (see the right drawing of Figure 11). Four of four trials of this branching method were successful in propagating the reaction.

In the next series of trials, the pair of outputs from the one tee were sent into two additional tees for additional branching into a total of four LTT lines (see Figure 12). When the LTT lines between the first and the additional tees was approximately a full 300 mm (12 in), ten of ten trials successfully propagated the LTT reaction. However, when the length of LTT between the tees was reduced to approximately 76 mm (3 in), only nine of ten trials were successful. When the three tees were coupled directly together with no LTT between the tees, none of four trials was successful. Note that this is consistent with the gap testing, where it was found that the maximum gap providing relatively reliable propagation of the LTT reaction was approximately 76 mm (1.5 in). The use of additional tees coupled directly to the first tee requires the LTT reaction to traverse approximately 48 mm (1.9 in) plus negotiate two 90° bends.

A third branching method consisted of simply cutting a series of notches into lengths of LTT using a standard hand-held paper punch. A typically produced notch is shown as the bottom photo in Figure 10. (Even though it is thought to be highly unlikely that punching notches in the LTT would cause its initiation, it is appropriate to employ all of the ordinary precautions that one would use in cutting any type of fuse.) Figure 13 consists of two images taken from a standard frame-rate video recording, demonstrating the basic arrangement used in the trials. The upper image shows a length of LTT with a series of 5

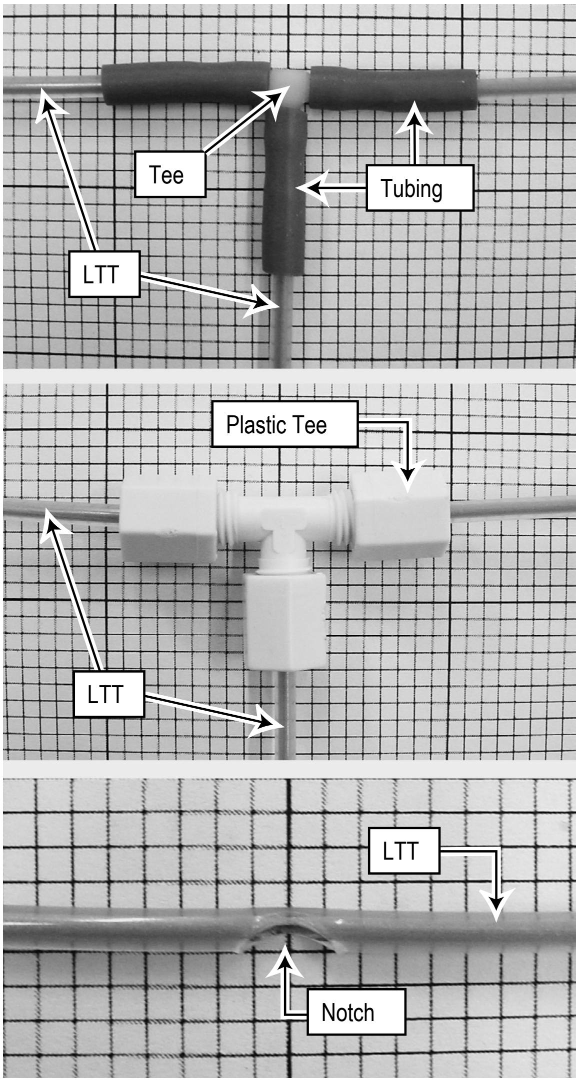

Figure 10 *Photographs demonstrating three of the LTT branching methods used in this study [2.5 mm (0.1 in) per division].*

paper punch notches prior to firing the LTT. The lower image shows the fire-spit from the five notches as the LTT fires. While the arrangement shown in Figure 13 is of essentially no use in itself, it can be useful in: (a) branching to additional LTT lines, and (b) igniting pyrotechnic compositions if a charge of powder is positioned in the immediate area of each notch.

Branching using the notch method is demonstrated in Figure 14. In this method, a notch was first cut into two LTT lines using a paper punch and the two notches placed over each other (notch to notch) and held on a small piece of tape. The two LTT lines were further secured using a second piece of tape. Only two trials using this method were attempted and both were successful. While easy to accomplish, this notch splitting method divides one LTT input line into three output lines. Another method was attempted in which the input LTT line was split into seven output lines (see Figure 15). This method used a short length of inert tubing with an internal diameter just large enough to accommodate the seven output LTT lines, which were inserted a short distance into the coupling tube. The input LTT line was fit through a sleeve that was large enough to fit securely into the larger diameter inert tubing. The input and output LTT lines were separated by approximately 5 mm (0.2 in) inside the coupling tube. Again only two trials were attempted using this method and again both were successful.

LTT Ignition Capabilities

One of the attractive characteristics of LTT is its ability to directly ignite typical pyrotechnic compositions (i.e., without using the shock-to-

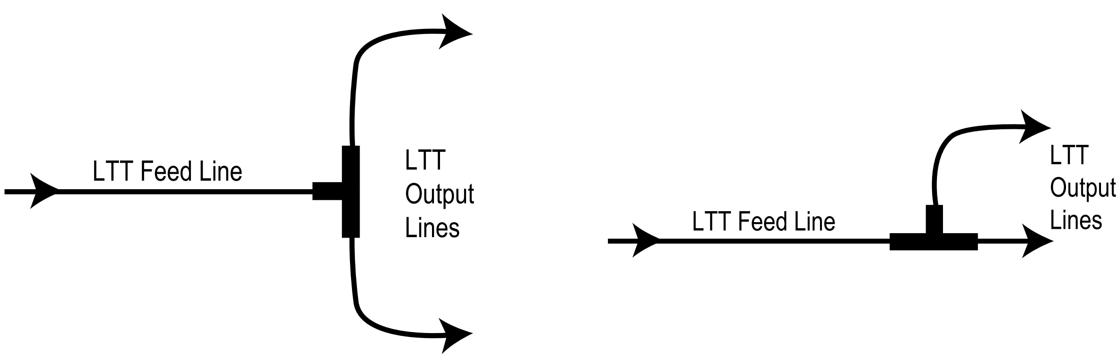

Figure 11 *Illustrations of the configurations used for the testing through a single tee: left, LTT reaction enters through the middle branch of the tee; right, LTT reaction enters through one side branch of the tee.*

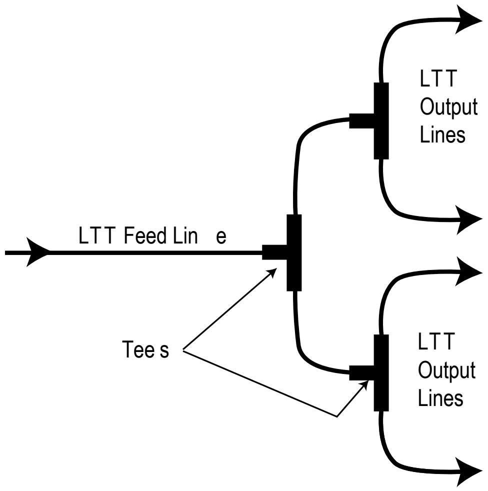

Figure 12 *An illustration of the configuration used for the testing through multiple tees.*

flame converters needed with conventional shock tube). The results from the ignition trials are summarized in Tables 5 and 6 and are discussed further below.

The first series of trials was conducted to determine the ability of LTT to ignite various pyrotechnic fuses. When the fuses were of approximately the same diameter as the LTT, both the LTT and fuse were inserted a short distance into a length of 3 mm (0.12 in) internal diameter (ID) inert tubing. This is illustrated in Figure 16 for coupling to visco fuse (also called

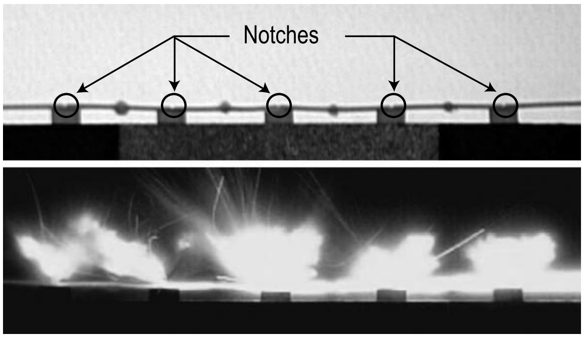

Figure 13 *Two images demonstrating the setup and fire spit produced from a series of 5 notches approximately 102 mm (4 in) apart in a length of LTT. The upper image is of the LTT hot melt glued to a support with pieces of tape below marking the location of each notch. The lower image documents the fire spit from the notches when the LTT was fired.*

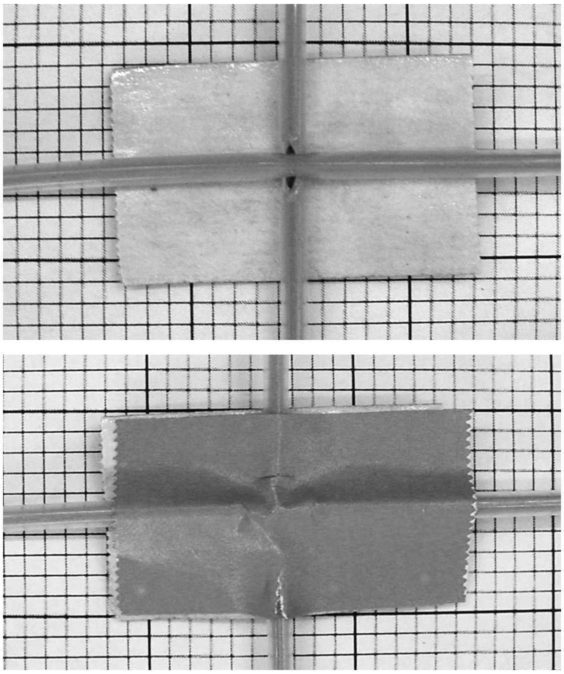

Figure 14 *Photos demonstrating a possible LTT branching method using the "notch" method [2.5 mm (0.1 in) per division].*

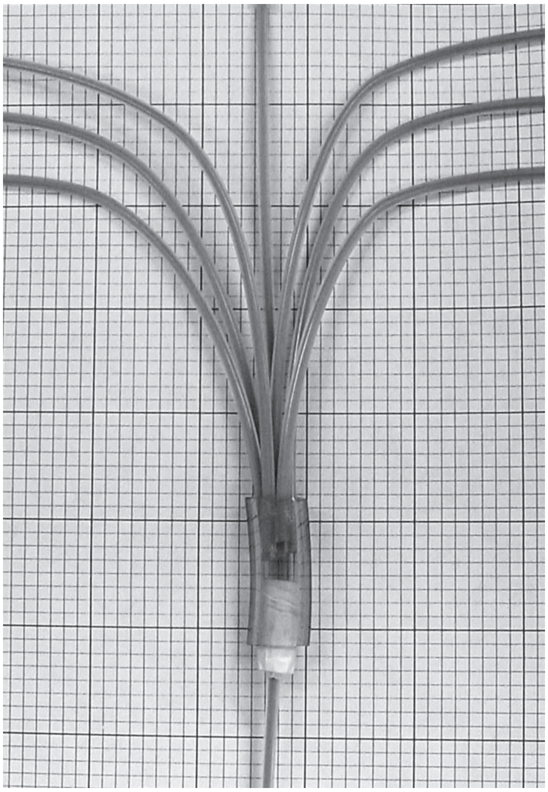

Figure 15 *Photo demonstrating one possible multiple branching method using a coupling tube [2.5 mm (0.1 in) per division].*

Table 5 *Results of testing LTT's ability to directly ignite various types of pyrotechnic fuse.*

Test Conditions[a]	Ignitions / Trials
Coupled to medium quality visco fuse[b]	10 / 10
Coupled to fast burning visco-like fuse such as used on reloadable consumer firework shells[b]	4 / 4
Coupled to fast Thermolite™ igniter cord[b]	4 / 4
Coupled to Mantidor™ plastic igniter cord[b]	10 / 10
Coupled to firework time fuse[b,c]	3 / 3
Coupled to medium quality visco fuse using a notch[d]	4 / 4
Coupled to quick match shell leader (Jumping Jack brand) using a notch[d]	5 / 5
Inserted into quick match shell leader	14 / 14

[a] To allow for the full development of LTT's propagating reaction, in each trial an approximately 300 mm (12 in) length of LTT was provided before its attachment to a pyrotechnic fuse. Trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. [b] In each case the LTT was coupled to the fuse using a short length of 3 mm (0.12 in) ID inert tubing, for example see Figure 16. The ends of the LTT and fuse were in contact or near contact within the coupling tube. [c] A 6 mm (0.25 in) ID inert coupling tube was used and the LTT was fit into a sleeve to increase its OD to fit securely into the coupling tube. [d] This notch method is demonstrated in Figure 17.

Table 6 *Results of testing LTT's ability to directly ignite various pyrotechnic powders.*

Test Conditions[a]	Trials / Ignitions
3Fg black powder[b]	4 / 4
4FA black powder[b]	14 / 14
2FA black powder[b]	10 / 10
Unconsolidated (loose) hand-made black powder[b,c]	4 / 4
Black Canyon™ 2Fg powder (a black powder substitute)[b]	10 / 10
4FA black powder[d]	4 / 4
7 : 3 flash powder (potassium perchlorate and dark aluminum)[b,c]	3 / 3
4 : 2 : 1 flash powder (barium nitrate, dark aluminum and sulfur)[b,c]	3 / 3
IMR 7828 smokeless powder[b,e]	4 / 10
Pyropack 2-second titanium whistles	3 / 3

[a] To allow for the full development of LTT's propagating reaction, in each trial an approximately 300 mm (12 in) length of LTT was provided before its attachment to a pyrotechnic powder. Trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. [b] In the trials to ignite loose pyrotechnic powders, a small container, typically 12 by 50 mm (0.5 by 2 in) was filled with the test powder. The LTT entered into the container through a hole, with the end of the LTT positioned a short distance into the powder charge (see Figure 18). [c] This powder was sufficiently fine grained such that it was possible that a small amount of powder might have entered into the end of the LTT. In the event that such powder infusion might need to be avoided, the US distributor of LTT[1] suggests that the end of the LTT can first have a thin coat of nitrocellulose lacquer applied over the hole in the end of the LTT. [d] In this trial all four charges of black powder were simultaneously ignited using 4 notches cut into a single length of LTT (discussed further in the text below). [e] This is a rather coarse powder and it is quite possible that a finer grained powder would be more readily ignited by LTT.

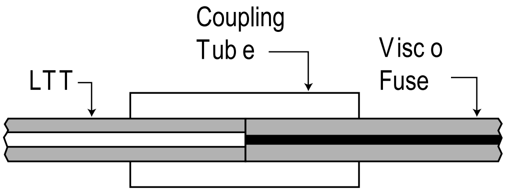

Figure 16 *An illustration of the inert tube coupling method used to ignite the visco fuse and other small diameter pyrotechnic fuse types.*

hobby, cannon or fireworks safety fuse). This method was tried using a medium quality visco fuse (10 trials), fast burning visco-like fuse such as used on reloadable consumer fireworks aerial shells (4 trials), and both Thermolite (4 trials) and Mantidor (10 trials) igniter cords. In each case, all trials were successful in igniting the various fuse types.

The inert coupling tube method was also tried using a reasonably high quality firework time

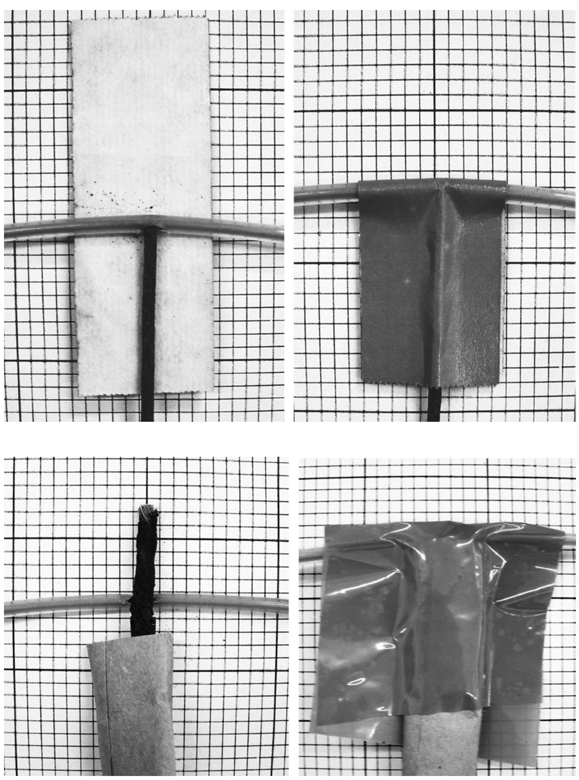

Figure 17 *Photos demonstrating the notch method of coupling fuse to LTT. The upper pair of photos used visco fuse and the lower pair used a short length of black match from a shell leader [2.5 mm (0.1 in) per division].*

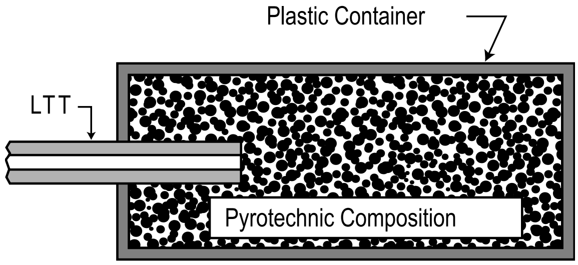

Figure 18 *An illustration of the test method used in the trials of LTT ignition of loose pyrotechnic powders.*

fuse. However, in this case, because of the larger diameter of the time fuse, a 6 mm (0.25 in) ID inert coupling tube was used. For the LTT to be reasonably well secured into the larger diameter coupling tube, the end of the LTT was first fitted into a very short length of a spacer tube to enlarge its effective outside diameter from 3 to 6 mm (0.12 to 0.25 in). Three of three trials produced successful ignitions.

One potential drawback of the coupling tube method described above (as in Figure 16) is that it terminates the LTT line, which is then not available to produce more than the single ignition. Thus a variation on the coupling tube method was tried. This method employed a notch cut into the side of the LTT using a paper punch. The end of the fuse to be ignited was positioned against the notch and then held in place using tape. In the first of these trials visco fuse was used, as shown in the upper pair of photos in Figure 17. In these trials, four of four fuse ignitions were successful. The lower pair of photos in Figure 17 is a similar notch coupling method using quick match with a short length of black match exposed. After the notch was made in the LTT, the black match was laid into the notch, folded back over the LTT and

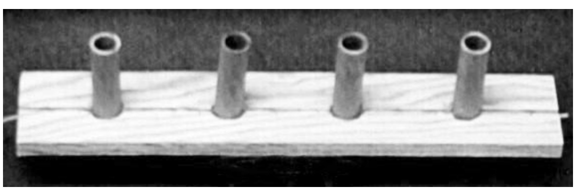

Figure 19 *Photo of the test configuration for simultaneously firing four small mortars from a single LTT line running under the mortars in a grove cut into the mounting board.*

secured with 50 mm (2 in) wide plastic packaging tape. In these trials, five of five fuse ignitions were successful.

A final series of fuse ignition trials was attempted in which the end of the LTT was simply inserted into quick match either into the end of a length of quick match or through a small hole made in the match pipe somewhere along the length of quick match. Using either method, care was taken to assure that the end of the LTT was immediately alongside the black match in the shell leader. Shell leaders from three manufacturers (Thunderbird, Jumping Jack and Sunny) were used in these trials, where 14 of 14 attempts to ignite quick match were successful.

Having completed the trials of fuse ignition, LTT's ability to directly ignite a variety of pyrotechnic compositions was investigated. The results of these trials are presented in Table 6. In those trials, the powders, whether loose or granulated, were placed in a small container and the end of the LTT was introduced a short distance into the powder charge, as shown in Figure 18. The first powder type to be investigated was black powder. These trials used 3Fg, 4FA, 2FA commercially manufactured powder, loose fine-grained hand-made black powder, and Black Canyon™ powder (a commercial black powder substitute based on ascorbic acid as the primary fuel). In these trials, all 42 of 42 attempts were successful.

The direct insertion method described above (as in Figure 18) also has the potential drawback that it terminates the LTT line, which is then not available to produce additional ignitions. Thus a variation on the direct insertion method was tried. In one trial of the ignition of small charges of black powder, a series of four small mortar tubes were mounted over a single length of LTT (see Figure 19). At the location of each tube, a notch had been cut in the LTT with a hand-held paper punch. The distance between notches was approximately 102 mm (4 in). A small charge of 4FA black powder and a projectile were added to each of the four small mortar tubes. Upon firing the single LTT line, all four black powder charges were simultaneously ignited and successfully fired the four small projectiles into the air.

Next, two types of flash powder were used in the ignition trials. Both flash powders were of standard formulations. One was a mixture of 70% potassium perchlorate and 30% dark-pyro aluminum, and the other flash powder was a mixture of 58% barium nitrate, 28% dark-pyro aluminum, and 14% sulfur. Again the end of the LTT was placed into a small charge of the powder (see Figure 18). In these trials, six of six attempts were successful.

One type of smokeless powder (IMR 7828) was used in the ignition trials. This type of smokeless powder was chosen only because it was immediately available in the laboratory. It is a rather coarse powder and is somewhat unlikely to be chosen for most entertainment pyrotechnic uses. Only four of ten attempts with this powder were successful. As a result, if it were desired to reliably ignite such fairly large particle size smokeless powders (and perhaps others as well) it is likely that the output of the LTT would need to be augmented, such as perhaps by first igniting a small charge of black powder.

As a final trial, the ignition of three small whistles (Pyropak, manufactured by Luna Tech, Inc.[12]) was attempted. In these attempts, the end of the LTT was simply inserted into the end of the whistle tube, such that the end of the LTT was in near contact with the compacted whistle composition. The LTT was temporarily held in place within the whistle using a small plug made of wadded-up tissue paper. All three whistle ignition trials were successful.

Conclusions

While the number of trials reported in this paper give some indication of the capabilities of Lightning Thermo Tube (LTT), often the number of individual trials was not statistically significant. This notwithstanding, it seems reasonably certain that LTT is a useful product and will find a number of uses in fireworks and proximate audience pyrotechnics. Probably the most desirable features of LTT are:

- its ability to be reliably initiated using reasonably energetic electric matches (without having to use flame-to-shock converters);
- its ability to reliably ignite typical pyrotechnic fuses and powders (without having to use shock-to-flame converters);

- its ability to produce a bright flash of light (with or without a fairly loud explosive sound);
- its resistance to accidental ignition due to strong impact and high temperature flame;
- its ability to be coupled and branched using the same methods commonly used for shock tube;
- its non-hazardous classification for transportation.

In considering the results reported in this paper, it is important to note that all trials were conducted at a temperature of approximately 15 °C (60 °F) and a relative humidity of less than 40%. Certainly, it is possible that the performance of LTT under more extreme conditions may be different. Thus further testing under more adverse conditions would be appropriate.

While there undoubtedly are many potential uses for LTT in fireworks and proximate audience performances, and while this paper may have put readers in mind of some applications, it was not the purpose of this paper to suggest or recommend any specific applications for LTT.

Acknowledgments

The authors are grateful to R. Webb for supplying some patent and background information about thermo-tube, to R. Gilbert for supplying samples of LTT for evaluation, and to E. Contestabile and L. Weinman for commenting on an earlier draft of this paper.

Notes and References

1 Trade marked and distributed in the US by Lightning Thermo Tube, 12707 N. Freeway, Suite 330, Houston, TX, 77060, USA. 1-800-279-4563 or +1-713-728-1437.

2 M. A. Falquete, "Process for the Production of a Thermal Shock Tube", US Patent 205/0109230 A1.

3 P. A. Persson, "Low Energy Fuse for Transmission or Generation of Detonation", Swedish Patent 333 321, July 20, 1968.

4 P. A. Persson and G. Lithner, "Wherl Element", US Patent 3-817-181, Jan. 5, 1972, granted Jan. 18, 1974.

5 E. Contestabile, A New Non-Electric Blasting System – NONEL, Energy Mines and Resources Canada, MRL/75-20, 1975.

6 In the 1990s in the US "No Match"™, a product intended for the fireworks trade, was introduced. No Match was based on conventional shock tube as used in the blasting industry. However, to facilitate its use in fireworks, it required flame-to-shock initiators for use with pyrotechnic fuse or electric matches, and shock-to-flame converters for reliable ignition of pyrotechnic materials.

7 Lightning Thermo Tube, Draft Technical Data Sheet, Sept. 2005.

8 The high frame-rate video camera was provided by Speed Vision, 3970 Sorrento Valley Blvd. Suite E, San Diego, CA 92121, USA, +1-858-450-7107.

9 Martinez Specialties, Inc., 205 Bossard Rd., Groton, NY 13073, USA, +1-607-898-3053.

10 Material Safety Data Sheet, IBQ Industrias, Quimicas, Ltda, Quatro Barras, PR, Brasil.

11 "Classification of Explosives", US Department of Transportation, Tracking Number 2005030367, 2005.

12 Luna Tech, Inc., 148 Moon Drive, Owens Cross Roads, AL 35763, USA. +1-256-725-4224.

13 K. L. and B. J. Kosanke, "Evaluation of 'Quick-Fire' Clips", *Fireworks Business*, No. 263, 2005.

14 K. L. Kosanke, "Electric Shock Tube Firing Systems", *American Fireworks News*, 156, 1994; also in Best of AFN III, *American Fireworks News*, 1995; and Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 3 (1993 and 1994), *Journal of Pyrotechnics*, 1996.

15 In one study of the ability for conventional shock tube to propagate its reaction through various lengths of inert tubing, it was found capable of spanning a length of nearly 200 mm (8 in).[5]

16 The collections of photographs in Figures 8 and 9 were produced using a frame-rate of 20,000 fps; however, only every other photo is included in the two figures. This was done to limit the size of the figures for publication.