A new look at the explosion that caused the Sultana disaster

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In the early morning of April 27, 1865, just north of Memphis Tennessee, three of the four boilers on the Sultana steamboat exploded. Samuel Clemens (not the famous author) was the engineer on duty that night. He suffered severe scalding and died later that day, after giving testimony to the first investigators.

One woman, a member of the Christian Commission, whose name is forever lost, calmed a group of men hanging onto ropes while the boat, full of flame, drifted down the Mississippi. As the fire approached her, she didn't want to panic the men so she stepped backward into the fire rather than jumping in amongst them.

Joseph Test, a soldier from Ohio, was killed almost instantly by a piece of timber blown into him from the force of the explosion. We know about Joseph because of his friend, who had the most unusual story of the survivors. Joseph's friend couldn't find any wood to use as a raft so he ran to the boat's mascot - an alligator - stabbed it three times and then used its wooden crate as his life raft (Berry, 1892).

While the boat was rated to carry 376 total passengers, it was packed with over 2,400 people. The explosion, ensuing fire and cold Mississippi river claimed more than 1,700 lives and this tragedy remains the largest maritime disaster in U.S. history. The majority of the passengers were men returning home after surviving horrendous conditions in Confederate prisoner-of-war camps, who anticipated reuniting with their families and friends.

The sinking of the Sultana occurred in tumultuous times; which included the deaths of Abraham Lincoln and John Wilkes Booth, the surrender of Lee's army and the effective end of the Civil War. All of this occurred in the month of April, which relegated the Sultana to the back pages, where the story was nearly lost to history.

This research examines the factors that led to the boiler explosion through eyewitness accounts, testimony to investigators and at trial, as well as texts describing boiler technology and knowledge of the time. It also discusses and rebuts popular alternate theories.

Figure 1 - The Sultana burning

1866
Hartford Steam Boiler

Boiler explosion theory

In the early years of steam use, boiler explosions were common, yet misunderstood. At various times explosions were blamed on acts of God, spirits, electric generation within the boilers or hydrogen caused by the disassociation of water in the boilers. By 1865, it was generally accepted by boilermakers and engineers that the cause of most boiler explosions was low water (Thurston, p. 36).

In this theory, low water caused a boiler plate exposed to the fire to overheat and turn red hot. It was assumed that when water struck the plate it instantly turned to steam over-pressuring the boiler and resulting in an explosion. This didn't explain many explosions however, and there was often vagueness in the explanations that referenced unusual circumstances and the power of gunpowder.

Engineers recognized that a sudden burst of steam generation was occurring, but did not understand the incredible amount of potential energy stored in a boiler, nor how the sudden burst of steam generation occurred. Detailed scientific investigations of steam and steam properties took place in the early 1860's, but the first tables that documented steam properties weren't issued until later.

In 1887, Robert Thurston, who was the first President of the ASME, published *"Steam Boiler Explosions, In Theory and Practice"* and by that time, the science was well understood and the two key things that earlier generations of engineers did not know were that:

1. There is a tremendous amount of energy stored in a boiler under pressure, and almost all of this energy is in the water.

2. A sudden drop in pressure will cause a portion of water to instantly boil creating steam; each cubic foot of water then expands up to 1,600 cubic feet of steam. This expansive power is what creates catastrophic explosions.

Figure 2 (Thurston, p. 26) is a table from Thurston's book that shows the amount of energy stored in a boiler. According to this data, the energy contained in a plain tubular boiler was sufficient to launch the boiler 5,372 feet - over a mile high. The table also shows that the energy stored in the steam in the boiler is less than 3% of the total energy in the boiler.

Water boils at 212°F under normal conditions. If boiling water is contained, as in a boiler, the pressure increases and the temperature at which water boils increases. At the Sultana's normal operating boiler pressure of 145 psig, water boils at 363°F. If there is a leak or break in the boiler, the pressure will drop and therefore the temperature at which water boils will decrease. At this point the water temperature will be greater than the boiling temperature. Therefore, some of the water flashes to steam, expanding and re-pressurizing the boiler.

If the leak or opening in the boiler is small and the boiler strong enough, the boiler contains the pressure and the water or steam slowly leaks out and the boiler pressure slowly decays. However, if the boiler can't contain the pressure due to a weakness, more and more water flashes to steam and continues to rip the openings wider - almost instantaneously. For the Sultana, if the pressure in the boiler dropped from 135 psig to zero, up to 950 lb or 15% of the water in the boiler would turn to steam. Each cubic inch of water expands to as much as one cubic foot of steam or 1,600 times the volume. It is this tremendous expansion that results in the ferocity of the explosion. At the time of the disaster, this knowledge of boiler explosion theory was incomplete and led to the most commonly cited, but incorrect, theory of the explosion, a combination of low water and careening of the vessel.

TOTAL STORED ENERGY OF STEAM BOILERS.—*Continued.*

Type.	Stored Energy in (available)			Energy per lb. of		Max. Height of Project'n.		Initial Velocity	
	Water.	Steam.	Total.	B'l'r	Tot W't	B'l'r	Tot	B'l'r	Tot.
	Foot lbs.			Ft. lbs.		Feet.		Feet per Second.	
1 Plain Cylinder...	46,605,200	676,698	47,281,898	18913	5714	18913	5714	1103	606
2 Cornish.	57,570,750	709,310	58,260,060	3431	1314	3431	1314	471	290
3 Two-flue Cyl'der	80,572,050	2,377,357	82,949,407	12243	6076	12243	6076	888	625
4 Plain Tubular. .	50,008,790	1,022,731	51,031,521	5372	2871	5372	2871	588	430
5 Locomotive......	52,561,075	1,483,896	54,044,971	2786	2189	2786	2189	423	375
6 "	69,148,790	2,136,802	71,284,592	2851	2231	2851	2231	428	379

Figure 2 - Stored energy of steam boilers

Low water and careening of the boat

Engineers in 1865 did understand that it was a sudden burst of steam that created boiler explosions. However, in the case of the Sultana they thought that this burst of steam was due to a low water level and careening of the boat.

According to this theory, as the boat rocked, or careened, the boiler was exposed to the heat of the fires without water covering and cooling it. This iron turned red hot and when the boat rocked back, the water striking the red hot iron flashed to steam creating a sudden pressure surge and subsequent explosion.

The emphasis to this day on this explosion theory is due to the large amount of testimony that discusses careening and low water. In the records, Isaac West, W.B. Richardson, J.J. Witzig, and Chief Engineer Wintringer all noted that careening of the boiler may have been the cause of the explosion (Archives, 1865). Of these four, three were not present on the boat and the fourth, Chief Engineer Wintringer, was asleep at the time of the accident.

The prosecution at the trial of Captain Frederic Speed asked multiple questions regarding the careening of the boat. Due to the large number of troops on board and the small amount of cargo in the hold, the boat did rock when many men rushed to one side, most notably during the last picture taken of the Sultana in Helena Arkansas, shown in Figure 3.

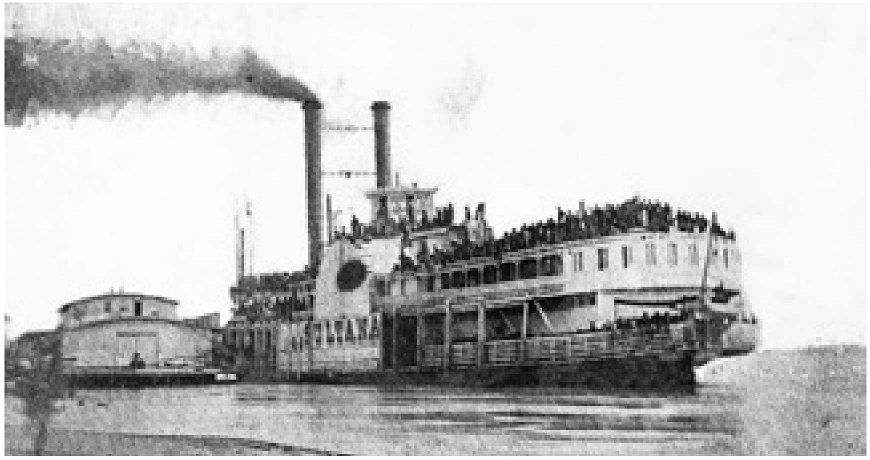

Figure 3 - Sultana at Helena Arkansas

In 1865, boiler engineers, captains and others in the trade believed that a boiler full of water could not explode (Thurston). This was stated directly in the testimony of R.G. Taylor, who said, “So long as there is a sufficiency of water in the boiler there is no danger of explosion (Archives, 1865). “

Therefore when reading the testimony, it is important to understand that they didn’t have today’s knowledge of steam theory or why boilers explode. As the physics behind the immense power of steam explosions became known, the pendulum swung the other way and by the late 1800’s some believed that no explosions were caused by low water (Thurston, p. 36). We now know that introducing water into a hot boiler can cause an explosion under the right conditions, but is fortunately, a rare event.

There are two areas of investigation that counter the careening water theory. The first is to calculate how much steam may be generated in a boiler during a careening event and compare that to the theory presented in this research and the second is to review testimony from people who were on the boat and awake at the time of the explosion.

It is possible to calculate the theoretical steam generation by a red-hot section of iron. This calculation shows that the red-hot iron may double the amount of steam in the boiler from 16 to 32 lb of steam. This is 60 times less than the 950 lbs of steam that could be generated due to a break in the boiler. Therefore the pressure that can be generated by a careening event is significantly less than the pressure that can be created from a full boiler with a simple break.

Maintaining a proper water level is critical to ensure that the heat absorbing tubes are covered in cooling water and generating steam. The engineer on duty the night of the accident was Samuel Clemens, who died shortly after the accident from the injuries he received.

According to Wintringer, Clemens had been working around boilers for about 25 years and the Chief Engineer considered Clemens an able engineer. He clearly understood the need to maintain a full boiler. It was reported that he stated the boilers were full of water. In his short testimony before he died, he did note that as the boat was light, it did roll during the trip. Even though Clemens noted that the boat was light and rolled, he did not place the blame on low water and careening, but on defective repairs (Archives, 1865).

“All was peace and no sign of disaster. I spoke to the engineer of how nicely we were going…” stated George Clarkson, a survivor who was awake at the time of the explosion (Berry, p. 94). If the boat was rocking enough to expose the bottom of the boiler for a period of time long enough to heat it to red hot, it would have been noticed.

At the time of the explosion, the men were mostly asleep (and not moving side to side) and there was no mention in any of the survivors’ stories of careening before the explosion. In a letter to the Secretary of War dated May 19, 1865, General Hoffman noted that “There is nothing to show that there was any careening of the boat at the time of the disaster, or that she was running fast; on the contrary, it is shown that she was running evenly and not fast (Berry, 1892).”

A boiler explodes when the internal pressure is greater than the pressure retaining ability of the boiler. This can occur when a drop in pressure creates a sudden release of steam that then over pressurizes the boiler. In the case of the Sultana, the evidence is clear that the boilers were weakened and based on the results, could not withhold the steam. This boiler explosion knowledge was unknown to engineers of the time and it follows that boiler explosions are more likely and more damaging if the boiler has weak points. The boilers on the Sultana had known deficiencies.

Boiler Weakness on the Sultana

The steamboat was inspected on April 12, 1865 in St. Louis, Minnesota by federal inspectors John Maguire and John Schaffer in accordance with the Steamboat Act of 1852. The boilers were subjected to a hydrostatic test of 210 psig and deemed acceptable (Inspector’s Certificate, 1865). Although they were deemed acceptable, there is substantial evidence that these boilers had incurred damage over two years of operation.

With the clarity of hindsight, this is no surprise. As the experience and knowledge surrounding boilers increased during the latter half of the 1800’s it became clear that weaknesses due to wear and tear on the boiler had caused many explosions that were formerly attributed to other causes. “Without becoming marked in any one part of place such wear steadily reduced the factor of safety represented in the boiler as originally made and might eventually result in an explosion far more destructive than one growing out of a more obvious defect or weakness (Hunter, p. 295).” The evidence that the Sultana had been weakened includes a recent repair history - one of which was incomplete - burnt boiler plates and an earlier re-tube of the boiler.

On the final trip upriver, between New Orleans and Vicksburg, the boiler developed a bulge and a leak. The leak was in the inner larboard (left) boiler. It was noted as being on the third sheet from the forward end, a few inches below horizontal, and was located in the outer seam with cracking noted between two to three rivets. Cracking between rivets at the seam was a common and well-known concern for riveted boilers. The boat, operating under reduced pressure, made it to Vicksburg where chief engineer Wintringer contracted R.G. Taylor, a boilermaker with 28 years experience, to repair the boiler. The repair consisted of a patch that was 11” x 26” along the straight seam of the third sheet. This size patch was the length of the seam for one boiler plate (approximately 2’) and sufficient width to cover the seam area. The area near the seam was bulged out and this patch was fitted to the bulge. The boilermaker considered the patch only a temporary repair and he stated that the chief engineer had agreed to make a full repair in St. Louis. According to Taylor’s testimony, a full repair would have consisted of forcing back the bulge and replacing the two sheets adjacent to the patch. While he considered the patch a good job, he did not believe the boilers were safe (Archives, 1865).

While the leaking seam is one indication of weakness, Taylor’s testimony indicates that the boilers had suffered “burnt plates,” which he suspected were the result of operation with low water (Archives, 1865). It is more likely that the cause of the burnt plates was the accumulation of sediment in the boiler, which will be discussed below. Although he suspected low water conditions, he noted that the flues were in good condition with no defects. They were in good condition because these boilers had already been re-tubed once (*The Sultana Disaster*, 1865).

The one piece of boilerplate retrieved from the wreckage was burnt (Argus, 1865). This matches Taylor’s description of the plate. While it is possible that the fire on the Sultana was responsible for the burnt look of this plate, it is clear that the plates were in poor condition at the time of the explosion. W.B. Richardson, Chief Engineer of the steamboat Marble

City who examined the recovered piece noted the burnt look and stated that the iron was of "very poor quality." The explosion tore the piece transversely (at right angles from the length) from the boiler and that at its widest was the width of a sheet (Archives, 1865). This is very typical damage in explosions caused by a sudden and massive overpressurization.

Other evidence that the boilers were in a weakened condition is the recollection of Charles Lyda, an employee on the boat. He stated that in addition to the repairs in Vicksburg, the boilers had also been repaired the prior month in Natchez. This means that the repair in Vicksburg was the second repair in two months. Charles Lyda felt that the boilers were not in good condition (Berry, 1892).

These boilers were in a bad condition, almost destined to explode. While these boilers were under three years old they had been repaired twice in the previous two months, had been re-tubed earlier and the condition of the existing sheets was suspect. These weaknesses resulted from the combination of several factors. The first factor to consider is the quality of iron used in construction.

Material of boiler construction

While the iron used in the boiler construction, Charcoal Hammered No. 1 (CH 1), was the best quality material available in 1863, CH 1 iron is not a suitable material for boiler construction. CH 1 iron is now known to be unsuitable due to its method of fabrication as well as its mechanical properties after being heated and cooled repeatedly.

CH 1 is a wrought iron that is heated and wrought (or worked) with charcoal to increase the carbon content, which increases material hardness. The process of making charcoal hammered iron leaves imperfections that weaken the iron plates (Figure 4). These are seen as black lines in the plate. Based on the construction techniques of the time, there would have been inclusions and imperfections in the iron used in the boilers, as well as poor control of other elements such as sulfur. In addition to weakening the plates, the inclusions and imperfections can be locations for corrosion to occur. While the material may look acceptable on the surface, it is often weakened due to the inclusions. Very often, the inclusions in iron can reach the surface and allow corrosion to occur in the interior of the iron as shown in Figure 5. In this wrought iron sample illustrated, the inclusions led to a complete separation near the surface as well as corrosion in the interior of the plate. We do not know the extent of corrosion of the Sultana boilers were, but some level of corrosion is probable.

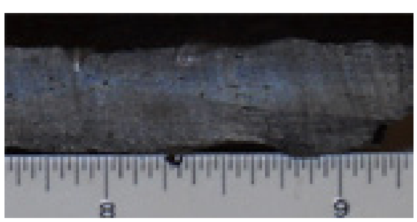

Figure 4 - Wrought iron plate showing internal imperfections

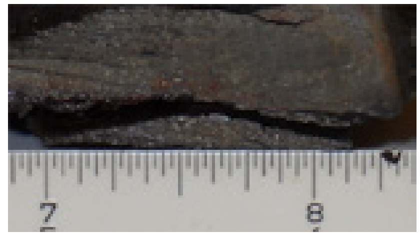

Figure 5 - Wrought iron plate with internal corrosion and separation

As is common in many industries, new technologies overtake older ones, and this was the case regarding iron manufacture for boiler plate material. *"A Practical Treatise on High Pressure Boilers"* by William Barr provides a review of boiler material available in 1879. By then, another grade of iron called Flange Iron was the preferred marine boiler material. CH No. 1 iron was noted as "Not a suitable iron for boiler construction." This iron was considered an unacceptable material due to its "Having but little elasticity and breaking with a sudden jerk (Barr, p. 22)." In addition, Barr noted that as CH No. 1 is heated and cooled repeatedly, it becomes very brittle. George Tower, in his contemporary book *"Useful Things to Know about Steam Boilers"* also noted that CH No. 1 iron behaves "most unsatisfactorily" and was of a "brittle character and unfit for use in a boiler (Tower, p. 113)."

The iron used in the Sultana boilers contained inclusions, likely had some level of corrosion and became brittle when heated and cooled repeatedly. The boilers did experience overheating on a regular basis and while overheating was often blamed on low water, the cause of overheating was due to mud and other impurities collecting on the boiler parts. These boilers used make-up water straight from the Mississippi river, which was the source of this sediment.

Sediment in the Sultana boilers

The Sultana boilers used Mississippi river water with no filtering or treatment, and silt and mud suspended in the river water entered the boilers. On the Sultana, all the steam generated in the boilers was made up from this dirty river water. Sediment in the water collected on the boiler surfaces, particularly the boiler bottom which was exposed to the direct heat of the flame. This accumulated material acted as insulation, slowing the heat transfer from the metal to the water causing the plate to overheat. Blow-down or mud drums, as they are also called, were standard construction practice at the time to help collect and get rid of mud or impurities. This would have helped eliminate some sediment, but even with this, the boiler needed regular cleaning and this was a well-known issue at the time. The boilers were cleaned both in New Orleans in March and in Vicksburg according the Chief Engineer (Archives, 1865).

According to a Hartford Steam Boiler Locomotive article from 1880, scale and sediment, as well as burned or blistered plates, were major concerns for many boilers - not just boilers on the Mississippi river.

Fig. 71.

Figure 6 - Sediment and incrustation

Yearly Summary of Inspections for the Year 1879.

Whole number of visits during the year, - - - - -	17,179
Whole number of inspections, - - - - - - -	36,169
Whole number of thorough annual inspections, - - - -	13,045
Whole number of boilers subjected to hydraulic test, mostly new or repaired,	2,540

Whole number of defects discovered, 16,238. Dangerous defects, 3,816.

Details for the year 1879.

	In all.	Dangerous.		In all.	Dangerous.
Furnaces out of shape, -	848	195	Cases of internal grooving, -	126	56
Fractures in all, - - -	1,387	684	Water gauges out of order, -	405	133
Burned plates, - - -	963	302	Blow-out ap'atus out of order,	181	61
Blistered plates, - -	2,597	234	Safety-valve overloaded, -	234	102
Cases of deposit of sediment,	2,177	456	Pressure gauges out of order,	1,393	298
Cases of incrustation & scale,	2,791	388	Boilers without gauges, -	714	8
Cases of external corrosion,	1,162	352	Cases of deficiency of water, -	55	38
Cases of internal corrosion, -	743	188	Broken braces and stays, -	462	221

Figure 7 - Summary of 1879 inspection results

One engineer estimated that in a 12-day run, a boiler would have ingested 200 tons of mud (Hunter, p. 263). It is possible to estimate the amount of mud that the Sultana boilers would ingest using United States Geological Survey (USGS) river water data and boiler volume. Based on USGS data from the 2011 Mississippi flood, a straight average of the sediment numbers results in value of approximately 500 mg per liter or approximately ½lb of sediment for every 1000 lbs of water. Therefore each time a Sultana boiler was filled, approximately 3 lbs of sediment was introduced.

In addition to sediment, the water also contains dissolved minerals that create scale, or as it was called at the time - incrustation - of the boiler. Scale also acts an insulator, again reducing the heat transfer from the iron into the water. As a result, the iron temperature will be higher, which can lead to burnt plates (Tower, p. 106). Cleaning and scraping will not remove hard scale on boiler tubes or sheets. Even washing a boiler will not eliminate the hard, baked on scale that tends to accumulate on the hottest sheets. The leak that was repaired in Vicksburg was near the fire bars. (Archives, 1865). In this area, the boiler is exposed to the hottest part of the fire where it sees both the direct radiant heat from the flame as well as the heat from the combustion gases flowing over the boiler shell. W.B. Richardson testified that the tear in the boilerplate appeared to begin "near the bottom," another indication that this portion of the boiler was weakened (Archives, 1865).

Based on the testimony indicating burnt plates and the known issues of sediment and scale, it is clear that the boiler iron suffered overheating. This overheating cycling would have led to the brittleness of the Charcoal Hammered Iron, leaving the boiler susceptible to a sudden failure.

Steamboat Boiler Design of the 1860s

The overheating due to the sediment and the weakness of the plate was exacerbated by the boiler design. There are two aspects of the design that contributed to the weakening of the boiler. The first is the arrangement of the tubes in the boiler, and the second is common to all boilers of the time and relates to the joint between the boiler sheets.

The standard boiler installed on steamboats was a dual flue boiler set into a casing above the firebox. In a typical design, the boilers were arranged in a battery of 3-4 boilers located side by side on the boiler deck. The fires were under the front of the boiler and the flames and heat traveled underneath along the shell bottom. At the rear, the combustion gases turned and entered the dual flues transferring heat to the water in the boiler. This two-flue design provided sufficient space inside the boiler to remove sediment and scale, and supported circulation to keep the sediment in suspension and allow it to be blown out through the mud drum.

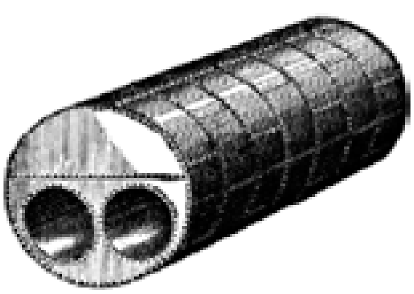

Figure 8 - Double Flue Boiler

The Sultana had four fire-tube boilers, each 46” in diameter and 18’ long. In a firetube boiler, instead of two large flues, the boilers had 24 flues (tubes) each 5” in diameter arranged in a staggered arrangement that carried the gases through the boiler. This larger number of smaller tubes increases the surface area between the hot gases and the water, significantly improving both boiler efficiency and capacity. With this design, the spacing between tubes or between the tubes and the bottom would have been very tight, as indicated in Figure 9.

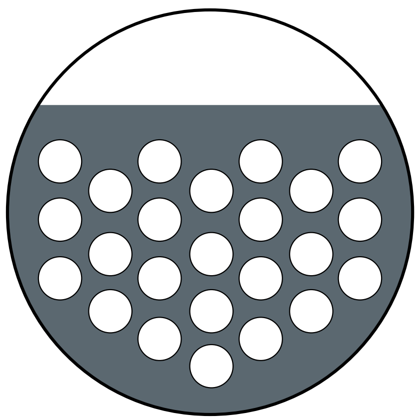

Figure 9 - Firetube boiler layout

While the design is more efficient, it significantly worsened the sediment problem. The number, location and close spacing of the tubes made it difficult to clean the boiler. In addition, during cleaning, the condition inside the boiler would have been hard to see. J.J. Witzig, the Supervising Inspector of the Fourth District, noted this after the the Sultana disaster. This boiler design was not suited to the harsh conditions of the Mississippi, and both Nathan Wintringer and Charles Lyda noted that the tubular boiler design was “done away with” from operation in steamboats and no longer used on the lower Mississippi (Berry, 1892). This change occurred after the explosions of the steamboats Walker R. Carter, Missouri and of course the the Sultana. Not only were firetube boilers no longer built for steamboats, many boat owners replaced firetube designs with the traditional two flue design (Hunter, Perils of River Navigation, p. 158).

The second design aspect that was detrimental is the method of joining two sheets together. A boiler is cylindrical because that is the strongest shape for withholding pressure. As was standard practice of the time, this boiler had lap joints where the plates were overlapped and riveted together. Lap joints in longitudinal seams are problematic because the joint breaks the cylindrical shape of the shell. When pressurized, the shell wants to become cylindrical which can flex the sheets in the joint area. If not carefully made, this flexing can be significant and will eventually lead to cracks forming, most often at the weakest part of the sheet between rivet holes (Moedinger, 2014). In a British report on steam boiler explosions in 1865, half of the boilers that had exploded did so at the lap joint due to grooving where the forces were concentrated due to the shape (Thurston, p. 121).

Summary of the root cause of the Sultana explosion

Unfortunately for the 1,700 men, women and children on board, the condition of the boilers, the burnt plates and the history of repairs on the Sultana all point to an explosion as inevitable.

Three factors are included in the root cause of the explosion. The first was the poor quality, brittle iron. This iron was made more brittle due to the overheating caused by the insulating effect of the mud brought in with the Mississippi river water. While other boilers on Mississippi steamboats could usually tolerate this combination, it was the third factor - the design of the boiler - that made it hard to clean.

These three factors caused the magnitude of the disaster. All it took was one little break and a drop in pressure to unleash the steam's power, as the boiler clearly could not handle the sudden pressure. In reviewing the testimony, the Sultana history and boiler explosion data, the most likely culprits of this initial break were the burnt plates at the bottom or a seam that suffered the same damage as the one repaired in Vicksburg.

After the careening theory, there are two other common theories that are often cited as the cause of the explosion; improper thickness of the repair patch and sabotage.

The thickness of the patch used on the Sultana boiler repair

Another theory that is discussed is based on statements from J.J. Witzig. In his testimony at the trial of Captain Speed, he stated the allowable pressure based on 0.25" iron would have been 100 psig (Archives, 1865). He also repeated this in his section of a report by the Secretary of the Treasury (Treasury Department, 1865).

The allowable pressure has a safety factor above the anticipated bursting point. Taking out the safety factor that is used for design, if the patch was good material and applied correctly, it theoretically would have been capable of holding pressure over 300 psig using current calculations. While Witzig was correct that the thickness of the boiler patch would have lowered the allowable working pressure, it was unlikely the patch material thickness itself was the cause of the explosion.

Sabotage

There was some suspicion at the time, which persists to this day, that the boiler may have been destroyed by the sabotage of Confederate spies that used of a coal torpedo. A coal torpedo is an iron casting that resembles a hunk of coal, and is filled with gunpowder, dusted with coal and put into the coal bins. The suspicion of the day makes sense due to emotionally charged feelings at the end of the Civil War. The evidence for this theory is only circumstantial, and is based on a reported confession years after the explosion.

Based on forty years of western river data, 30% of all steamboats suffered accidents. While snags were the most common cause of steamboat accidents, boiler explosions were the second. Approximately 1 out of every 5 steamboats that suffered an accident experienced a boiler explosion (Hunter, p. 1949). Boiler explosions on the Mississippi river were common and there is a preponderance of evidence that the boilers were weakened due to the material, the design of the boiler and sediment in the water. The firetube design of the Sultana was an experiment on the lower Mississippi with additional explosions attributed to this boiler design, which was removed from use shortly after.

Summary

No one goes to work thinking that his or her decisions may kill over 1,700 people, including themselves. But indeed, the decisions of those involved combined to result in the large loss of life. The boat captain who accepted more men than allowed, the Army personnel who crowded men on one boat while other boats left the same wharf empty, the boiler repairer who performed a job he felt was incomplete and the first engineer and captain who pushed for this incomplete repair; all of these men's decisions contributed to the tragedy. Investigating and analyzing the cause of the boiler explosion is one small part of understanding the events that led up to the disaster on April 27, 1865.

During the second half of the nineteenth century, great strides were made in boilers; in theory, operation and materials of construction. However, in 1865 when the Sultana exploded, this knowledge was absent, and stepping back to the time period to understand this is vital to understanding the cause of the explosion. The cause of the explosion is straightforward; it was the result of a poor quality material, overheating due to Mississippi sediment accumulations and a design not suited for the water conditions. This theory requires no assumptions or constructed scenarios, fits the testimony (noting the lack of knowledge at the time) and matches the common causes of boiler explosions in the period.

The tragedy of the Sultana should not be forgotten. Understanding the causes of accidents allows us to prevent others, and today's improved boiler designs and inspection regulations are the result of the loss of the Sultana and other notable boiler explosions.

For further information, watch the video of Pat's presentation on his Sultana research at go.hsb.com/sultana150

Figure 1 - The Sultana burning
Hartford Steam Boiler

Figure 2 - Stored energy of steam boilers
From Thurston - Steam Boiler Explosions, in Theory and Practice

Figure 3 - Sultana at Helena Arkansas
Photo from Library of Congress
http://www.loc.gov/pictures/item/2013647457/

Figure 4 - Wrought iron plate showing internal imperfections
Photo by Patrick Jennings

Figure 5 - Wrought iron plate with internal corrosion and separation
Photo by Patrick Jennings

Figure 6 - Sediment and incrustation
Graphic from "Records of Steam Boiler Explosions", by Edward Bindon Marten, London 1872
a Project Gutenberg eBook.

Figure 7 - Summary of 1879 inspection results
Table from "Locomotive"
New Series Vol. 1 No. 2 February 1880

Figure 8 - Double Flue Boiler
Graphic from "Records of Steam Boiler Explosions", by Edward Bindon Marten, London 1872
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Figure 9 - Firetube boiler layout
Graphic by Matthew DiMascio (HSB)

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Note on the Archives. The National Archives has a collection of records on the three commissions that investigated the explosion (Washburn, Hoffman, Dana) as well as the trial of Army Captain Frederic Speed.

NOT IF, BUT HOW