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ABSTRACT

Lift has been generated thermally in aerostats for 219 years making this the most enduring form of lift generation in lighter-than-air aviation. In the United States over 3000 thermally lifted aerostats, commonly referred to as hot air balloons, were built and flown by an estimated 12,000 licensed balloon pilots in the last decade. The evolution of controlling fire in hot air balloons during the first century of ballooning is the subject of this article.

The purpose of this assessment is to separate the development of thermally lifted aerostats from the general history of aerostatics which includes all gas balloons such as hydrogen and helium lifted balloons as well as thermally lifted balloons. Through this separation the unique developmental lineage of thermally lifted balloons is established with its own set of participants. Some of aerostatics' most famous names in history such as Blanchard, Lowe, and Lunardi will notably be missing owing to their involvement in hydrogen ballooning and their lacking any significant contribution to thermal lift balloon development.

The main source for the information contained herein was the literature on the subject supplemented by a review of the patents involved. This study clearly revealed advances on the first manned aircraft as designed by the Montgolfiere brothers and credits the individuals responsible. It furthermore distinguishes the developmental history of thermally lifted aerostats from gas lifted aerostats.

INTRODUCTION

The Montgolfieres, the original aviation brothers, dispatched Pilatre de Rozier and Marquis D'Arlandes aloft in their hot air balloon in the first manned hot air balloon flight on November 21st 1783 (Cottrell, 1970; Crouch, 1983;Norgaard, 1970; Wise, 1850). This original half hour flight at the Chateau de la Muette in France was fascinating in many respects, not the least of which was the feet that de Rozier and the Marquis D'Arlandes ascended and descended by tending an open fire in the passenger compartment of the balloon (Block, 1974; Haydon, F.S.; Norgaard, 1970; Wise, 1850). Although the term Monteolfiere is synonymous with hot air balloon in historical accounts in many countries (Beaubois, 1974) around the world, the idea of an open fire in an aircraft would be cause for alarm in 2002.

However, during the early days of hot air ballooning, an open fire was the essential component for flight. The means of inflating a balloon was by suspending the envelope fabric from masts and feeding a fire beneath it until the envelope inflated. In order to lift the balloon, the temperature of the volume of air inside the balloon's envelope was elevated further. For a fixed volume, there exists is a certain temperature to which the air needs to be heated which will produce sufficient lift to counter the force of gravity. This temperature is called equilibrium temperature (Crouch, 1983). Deviating from equilibrium by just one or two degrees will cause the balloon to ascend if the temperature is above equilibrium and descend if it falls below (Marion, 2000). Therefore, in order to maima*" flight with a thermal lift balloon, this equilibrium was maintained with airborne fire.

Early Thermal Lift Problems

The account of the first Montgolfiere flight written by d'Arlandes (d'Arlandes, 1965; Ferguson, 1972; Wise, 1850) explains the difficulty of dividing one's attention between the fascinating view of the world from above and the urgency of keeping a steady flame. However, the crew had another urgent endeavor while aloft. Aeronauts at that time not only had to keep their balloons aloft, but also had to keep them from burning up. Early aeronauts employed sponges on the ends of pitchforks (Bacon, 1997 ; Clarke, 1961; Norgaard., 1970; Wise, 1850) dipped in water to douse envelope fires caused by embers rising from the flames. These fires were common considering the envelopes were made out of paper and cloth (Block, 1966; Norgaard, 1970; Wise, 1965).

There were other obvious problems with the early hot air balloons. Providing a place for the fire and the crew resulted in construction of a rather large gondola so the aeronauts would not be burned. The need for a platform upon which to build the fire resulted in the use of a large wrought iron fire basket (Crouch, 1983). Both of these features added significant weight to the aircraft. This additional weight made it necessary to generate a greater amount of hit by increasing the size of the fire. Controlling the heat and the amount of lift generated was difficult.

Directly related to this was the choice of what was to be burned. Whatever fuel was chosen, it was needed in great quantities for a flight of significant duration. Thus space needed to be reserved for fuel storage and the fuel itself added to the weight to be lifted. All weight hindered lighter than air flight. Furthermore, at the conclusion of a successful flight, there was still the issue of having a rather significant fire burning upon re-contacting the earth. The real or perceived threat of fire from hot air balloon operation was so great that it prompted Catherine the Great to ban their operation in Russia in 1784 (Alexander, 19%). The evolution of thermally lifted aircraft was dependent on the resolution of these issues. *Predominance of Hydrogen Ballooning*

Ten days after the first thermally lifted aerostat flew, Jacques Charles ascended in a hydrogen filled aerostat (Cottrell 1970; Crouch, 1983; Norgaard, 1971). Lift was created due to hydrogen gas already being lighter than air. The hydrogen-filled aerostats once inflated, were easy to manage in the air. Ballast was dropped to ascend, and the gas was vented to descend. Table 1 provides insight to the advantages and disadvantages of the two forms of lift generation available for aerostats in 1783.

Table 1. ***Comparison of Aerostat Characteristics hi 1783***

	Cost	**Durability**	**Size**	**Inflation time**	**Flight**	**In-flight**	**In-flight**	**duration**
Thermal lift aerostats	Inexpensive due to low fuel cost	Short life due to heat degradation and envelope	Large	10 to 30 minutes	Minutes to afew hours	Challenging to regulate heat and control fire	Acceptable for a short time	Perilous due to fire and disruption upon ground
Hydrogen lift aerostats	Expensive due to the cost of producing	Repeated use with care of envelope	Small	Several hours	Several hours	Easy with ballast and venting	Good	Simple by venting hydrogen

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Hydrogen balloons were easier to regulate and control while in the air. Most of the difficulty in operating a hydrogen balloon occurred on the ground during inflation (Wise, 1850). Hot air balloons were relatively easy to inflate but the majority of the operating difficulty resulted from trying to regulate the fire in flight to control the balloon air temperature and ensure the envelope did not burn. Given the choice between problems in the air or on the ground, most fledging aeronauts preferred the latter (Crouch, 1983; Lunardi, 1965; Wise, 1850).

In a short time the benefits of flying with hydrogen were nearly universally accepted (Wise, 1850,*1965).* As a result, most historical accounts of aviation prior to the Wright Brother's development of heavier-than-air flight concentrate on hydrogen gas ballooning. The use of airborne heat generation for lifting aerostats was still pursued but it was a very secondary choice for lift production. Although early accounts of hot air ballooning with airborne thermal lift are scarce, they do exist and provide clues as to the development of thermal lift generation during this period.

Early Design Safety Adaptations

In the original Montgolfiere built by the brothers Joseph and Etienne Montgolfiere, the fire was located in the center of a large, round passenger carriage (Crouch, 1983). The fire basket was made of wrought-iron wire hung from the neck of the balloon by chains with the neck being 16 feet in diameter (Norgaard, 1970; Rolt, 1966). Additionally, around the perimeter of the fire basket was a three foot wide wicker gallery suspended by small cords sewn into the balloon envelope fabric (Rolt, 1966). Passengers could reside at a safe distance from the flames in this large size carriage.

Thus the designers attempted to safely generate thermal lift with fire by creating the first balloon's carriage with a total diameter of 21 feet. It was necessary for the aeronauts to stand on opposite sides of the fire basket to keep from stressing the envelope due to weight imbalance (Wise, 1850). The Montgolfieres built the neck so it extended all the way to the floor of the gallery and provided an opening on each side through where the aeronauts could tend the fire.

The first Montgolfiere also had an elevated fire basket. It is clear from drawings that the access holes in the balloon's neck for tending the fire extended only slightly higher than the height of a crew member (Cottrell, 1970). Allowing for the height of the stacked fuel, in this case straw and rags soaked in spirits of wine, it is likely that the fire basket on the first Montgolfiere was no higher that three or four feet off the floor of the gallery. Passengers in these early Montgolfieres no doubt experienced the heat from the fire and felt significant discomfort.

From these crude beginnings aerostats using thermal lift systems evolved. In 2002 propane fed fires generated by burners with enormous output are positioned safely overhead of the crew and passengers. Changes to the systems employed for generating thermal lift went though a rather slow and extended evolution. The slowness of this development was due to the prevalent use of hydrogen as a lifting agent for nearly the next two hundred years. However in the year 1784 much flying with thermally lifted balloons did occur and the shortcomings of thermally lifted aerostats began to be addressed.

Passenger Comfort Improvement

Chevalier Paulo Andreani and his brothers, Augustin and Charles, attempted to alleviate the problem of fire and people coexisting in the same carriage by suspending the passenger car beneath the fire brazier (Rolt, 1966). Their new design was employed in the first flight of a manned hot air balloon in Italy on February 25, 1784 (Crouch, 1983) This design certainly would have provided a cooler ride for the aeronauts and reduced the dimensions of the carriage. Unfortunately, there still was a problem with embers and ash falling on the passengers below, and it was also difficult to control the fire from beneath the brazier (Rolt, 1966).

Simple remedies such as a pan under the fire would have protected the passengers from falling ash and a ladder would have allowed a single individual to have tended the fire from an elevated position. Yet there is no indication the Andreani brothers continued to use this design or made these simple adaptations. Regardless, the brothers were the first aeronauts to place the thermal lift generating apparatus above the passengers which is a key to the success of thermal lift aerostats constructed between 1960 and 2002.

Landing With Fare

The open fire in the carriage continued to be a problem during landings in the early Montgolfieres. Any but the softest landing would shake the fire scattering burning material onto the ground, the balloon, and sometimes the passengers (Rolt, 1966). During a very rough landing, the entire fire might dislodge from the brazier. The Montgolfiere brothers were known to have experimented with releasing the fire basket upon landing so it would not ignite the rest of the balloon (Rolt). It is likely that they abandoned this idea quickly. The brothers evidently discovered that removing the weight of the brazier and fire from the aerostat resulted in too much lift for the remaining weight of the system. Upon detachment the balloon would have become buoyant again, only this time, with no fire to temper the descent rate when the balloon cooled below equilibrium. An alternate solution was required to prevent balloon fires upon landing.

In England, John Sheldon built and attempted to fly a hot air balloon on August 16th, 1784 and again on August 29* of the same year (Rob, 1966). The balloon had a seven foot diameter fire basket with a hinged lid to act as a snuffer in case of an emergency (Rolt, 1966). No doubt this snuffer was to be lowered upon landing and would have aided in containing the fire during the jostling. However, Sheldon's balloon was destroyed without ever having flown successfully (Rolt, 1966)

Shortly thereafter, on October 4th, 1784, James Sadler, also an Englishman, incorporated an enclosed furnace into the design of his Montgolfiere (Rolt, 1966). Although heavy (300 pounds), this development seemed to have been the answer to containing the fire in thermally lifted aerostats. It also offered improved regulation of the flame via a damper. Sadler, however, had only one successful flight with this furnace. The flight ended with a preemptory landing shortly after he dropped his tool for tending the fire in the furnace overboard (Rolt, 1966). Sadler's subsequent flights were done with hydrogen (Rolt). Unfortunately, by the end of 1784, interest in flying with hydrogen had become so prevalent that further developments on a furnace seemed forgotten by Sadler and most other aeronauts.

Enormous Balloons with Furnaces

Ironically, Sadler's idea was reborn not because of a modification to the furnace but due to the development of hydrogen ballooning. Through the turn of the century and into the early part of the 1800s, hydrogen ballooning was progressing (Crouch, 1983; Rolt, 1966). In order to carry a larger number of people or to fly greater distances, enormous hydrogen balloons with great lifting capacity and flight duration were built. Emulating this trend toward larger craft in 1838, Englishman J. W. Hoar employed hot air to lift a large balloon (Rolt, 1966). He built a 170,000 cubic foot thermal lift aerostat with a stove to provide heat for lift (Rolt). This balloon had a chimney that extended into the neck of the balloon. However, Hoar never successfully inflated this balloon.

Whether there was too much fabric for known inflation techniques or the stove was not sufficient is unknown. Hoar tried again with a 215,000 cubic foot balloon in 1839 (Rolt, 1966). He again failed to accomplish an inflation. John Wise, a scholar and the most experienced American aeronaut of the nineteenth century, wrote a very encompassing volume on balloons in 1850. Wise (1850) however, did not cite either Sadler's or Hoar's attempts to fly with thermal lift. He wrote that flying with Montgolfiere balloons was dangerous and their only future for sustained flight depended on the development of a better method than the open brazier for carrying the fire.

Into the mid 1800s, attempts to fly with fire aloft in the basket were still encumbered with the same problems encountered in 1783: a.) the carriage remained too weighty, b.) the risk of envelope fire, c.) the danger of fire upon landing, and d.) the passengers remained exposed to the heat from the fire. A gigantic hydrogen balloon built by Felix Tournachon, who was also known as Nadar , was flown by the prominent French aeronaut Eugene Godard in 1863 (Dollftis, 1961). This experience inspired Godard. In 1864, he built his 500,000 cubic foot hot air balloon (Rolt, 1966) . The enormous diameter of the opening at the bottom of the balloon allowed a carriage of similar dimensions as the original Montgolfiere design. Lift was generated with a round stove approximately 12 feet in diameter and weighing 950 pounds. Although heavy, the large envelope capacity easily enabled sufficient thermal lift to be applied for bouyancy (Rolt).

Godard patented this furnace (British Patent No. 2859, 1863) which contained a number of features that addressed the problems of generating lift with fire. The stove had an outer shroud enabling air to circulate between the core stove and the exterior thus providing a cooler ride for occupants of the carriage. Within the stove was the iron platform upon which the fire was built but below it was an ash pan that doubled as a draft (British Patent No. 2859, 1863). This platform could be raised and lower to regulate combustion airflow thus improving temperature regulation. Below the pan a perforated cone guided air into the stove. A conical chimney extended upward 18 feet (Bacon, 1997) in an effort to guide the heat into the balloon. In the chimney, a wire gauze disk was placed to prevent embers from entering the envelope. The chimney also had regulating dampers. This stove filled a significant void in the development of lighter than air flight with airborne heat generation. Its downfall was its enormous size. The entire

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balloon weighed well over two tons, making it cumbersome to launch and to land (Dollfus, 1961). However the balloon did provide a relatively comfortable ride with a reasonable amount of control for an aircraft so large and the risk of fire was greatly reduced.

Godard's behemoth balloon of the 1860s defined the state of the art of Montgolfiere balloons in the first century of manned flight. No evidence indicates any further improvement to Montgolfieres in the subsequent two decades. *Early Fads*

Throughout the first century of experimentation and flight with airborne thermal lift generation, the fuel for the fire was always a choice open to the inventor/aeronaut. Pilatre de Rozier's accounts of tethered experiments and Marquis D'Arlandes' account of the first manned free flight in 1783 described feeding the fire with straw during flight (Crouch, 1983; Wise, 1850). Alcohol soaked rags were also used perhaps to start the fire for inflation and raise the balloon temperature to near equilibrium. Once buoyant, the highly flammable straw could have been introduced in precise quantities or withheld to finely regulate the fire temperature to precipitate ascent or descent.

These fuels were not the only fuels utilized during the formative years of hot air balloon flight. Many different fuels were used by various aeronauts including old shoes, decomposed meat, chopped wool and rabbit skins (Crouch, 1983). These experimental fuels likely reinforced doubts held by skeptics of thermally lifted flight. Yet Eugene Godard specified in his patent that the fuel was to be light wood and straw (British Patent No. 2958,1863).

It must be noted that Count Zambeccari of Italy used brandy as an alternative fuel. In 1800, Zambecarri flew a combination hydrogen and hot air balloon utilizing a *lamp* to heat the air in the balloon (Stehling, 1975; Penny, 1996; Zambeccari, 1965). This marked the first use of liquid fuel in airborne thermal lift generation and the first use of a burner device. These are noteworthy developments since modern hot air balloons utilize liquid propane. But combination balloons require very little heat when compared to a Montgolfiere due to the hydrogen portion of the balloon providing most of the lift. Brandy was never used in a pure Montgolfiere balloon and records do not indicate any other aeronauts adopted its use.

CONCLUSION

Although the first 100 years of manned flight was dominated by hydrogen balloons, thermal lift ballooning continued. The scattered efforts put forth by many early aeronauts succeeded in improving the original design of the Montgolfiere thermal lift aerostat. Eugene Godard was responsible for incorporating most of these design elements into his 1860's aircraft but did so without addressing the large size and weight problem. Credit goes to Zembacari and the Andreani brothers for employing design elements that become the standard during the second century of ballooning. Despite alternative fuel choices, it is justified to label the first 100 years of the airborne generation of thermal lift in aerostats the "straw powered era. "4-

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