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The Hindenburg tragedy revisited: the fatal flaw found

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A television commercial much heard in the U.S.A these days asks: 'Will we ever say fill'er up with hydrogen?' This must seem a form of public acceptance to many readers of this journal, who have been implicitly answering, a priori, in the affirmative over the past twenty-five years. We can at last sense that the day of hydrogen fueled transportation is indeed coming, although we know better than most that problems remain to be solved. While most of these are technical in nature, the most critical may be social—that of public acceptance. This revolves about the issue of safety.

Safety, of course, is an issue with any fuel. The properties that make a substance a good fuel inherently make safety a most important consideration, and require appropriate procedures for safe handling. It is, as a matter of fact, difficult to imagine a fuel more dangerous than gasoline, as numerous tragic explosions and fires testify. Still, we have learned to handle it with a high degree of safety, and do not hesitate to serve ourselves at our local gasoline stations. We have come to accept gasoline with all its hazards, as we have learned to handle it with the necessary respect and precaution. Those of us with some experience in handling hydrogen are confident that hydrogen will also come to be accepted in this manner.

At the same time, it must be acknowledged that, today, the mention of hydrogen as a vehicular fuel raises questions by the general public as to the safety of such usage. Much of this concern may be traced to having heard of the 'hydrogen bomb', and the tragic demise of the great German Zeppelin, the Hindenburg—at least, this is the experience of the authors in presenting the case for hydrogen as a transportation fuel. The 'hydrogen bomb' fears may be dealt with quite promptly and directly; after the appropriate explanation, people accept the fact that it simply has no relation at all to hydrogen usage in vehicles. The 'Hindenburg syndrome' is another matter, however. There was certainly an abundance of hydrogen aboard, and, although a satisfactory explanation of how it might have been ignited has never been advanced, the assumption of its guilt was not unreasonable. The authors strongly contend otherwise, however, and consider it appropriate to summarize the case for hydrogen's exoneration in these pages. Hopefully, readers will then—over time—help 'spread-the-word' and reduce, if not eliminate, the negativity generated by the misinterpretation of the cause of the Hindenburg tragedy.

Figure 1 shows the Hindenburg in a routine landing at the Lakehurst Naval Air Station in New Jersey, U.S.A., in 1936. It was a stately ship, 804 feet in length with a maximum diameter of 135 feet and weighing in at 240 tons. The total gas capacity (max design) was 200,000 cubic meters, or a little over 7,000,000 cubic feet. It was filled (99%) at Frankfort before departure to Lakehurst, and was about 80% full on arrival. Interestingly enough, there were earlier plans to add an engine to run on hydrogen, but these were not implemented. There was space, luxuriously appointed, for 72 passengers.

Figure 2 shows the beginning of the disaster of 6 May, 1937, in which 35 of the 97 persons aboard perished. It is worthy of more than a passing glance, especially in view of the conclusions reached by the Board of Inquiry in seeking an explanation of it. There were two such Boards, in fact, and each concluded that some hydrogen had, in a manner never explained, become free, was ignited electrostatically and exploded. Figure 2 is a photograph made from a 'newsreel' film being made of the landing, and defines the first fraction of a second of the ignition. In studying the frames of the newsreel following that reproduced as Fig. 2, it can be inferred that one or two of the hydrogen gas cells in the rear, severely overheated and consequently overpressurized, burst providing a 'jet effect' from the escaping (and then burning) hydrogen which gave a forward thrust to the airship—still in trim. This sudden motion dislodged two waste water tanks (which, in the newsreel, can clearly be seen to be in free fall). This loss of ballast in the front end of the ship caused the nose to rise. Thus the fire moved forward, making survival even more difficult. It would take undue space to reproduce the several frames in the newsreel as figures here, but study of Fig. 2 itself

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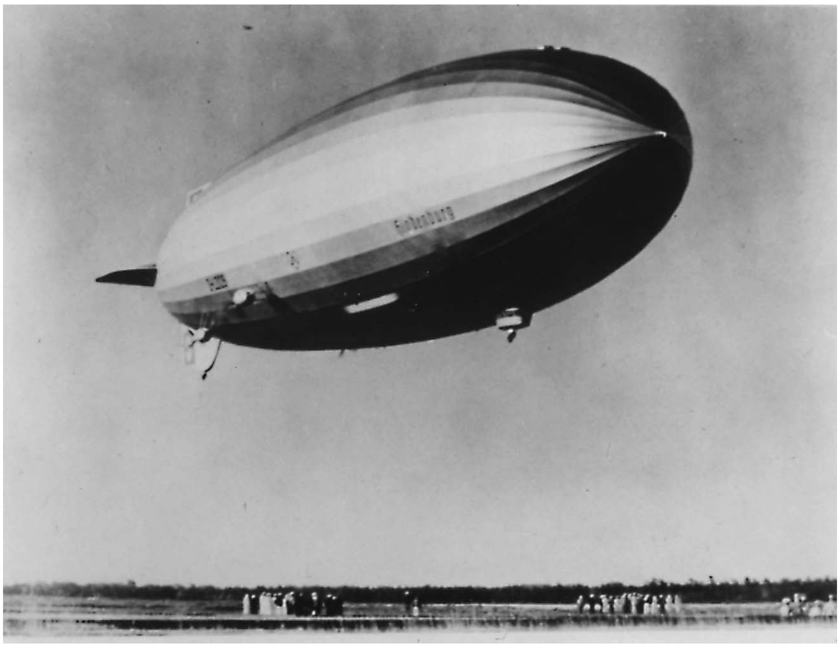

Fig. 1. The Hindenburg, 1936.

Fig. 2. The Hindenburg, 6 May, 1937.

raises issues. Clearly, there was no instantaneous explosion, and the ship is still in trim. What was burning? Hydrogen burns with a colorless flame, while witnesses compared the flames with a fireworks display. And, the picture indicates some downward burning. Hydrogen would typically burn only upward!

These issues and other concerns stimulated one of the authors (Bain) to undertake a long journey (physically as well as intellectually) in search of answers. The mission soon revolved about the nature of the skin, or envelope, of the Hindenburg. If hydrogen did not ignite initially, and if there was no evidence of an internal ignition source, the electrostatic activity over the skin became a prime suspect. An exhaustive review of the literature was conducted, and contacts made with airship experts and airship historians. Several of the pictures made from the newsreel of the burning airship were colorized based on eyewitness recollections; the Fire Sciences Laboratory in Missoula, Montana (U.S.A.) was visited. Specimens of the actual fabric were obtained. A former airshipman who had been stationed at Lakehurst provided some samples of the Hindenburg fabric that he had recovered from the mooring site. The editor of *The Zeppelin Collector* furnished a sample of the fabric from the LZ-130, the sister ship of the Hindenburg (the Graf Zeppelin II) and from LZ-127, the initial Graf Zeppelin. Survivors and witnesses of the disaster were located and interviewed. The NASA Materials Science Laboratory provided analysis of the fabric samples through electron microscopy and infra red spectroscopy. The Hindenburg files of the archives of the (U.S.A.) National Air & Space Museum were studied, and the files of the Zeppelin company archives in Friedrichshafen, Germany, were examined in detail. The latter was made possible by the very special (for an American) privilege extended by the Zeppelin company. The Zeppelin works, and the museum were also visited. The statements and discussion that follows are based on the information obtained from these sources. In particular, this information, and the laboratory tests implied, allow an authoritative description of the fabric. The covering itself was made of a cotton fabric. In order to tauten and weatherproof the fabric a 'doping' was applied—in a rather primitive manner, as shown in Fig. 3. The procedure made for an uneven application, to say the least. And the choice of the doping materials does defy (today's) logic. The first coat was an iron oxide and was followed by four coats of a cellulose butyrate acetate, which included a suspension of aluminum powder. The total mix might well serve as a respectable rocket propellant. Figure 4 is also worthy of note. It shows the manner of securing the cotton fabric covering to the Hindenburg's structural frame. The cord used to draw the two edges of the fabric together was made of ramie, a very strong textile made from a nettle native to China. The opening had to be covered, of course, and this was accomplished by the use of wooden dowel spacers and faring strips over which a strip of the covering fabric was held in place with the cellulose acetate doping compound. This made the covering highly non-conductive. There must have been about 100 such closures dis-

Fig. 3. Application of the 'Doping' compound.

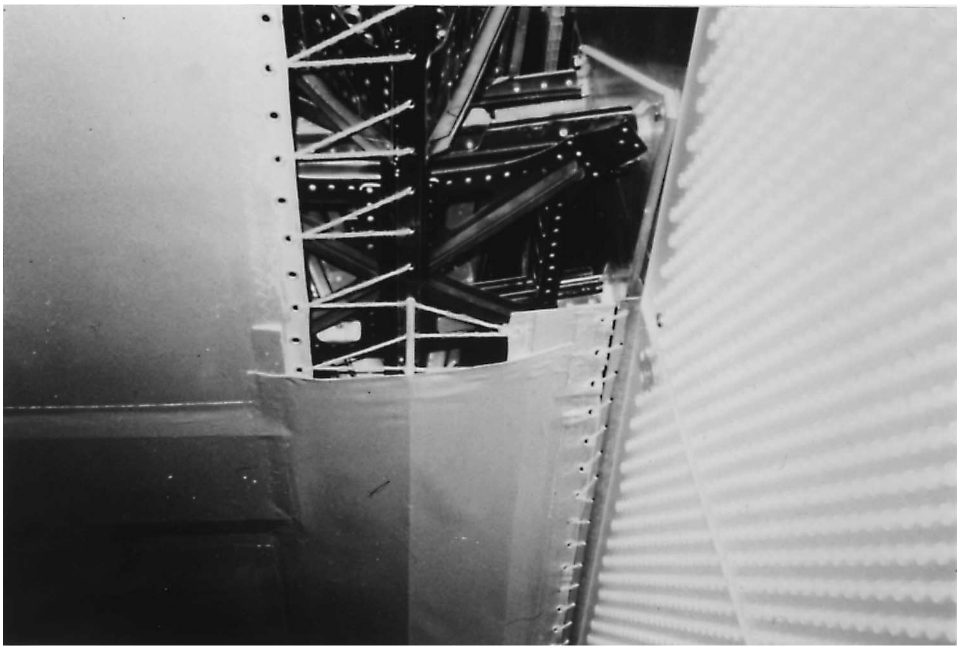

Fig. 4. Securing the skin fabric of the Hindenburg.

tributed around the surface of the Hindenburg. As a result of the electrostatic activity, the skin became highly charged, and finally passed the current through the skin to the frame. In the process, the skin and its highly energetic doping constituents were ignited, setting off the conflagration. The fire quickly engulfed the wood doweling and fairing, the doped fabric, and other fabrics—even silk in the passenger staterooms. It became a raging inferno in seconds, and, according to information from the Fire Sciences Laboratory, would be classed (from the colorized photograph) as a cellulose fire, not unlike a forest fire.

It must be remembered of course, that the time of construction of the Hindenburg was the early 1930s—before plastics, before thin metal cladding, and before rocketry so that the extreme flammability of the substances used may not have been fully appreciated. Yet, analysis of the fabric from its sister airship, the Graf Zeppelin II (LZ-130), being completed at the time of the Hindenburg accident indicates that remedial measures were quickly undertaken. Calcium sulfamate was apparently added to the doping mixture, for example; calcium sulfamate was widely used as a *fire-proofing* agent in the textile industry. The doping compound was further modified by substituting powered bronze for aluminum. Though heavier, the bronze would be far less combustible, and more conductive. Further, the ramie cord holding the fabric in place, as shown in Fig. 4, was impregnated with graphite so as to make it conductive, thus reducing the potential between skin and the structure. Clearly, there must have been strong suspicion that the fabric was the real culprit. This conclusion is strengthened by two letters, copies of which were obtained by Bain from the Zeppelin museum. An electrical engineer, Otto Beyersdorff, reported to the Zeppelin company after investigating the cause(s) of the fire wrote: 'The actual cause of the fire was the extremely easy flammability of the covering material brought about by the discharges of an electrostatic nature.' He went on to state that he had tested samples of the material in the laboratory '. . . matching the conditions of the accident, . . . which proved the material to be easy to inflame.' So, the company knew the actual cause of the disaster, even though its chairman, Hugo Eckener publicly blamed hydrogen. Why? Perhaps to put the United States in an unfavorable light for not being willing to supply helium for use as the buoyant force. Perhaps to cover up what proved to be poor design decisions in the choice of doping materials. Perhaps thinking that blaming the hydrogen would do less damage to the Zeppelin industry than faulting the construction of the Hindenburg itself.

Figure 5 shows an airship engulfed in flames. The cause of the fire is not clear, but it is known with certainty that helium supplied the buoyant force—not hydrogen! This, in addition to the factors presented above, supports the conclusion that *hydrogen was not responsible for the Hindenburg disaster!* It would, indeed, have occurred if helium had been used in place of hydrogen.

The foregoing notwithstanding, the authors wish to acknowledge their admiration of the Zeppelin company's

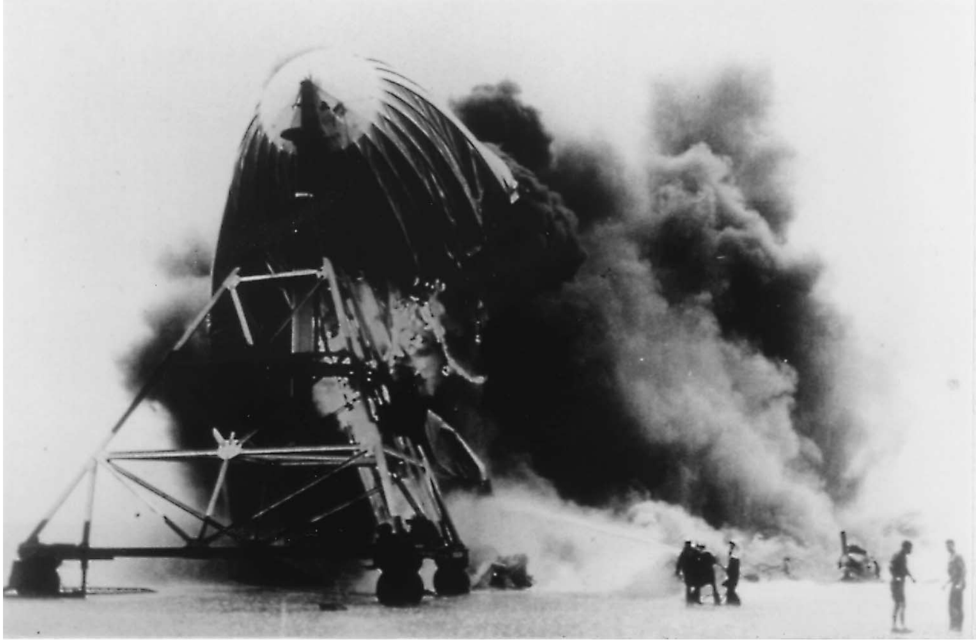

Fig. 5. Burning of a helium-filled airship.

successful design, construction and operation of their series of lighter-than-air craft. It was a remarkable engineering achievement. In the end, it was an unfortunate flaw—not unlike that in the Titanic (the use of sulfurous brittle steel) and the Challenger (the O-ring)—that failed because of unanticipated environmental conditions.