DEPARTMENT OF COMMERCE

BUREAU OF AIR COMMERCE

SAFETY AND PLANNING DIVISION

REPORT NO. 11

THE HINDENBURG ACCIDENT

A Comparative Digest of the Investigations and Findings, With the American and Translated German Reports Included

By

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Acting Chief, Air Transport Section

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The views expressed in this report are those of the writer and not necessarily of the Bureau of Air Commerce or the Department of Commerce.

FOREWORD

In connection with the preparation of this report, acknowledgement is made to the Navy Department, the National Advisory Committee for Aeronautics, and the Bureau of Foreign and Domestic Commerce, of the Department of Commerce, for their services in translating the original German report.

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SECTION I

A COMPARATIVE DIGEST OF THE GERMAN AND AMERICAN REPORTS OF THE HINDENBURG ACCIDENT

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A COMPARATIVE DIGEST OF THE GERMAN AND AMERICAN REPORTS OF THE HINDENBURG ACCIDENT

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SUMMARY

This report presents a comparative discussion of the German and American reports, and gives the results of the investigations made to determine the possible cause of the destruction of the Airship "Hindenburg" on May 6, 1937, at about 6:20 PM, at the Naval Air Station, Lakehurst, New Jersey.

It is observed that both investigating bodies covered the same hypothetical points in much the same fashion. While the German Commission report is briefer than that of the American Accident Board, the basic conclusions are not far apart. It is noted that the actual cause of the fire still remains unknown.

The two reports are appended hereto.

INTRODUCTION

The "Hindenburg" misfortune occurred at Lakehurst, New Jersey, during the evening of May 6, 1937. It was caused by fire, and resulted in the complete destruction of the airship, death to 36 passengers and members of the crew, and injuries to numerous others.

Exhaustive inquiries were launched immediately thereafter to determine, if possible, the cause of the fire, which broke out in the stern just as the airship was preparing to land.

The Secretary of Commerce, pursuant to the Air Commerce Act of 1926, as amended, appointed an accident board composed of the following members, all of the Department of Commerce:

South Trimble, Jr., Solicitor
R. W. Schroeder, Bureau of Air Commerce
Denis Mulligan, Bureau of Air Commerce (now Director of the Bureau)

Those designated as technical advisors were:

Commander C. E. Rosendahl, U. S. Navy
Colonel O. deF. Chandler, U. S. Army
Colonel Rush B. Lincoln, U. S. Army
Colonel Harold E. Hartney, Technical advisor to the U. S. Senate Committee on Commerce
Hon. Gill Robb Wilson, Director of Aeronautics for the State of New Jersey
Hon. Grover Loening, Aeronautical advisor to the U. S. Maritime Commission

At the invitation of the Secretary of Commerce, the German Ambassador designated General-leutnant Friedrich von Boetticher, German military attache, as an observer at the investigation.

Members of the German Commission appointed by the Reichsminister for air General Oberst Goering, to investigate the accident arrived on the fourth day of the hearings. They were:

Dr. Hugo Eckener
Lt. Colonel Joachim Breithaupt
Professor Guenther Bock
Professor Dr. Max Diekmann
Director Dr. Ludwig Duerr
Staff Engineer Friedrich Hoffman

During the hearings they appeared as observers and testified as witnesses, but later they conducted their own investigation and released a report of their findings.

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DISCUSSION

1. General

The two reports concur on general information concerning registry, airworthiness certification, ship's log, crew, passengers, cargo, and operation. Likewise, they are in agreement regarding the details of the last flight from Frankfort, Germany to Lakehurst, N. J.

The American report goes into more detail concerning meteorological conditions existing prior to and during the landing approach. This report states there were scattered thunderstorms in eastern New Jersey of a local character and not severe, but conditions prevailed at the time of the airship's arrival which caused the Commander of the Lakehurst station to recommend, by radio, at 5:12 PM, a delay in landing. At 6:08 PM he again radioed the ship, recommending an immediate landing, and the airship approached the mooring mast headed approximately into the wind after a few turns made necessary by variable winds. The ship had passed through considerable rain.

2. The Landing Operation

The two reports are in general agreement with regard to the valving of lifting gas, dropping of water ballast, dispatch of 6 men forward due to continued tail heaviness, dropping of the landing ropes, control of the engines, and various other operations and maneuvers which are a matter of record.

3. Radio

Both reports state that the ship's radio transmitters had been turned off about 15 minutes prior to the fire and, therefore, were inoperative.

The ship's radio operator was listening in on the 278 kilocycle frequency, and testified at the hearing that he did not notice any interference which could have been caused by improper bonding or shielding. While not mentioned by the German Commission, this is considered a significant element of the American report.

4. Flutter of Outer Cover

Mention of the fluttering of the outer cover on the upper port stern, just prior to the conflagration, as testified to by a witness, is to be found in both documents.

Much importance was attached to this part of the testimony, since the fire appeared to originate in the vicinity of this flutter. It likewise helped both bodies of investigators to arrive at the most probable cause of the accident.

5. First Appearance of Fire

Both bodies of investigators are in complete accord with regard to the first appearance of open flame, concluding it to have been on the top of the ship, forward of the vertical fin, over cells 4 and 5.

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POSSIBLE CAUSES

A. Contributory Causes

1. Sabotage

The conclusion that no evidence of sabotage could be found is drawn in both reports. The German document goes a step further than the American report, however, by saying; "But the possibility of deliberate destruction must be admitted in view of the fact that no other originating cause can be proven". It gives little consideration to the possibility of an incendiary bullet causing the fire, as this type of ignition would not result in an explosion and this means of attack would be too easily detected. It discounts the possibility of time-fuses or other releases from within the ship, due to close supervision at all times, and it eliminates other possibilities, such as "attack from aircraft", by stating they "cannot be considered".

2. Presence of a Combustible Mixture of Hydrogen and Air through Diffusion

The reports concur generally on this subject, pointing out that the average rate of permeability of about one liter per square meter per 24 hours would be insufficient to account for a combustible accumulation of hydrogen and air within the ship, caused by normal seepage. This is further substantiated in both documents, which point to the effectiveness of the ventilating system. They further state that the system had a chimney (draft) effect that

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should have evacuated such a quantity of gas from the shafts. The German report further states that, because of "the good ventilation of the airship, it is completely out of the question," that such a rich mixture could have formed through normal diffusion.

3. Sticking of a Valve

The German report discusses the possibility of a gas valve failure, stating with certainty that the automatic valves did not operate during the latter part of the flight. It mentions that "it is not completely excluded" that one of the maneuvering valves may have become stuck during valving operations some minutes prior to the dropping of landing ropes, thus allowing hydrogen to escape into the shaft.

The American report points out the possibility of defect or failure of the valves, but states that no testimony is available on this subject.

The latter also dismisses as extremely remote the possibility of failure of the ventilating system, which is in agreement with the German Commission.

4. Entry of a Propeller Fragment

Both commissions concurred in the belief that no propeller breakage occurred until impact of the engines with the ground had occurred.

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5. Leaking of Gas Cell

Both reports discuss as a significant possibility the breakage of a steel brace wire which could puncture one of the rear gas cells, through which the gas could flow into the space between the cells and outer cover, resulting in the flutter mentioned previously. The German statement reasons that this assumption is supported by the ship's tail-heaviness during the last turn, also by the fact that gas was valved twice from forward cells, and that considerable water ballast was dropped from the rear, to correct this condition.

Both statements mention that shear wires had broken before with varying effects, but had caused no serious damage.

6. Major Structural Failure

No mention is made in the German report of the possibility of a major structural failure in the stern, which would cause hydrogen to be liberated by the rupture of a cell and the forceful breaking of an electric lead or metal part, thus producing a spark. Little weight is given to this possibility in the American report.

B. Ignition of the Gas Mixture

1. Mechanical Causes

Both statements are in agreement that, although conceivable, ignition or a spark caused by the breakage of a tension wire, or by friction of wires or other metal members of the ship due to failure is extremely remote, and such a hypothesis is unsupported by the evidence.

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2. <u>Chemical Causes</u>

Again the reports agree, that although such a gas mixture could ignite while flowing over metals which have a catalytic effect, it is significant that no such metal was in that part of the ship where the fire originated. The American report further states that evidence is inadequate to support the theory of a flame being produced by spontaneous combustion.

3. <u>Thermodynamic Causes</u>

Technical reasons of similar nature are given in both statements virtually eliminating the possibility of fire being caused by sparks, hot carbon, or by the heat of exhaust gases produced by the diesel engines.

4. <u>Electrical Causes</u>

(a) <u>Broken Contact</u>

Lengthy discussions of this subject are contained in both reports, which differ in some respects, but which are similar in conclusions. Both concede that it would have been possible, although highly improbable, that the "deterioration" (American report) or "dirty condition" (German report) of the contact rollers which transferred current between the fixed part of the pressure meter and the movable resistance element might have produced a spark igniting the gas in one of the pressure meters. This possibility is further

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discounted in the German report which calls attention again to the good ventilation within the axial walkway, and which is substantiated by the American findings.

(b) High Frequency Inductance

The possibility discussed at length in both reports, that electrical high frequency inductance or high frequency impulses traceable to radio transmission caused the ignition, was dismissed as being highly improbable. The ship's transmitters were in "off" position. Only the local direction transmitter of 15 watts (low power) on the Lakehurst Station was in operation, and it was at a distance of about 1800 feet from the airship. Both reports stated that the strength of this electrical field is so infinitesimal that it could not cause an electrical discharge.

(c) Electrostatic Causes

In principle, the reports agree in the technical discussions on the subject of electrostatics. They explain that an airship, as a body, is regarded as carrying an electric charge (positive or negative) depending upon the circumstances. For this reason, the airship is bonded or connected "so that electrically it becomes one complete metallic whole". This is done to preclude the possibility of an electric spark jumping from one metal unit to another.

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Not mentioned in the German report, but specifically mentioned in the American findings, was the fact that the electric wires at the stern electric lamp of the airship were not bonded. Even though one witness at the hearing indicated that a static charge could have been produced at this point, the American report considered it highly improbable.

(d) Ball Lightning

Mention is made in both reports of the possibility of ball lightning, which is said to "spread and split into segments, some of which continue for a distance along objects on which they alight."

This was brought out in the American report for "what it might be worth", but it was considered entirely remote in both statements, due to testimony of witnesses that no lightning was present.

(e) Brush Discharge, or St. Elmo's Fire

This was the subject of a lengthy discussion in both reports, resulting in comparable conclusions.

To both investigating bodies it appeared that a steep potential electrical gradient existed. The German report mentions that such a condition would be particularly applicable over the fin of the airship, stating further, "Between ship and atmosphere, the occurrence of a brush discharge or St. Elmo's fire could be well conceivable. As a hydrogen-air mixture burns nearly without color, under the given circumstances the first ignition could have happened on the upper part of the vertical stabilizing fin and could have quickly spread to the leading edge of the fin on the ship's body."

Both reports agree that the so called time constant of electrical discharge from ship to ground could be from a small fraction of a second to well over a minute. The time element in this case would depend upon the conductivity of the ropes, which were dry when thrown out, but which slowly became damp and thus becoming better conductors of electricity. The German report states that the free electricity of the influx charge of the airship can flow to the earth rapidly, and that the ship very quickly assumes earth potential, but that the free electricity of the humidity or dampness layer (water on top the ship) cannot flow off so quickly and harmlessly; "it jumps over the framework in the form of a spark if the tension difference is high enough and starts the catastrophe in the presence of inflammable gas mixture." It cites tests that were made at Air-electric Test Station Graefelfing, "during which the electric earth field was represented by an artificial one, and during which those conditions were logically recreated which probably were present during the landing and in many cases ignition of the hydrogen-air mixture could be produced."

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This theory is likewise substantiated in the American report, from a conclusion drawn by Dr. W. J. Humphreys of the U. S. Weather Bureau, who made a detailed study of the problem. His findings stated that a brush discharge, or several of them, could have occurred only after the landing ropes touched the ground and that this would have continued for some time, although it would have been invisible in the daylight. Quoting his report: "that such a discharge likely would have ignited any adequately rich stream of leaking hydrogen that reached it; and that from the point of ignition the flame would have shot back to the leak, there quickly would have burnt a larger opening and set going a conflagration of great violence and rapidity."

The German report further points out two improbable causes. The first is a division of electricity caused by the running engines, one charge remaining on the aircraft and the other disappearing with the exhaust gases. The other is the possibility of electrical charges and ignitions being caused by the escape of lifting gas carrying solid or fluid particles along the opening edges with sufficient speed to ignite. Both of these hypothetical possibilities were dismissed as being unfeasible under the conditions existing.

CONCLUSION

In its conclusion, the German Commission's report states that: "In spite of thorough questioning of all witnesses, in spite of thorough-going inspection and search of the wreckage, ... evaluation of all pictorial documents giving testimony of the

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sequence of the fire, no completely certain proof can be found for any of the possibilities cited above." It reviews the operation record and states that everything possible was done to prevent the occurrence of such an accident.

The German report again makes reference to the possibilities of criminal attack, stating that if they cannot be considered, the following explanation of the accident appears to be the most probable:

During the landing approach a leak developed in gas cell 4 or 5 in the stern, perhaps through the tearing of a wire. Leaking hydrogen then entered into the space between the cell and outer cover, causing an inflammable mixture of hydrogen and air to gather in the upper rear part of the airship.

It was concluded that ignition of the gas could have come from two sources:

(a) Brush discharges due to atmospheric electrical disturbances.

(b) A spark caused by equalization of tension between wet spots on exterior, and the ship's framework, the latter being better grounded than the covering after dropping the manila landing ropes.

Of the two ignition possibilities mentioned above, the German Commission believes the latter (b) to be the most probable one.

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The conclusion of the American report concurs with that of the Germans' in expressing the opinion that a leak occurred in the vicinity of cells 4 and 5 causing a combustible mixture of gas and air to form in considerable quantity. It does not, however, hazard an opinion as to the cause of the leak as the German statement does.

Pertaining to the ignition of this gas mixture, the American conclusion makes no reference to the possibility of the equalization of tension theory (b) which the Germans considered most probable, but concludes that the most likely cause was brush discharge (a).

Attention is called to the similarity of the two reports up to the final sentences of their conclusions, which reflect a difference of opinion as to the most probable cause of the spark that ignited the mixture of gas and air resulting in the catastrophe.

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SECTION II

TRANSLATION OF THE GERMAN COMMISSION REPORT

Report of the German Investigation Commission
about the Accident of the Airship "Hindenburg"
on May 6, 1937, at Lakehurst, U.S.A.

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SECTION II

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REPORT OF THE GERMAN INVESTIGATION COMMISSION
ABOUT THE ACCIDENT OF THE AIRSHIP "HINDENBURG"
ON MAY 6, 1937, AT LAKEHURST, U.S.A.

A. PRELIMINARY REMARKS:

Immediately after receiving news of the accident to the airship "Hindenburg" at Lakehurst (U.S.A.), an investigating commission was appointed by the Reichsminister for Air, General-Oberst GOERING, composed of:

Dr. Dr.-Eng. E. h. Hugo Eckener,
Director Dr.-Eng. E. h. Duerr,
Lieutenant-Colonel Breithaupt,
Professor Bock,
Prof. Dr. Ph nat. Dieckmann, and
Aviation Chief Staff Engineer Hoffman.

It was the mission of the commission to investigate the causes of the airship catastrophe in cooperation with the American Commission appointed by the Department of Commerce. The German investigation commission received the fullest assistance of all American authorities in its work. After the return of the commission from U.S.A., a series of tests were made in the laboratories of the German Institution for Aviation Research (Versuchsanstalt fur Luftfahrt), Berlin-Adlershof, the radio telegraphic and air electric testing station GRAEFELFING and of the LUFTSCHIFFBAU, Friedrichshafen, to investigate thoroughly the conditions which may possibly have been the causes of the fire. Following is the report of the result of the accident investigation and of the experiments made in consequence thereof.

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B. GENERAL INFORMATION:

The airship LZ-129 ("Hindenburg") was constructed by the Luftschiffbau Zeppelin in Friedrichshafen as the 118th airship and was placed in operation at the beginning of 1936. After a large number of test flights, the airship on March 19, 1936, received its airworthiness certificate from the Reichsminister for Air (Inspection Department for Aircraft). After acceptance by the DEUTSCHE ZEPPELIN REEDEREI, G.m.b.h., the airship made a total of 55 flights in the year 1936, in the course of which it covered about 300,000 kilometers (186,420 miles), crossed the ocean 34 times, and transported a total of about 2,800 passengers and more than 170,000 kilograms (374,782 pounds) of mail and cargo without accident.

Before the airship resumed its flight schedule in the year 1937, it was subjected to reinspection by the Inspection Department for Aircraft and its Airworthiness Certificate was renewed.

The construction of the ship and its most important data may be seen in Illustration No. 1.[1]

C. THE LAST FLIGHT:

The airship departed for the first 1937 North Atlantic trip from Frankfurt am Main (On The Main) on May 3, 1937, at 20.15 (8:15 P.M.) Central European Time, with a crew of 61 persons, and was under the command of Captain Pruss, who had commanded a large number of previous trips of the airship; on board were also 36 passengers. In addition there were

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carried 108 kilograms (239 pounds) of mail, 148 kilograms (326 pounds) of freight, and 879 kilograms (1938 pounds) of passengers' luggage, and two baskets containing dogs. At the landing approach at Lakehurst there were still left 8,500 kilograms (18,739 pounds) fuel oil, 3,000 kilograms (6,614 pounds) lubricating oil and 21,900 kilograms (48,280 pounds) water (for exact distribution, see Illustration No. 2.[1]).

The crossing of the ocean was uneventful except for retardation by opposing (head) winds. New York was flown over at 14.00 o'clock (2:00 P.M.) Eastern Standard Time. (See Illustration No. 3[1]). From there the course was set for Lakehurst, which was reached at 15.00 (3:00 P.M.). But the landing was not made then as a wide electric front was approaching Lakehurst from the west. The subsequent course of the ship was along the shore-line in advance of the electrical front, which slowly moved off towards the north after reaching the coast.

The airship was in continuous communication with the Lakehurst aerological station regarding weather conditions. When proceeding on a southeasterly course in the direction of Atlantic City with the electrical front to starboard, the ship received a radio message from Lakehurst at 17.12 (5:12 P.M.), to the effect that the weather conditions now were suitable for a landing approach. Consequently the airship turned around and headed towards Lakehurst, thereupon entering an area of increasing rain. At 18.08 (6:08 P.M.) it was suggested by Lakehurst that the landing be made as soon as possible.

D. <u>THE LANDING OPERATION AND SEQUENCE OF THE FIRE</u>:

When the airship approached the Lakehurst station from the West-Southwest at an altitude of 200 meters (656 feet), the lower cloud level

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over the station was 600 to 900 meters (1,969 to 2,953 feet), and slight rain was falling. But the sky showed signs of clearing from the west. The barometric pressure was 755 millimeters (30 inches), air temperature 16° C., relative humidity 98%. The ground wind was light and variable.

On first passing over the field (see Illustration No. 4[1]), the commander of the airship noticed that the ground crew was drawn up to correspond to a wind direction from the East, and that the landing approach therefore had to be made over the mooring mast in the westerly part of the field. The airship therefore went beyond the field about 5 to 6 miles, swung in a wide turn, and then approached from this direction towards the landing mast. Since, in the meantime, the wind had shifted towards southeasterly, the airship veered off to port to be able to approach into this new direction, and after completion of this second turn approached the mast from a northerly direction.

The maneuvers executed during the landing approach have been laid down in Illustration No. 4.[1] During the execution of the large turn, about 10 minutes prior to the dropping of the landing ropes, gas was valved from the five forward gas cells twice for 15 seconds and once for 5 seconds. For the same reason water was dropped three times at frame 77 for a total of 1,100 kilograms (2,425 pounds). The engines, after completion of the first large turn, were placed on "idling ahead". During the approach in the last curve, several brief engine maneuvers were executed. About 2 minutes prior to the dropping of the forward landing ropes, all engines were brought to "full speed astern" for the duration

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of about one minute. Afterwards, the forward engines were placed on "idle ahead" and the rear engines on "idle astern". With the exception of a short burst of "full ahead" on the forward engines, the engines remained this way to the end.

The distribution of the crew at the moment when landing ropes were dropped appears in Illustration No. 5.[1] Due to the tail heaviness of the ship, 6 men had been sent to the bow from the midsection during the landing approach in order to trim the ship heavier by the bow by this means.

At the moment when the forward landing ropes were dropped, the control car had an altitude of 90 meters (295 feet) above sea level, that is, about 60 meters (197 feet) over the ground. First the starboard landing rope and immediately thereafter the port landing rope was dropped. The port rope was at once connected with the rope of the hauling-in winch car because the ship began to drift toward the west, which then tautened considerably, whereas the starboard rope was held by the landing crew. The main bow cable, which served to connect the ship to the mooring mast had been let out about 15 meters (49 feet) at the moment when the fire broke out and was therefore still far away from the ground; the handling ropes at frame 62 also had been lot out. The pendant at frame 47 was just being paid out at the moment of the beginning of the fire and had only run out a few meters (yards).

Immediately prior to the beginning of the fire, fluttering of the outer cover on the upper port side between frames 62 and 72 enclosing cell No. 5, was observed by one witness (R. H. Ward). As the ship had no

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headway on and the propeller slip stream had to pass far below the point of the fluttering, this wave motion of the outer cover had possibly been caused by gas which was escaping from a gas cell.

At 18.25 (6:25 P.M.), about four minutes after the dropping of the landing ropes, the fire broke out at the stern of the ship. The testimony about the location of origin of the fire is, to a great extent, widely divergent. The explanation for this is to be found, in the first place, in the very speedy propagation of the fire itself, and then in the different positions which the different witnesses held at the landing of the ship and in the great size of the ship itself which made a comprehensive view very difficult. Evaluating the testimony of witnesses with these facts in mind, the conclusion is to be reached, that the first fire started on the topside of the ship and specifically in front of the leading edge of the vertical stabilizer over gas cells 4 and 5. From there it spread forward about 20 to 30 meters (66 to 98 feet) in the course of some 15 seconds until the first explosion took place. The further progress of the catastrophe can be seen from photographs 6^1 to 11^1. (NOTE: In Photographs 7^1 and 8^1, two falling water ballast tanks can distinctly be seen, which had been torn loose from their fastenings by the shock connected with the explosion).

Between the first appearance of the fire and the contact of the main body of the ship with the ground, there elapsed about one half minute.

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E. CAUSES OF THE CONFLAGRATION:

It appears from all testimony of witnesses that the landing of the airship was executed in a completely normal manner according to the opinion of all experts, and that the behavior of the whole crew prior to and during the catastrophe was exemplary; furthermore, there is no indication that the ship, prior to the landing approach, had perhaps not been in a faultless technical condition.

The ship was completely demolished by the fire as photographs 12 to 14 show. A thorough inspection of the wreckage therefore did not yield any clue to the possible cause of the fire. Although, furthermore, the landing was filmed from several points, that part of the airship in which the fire started was not included thereby, as the preparations for the landing were mainly at the bow of the ship and the cameras were all aimed in that direction. Amateur pictures of the stern of the ship immediately at the beginning of the fire also could not be procured. The only course remaining then, is to draw conclusions from the testimony of witnesses as to the possibilities of the origin of the fire, and to determine by theoretical and experimental analyses which of these possibilities can be considered and which have to be excluded.

For clearing up the accident, investigations were conducted fundamentally in two directions:

I. Has the ship been the victim of a criminal attack?

II. Did a series of physical or other circumstances combine in such a way that a fire could result?

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To clear the first question, the location of the accident and the wreck of the airship were thoroughly investigated for suspicious clues by the German and American Commissions and their experts. Furthermore, the crew members were thoroughly questioned as to whether they had noticed anything out of the ordinary in this connection. Outside of this, all suspicious angles, expressed in numerous communications to the German and American Commissions were investigated.

As causes for a deliberate destruction, the following possibilities can be conceived of:

(a) Devices which were fastened to the inside of the ship.

(b) Effects originating from outside the ship.

The attachment of devices which by way of timed detonators or other releases are able to cause an explosion had necessarily to be effected prior to or during the flight. It is proven that the supervision of the ship and all persons in contact with the ship prior to and during the flight had been done very strictly and thoroughly, so that the introduction as well as the attachment of such foreign objects within the ship was very nearly impossible.

As an effect from the outside on the airship, shooting with an incendiary bullet can be considered. In view of the numerous persons present and the American enclosure of the field, only shots from nearby seem possible out of a silenced gun in a group of persons working together or shots from a long range weapon. In any case the danger of detection would have been very great on account of the large number of people present. Against ignition by an incendiary bullet, there militates the fact

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that a heavy explosion occurred during the conflagration. But as experiences with kite balloons during the world war have demonstrated, balloons set off by an incendiary bullet burn generally without an explosion, as large amounts of explosive mixture cannot form. All other possibilities of explanation as for instance, attack from aircraft cannot be considered.

Proof of the execution of an act of violence as described above could not be found in spite of thoroughgoing investigation. But the possibility of deliberate destruction must be admitted in view of the fact that no other originating cause can be proven. On the other hand, based on the investigation and the experiments made, the unpremeditated ignition as a consequence of unfavorable circumstances, possesses perhaps greater probability as the origin of the fire. But if this possibility is accepted, then two main premises must be met simultaneously:

1. The presence of a combustible mixture of air and gas.
2. The occurrence of an ignition to set this mixture afire.

In the following, both cases will be investigated separately.

1. Development of an inflammable hydrogen - air mixture.

a. Diffusion of the hydrogen through the cell walls.

The walls of the gas cells consist of two cotton cloth layers between which a gas-tight film is imbedded and they possess a mean permeability of 1 liter/per square meter (1 quart/per 11 square feet) in 24 hours. As a purity check on April 28, 1937 shows, the purity in all gas cells was uniformly good; it can therefore be assumed with certainty that the gas cells at the time of the last flight were in faultless condition and the fabric of the cell walls showed no objectionable permeability due to ageing.

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The lower limit of combustability of a hydrogen-air mixture is at a content of about 15% in weight of hydrogen in air. Because of the good ventilation of the airship, it is completely out of the question that through normal diffusion of the hydrogen through the cell walls such a rich mixture could have formed as was claimed by one witness.

b. Sticking of a valve.

Between each two cells a gas shaft leads to the topside of the ship, where it is covered by a hood opening rearward. The draught appearing at the hood causes a strong ventilation of the gas shaft and the interior of the ship: in this it is assisted by the chimney effect of the air warmed in the interior of the ship and rising in the shaft. Above the axial walkway, from each gas cell two valves operate out into the gas shaft, one of which opens automatically upon reaching the pressure-height, whereas the other one is manually operated from the control car for maneuvering purposes. As the ship during the latter part of the flight was only about 80% full, it can be asserted with certainty that the automatic valves did not operate during this period. The maneuvering valves on cells 4 and 5 where the fire first was observed, were operated for the last time about 10 minutes prior to the dropping of the landing ropes. It seems not completely excluded, that one of these valves got stuck during this action and gas could thus escape into the shaft.

The degree of fullness is kept under observation in the control car by means of a precision pressure meter, which records as the lower limit of exactitude, differences in the inflation of 0.2 meters (8 inches) in height. In an 80% full gas cell therefore, with sufficient attention, the escape of about 100 cubic meters (3,531 cubic feet) of gas can be

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recognized. Whether the precision pressure meters were observed during the latter period of the landing approach with such an attention could not be determined. It may be stated however, that failures of the maneuvering valves on the airships "Graf Zeppelin" and "Hindenburg" have never been observed, except once during a flight to South America in the year 1936 when an automatic valve got stuck, the construction of which afterwards was changed.

c. Entering of a propeller fragment.

In the wreckage of the airship a propeller fragment of 30 centimeters' (12 inches) length was found at the port motor, and was covered up by outer cover fabric and was unburned. But after thorough investigation, this piece of propeller was in all probability only torn off after the motor and propeller hit the ground. This is indicated especially by the fact that the four blades of the rear port propeller had been broken off in various almost evenly differing lengths as must be the case if a running motor hits the ground. This observation coincides also with the testimony of the witness Deutschle who was in the rear port engine car and who did not observe any vibration of the engine prior to the crash, as would have to have been the case in the breaking of a propeller.

d. Leaking of a gas cell.

In order to prevent the gas cells from coming into direct contact with the framework, a system of steel wires is placed within the framework, and the cell walls bear against such wires. It sometimes, though very rarely, has happened that a wire of this wiring system has parted. But up until now, this never has had any consequences with respect to strength of the airship or the condition of the cells. It is nevertheless

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conceivable, that by chance a wire of the system tore during the landing approach of the ship, and that the sharp end of the wire caused a leak in one of the rear gas cells through which gas could flow into the space between cells and outer cover. This assumption is supported by the fact that the ship appeared to be strongly tail-heavy during the last turn so that a part of the crew was sent forward from amidships and also that gas was twice valved from the forward cells and a total of 1100 kilograms (2,425 pounds) of water ballast was dropped in the rear. The escaping gas can also have caused the observed flutter of the outer cover. As furthermore, the ventilation decreased in consequence of decreased headway, an inflammable hydrogen-air mixture could have developed inside the ship's covering in such a manner.

2. Ignition of the gas mixture.

(a). Mechanical causes.

Ignition by mechanical means would be conceivable if a construction element, for instance a tension wire, breaks causing a spark thereby which ignites a gas mixture present at that spot. At the moment of the first fire, the ship no longer had headway, so that the development of large stresses, which could have caused the breaking of a wire, is totally unlikely. Tests, which have been made at the Luftschiffbau Zeppelin have furthermore given the result that the energy of a spark at breaking of a wire is not sufficient to ignite a hydrogen-air mixture.

(b) Chemical causes.

A hydrogen-air mixture can ignite itself when flowing over certain structural materials acting as catalysts. But structural materials utilized in airships are out of the question as catalysts. It appears likewise completely out of the question, that any matter acting as a catalyst, as for

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instance sponge platinum could get to the spot where the fire was first observed and could remain there active for any lengthy period.

(c) Thermodynamic causes.

Causing of fire by exhaust gases or flying sparks from the motors was investigated extensively in joint experiments of the Luftschiffbau Zeppelin, the D.V.L. and the Inspection Department for Aircraft.

The exhaust gases of the Diesel engines of the airship have a temperature of about 600° C at highest power output immediately after leaving the cylinder into the exhaust pipe. By mixture of fresh air into the exhaust system, their temperature is decreased to about 500° C at the exit from the powercar, or gondola. Only 0.25 meters (10 inches) distant from the exhaust exit, the temperature of the exhaust gases is already decreased to around 350° C. This temperature is far below the lowest ignition temperature of a hydrogen-air mixture, which depends strongly on special circumstances and is around 550° C.

Sparks present in the exhaust gases, especially with sudden fuel delivery, which consist in the main of glowing oil carbon particles, have a considerably higher temperature than the exhaust gases themselves. It would be conceivable, that sparks from the exhaust of the rear engine cars have been carried to the topside of the ship thus igniting a gas mixture present there. But according to exhaustive experiments, a hydrogen-air mixture cannot be ignited by flying sparks even under circumstances much more favorable than those existing at the airship; apparently the heat energy of the sparks is too small for that.

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(d) Electrical causes.

(a) Disturbances in the electrical equipment of the airship.

The electrical plant is situated between frames 140 and 156. It contains two generators for 220 Volts, which are powered by a Diesel engine each and deliver mainly the power for illumination, heating and radio transformers; in addition a 24-volt generator is attached to each Diesel engine which supplies instruments and emergency lighting through batteries. All wiring, plugs and switches of the installation have been installed according to the safety regulations of the mining authorities. In the neighborhood of the location of the presumed first fire, there are of electrical devices only the precision pressure meters, which transmit electrically the record of the gas pressure within the gas cell to the control car. The precision pressure meter (see Illustration #15[1]) contains a membrane which rests against a plate on springs. An electrical resistance element is solidly connected to the plate in potentiometer coupling, whose relative resistances change with the position of the plate. The current transfer between the fixed part of the pressure meter and the movable resistance element is done through rollers. It is now conceivable that with very dirty rollers a spark may appear at this spot, which could ignite a hydrogen-air mixture present there. But in experiments, jointly conducted by the Luftschiffbau Zeppelin (Zeppelin Contruction Company) and the radio electric testing station Graefelfing, the ignition of a hydrogen-air mixture within the body of the pressure meter never succeeded even under circumstances which were especially favorable for spark formation.

As furthermore, the accumulation of a hydrogen-air mixture within the housing of the precision pressure meter due to its good ventilation within the axial walkway of the airship is quite improbable, a disturbance

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at the precision pressure meter can be excluded as the cause of ignition.

B. High-frequency impulses.

High-frequency impulses can be created under certain circumstances through induction effects by a strong short-wave transmitter working near the airship, which leads to an electrical discharge within the ship. This suspicion seemed especially pertinent because the explosion happened at that moment when a pendant consisting of wire cable was paid out from the rear of the ship. During the landing, only a local direction transmitter was working on the Lakehurst station, whose frequency was 278 kilocycles and whose transmission energy was 15 watts. The airship was about 600 meters (1,969 feet) from this transmitter at the moment of ignition. The field energy at the position of the ship was therefore so small, that it could not cause an electrical discharge.

According to information from the Radio Officer of the airship station, other short wave stations are not present in the neighborhood of Lakehurst. The stations situated at greater distances create only such small field energies at Lakehurst, as approximate calculations show, that they would be insufficient for a spark discharge.

The radio station of the airship has not operated during the landing. As is apparent from the record of the radio communications between the ship and the Lakehurst station, the last communication between the ship and the ground was exchanged on a long wave at 1810 (6:10 PM), that is 15 minutes prior to the start of the fire. A discharge on any part of the ship by its own transmission equipment is therefore also impossible.

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Electrostatic causes.

In landing an airship, the ship, floating at some altitude, is connected with the ground by the more or less well conducting landing ropes in a more or less speedy working electrical equalization process. The self charge and the unbound induced charge of the airship flow down to the ground, the framework and connected metal parts of the ship joined to it taking up the ground potential.

All equipotential surfaces pass out over the upper edge of the grounded airship. Especially over the bow and particularly over the protruding parts of the stern, as for instance on the stabilizing fins an increased potential gradient results. At the time of the landing there probably existed at Lakehurst, strong electrical disturbances in the atmosphere. The fact that direction and temperature of the wind changed, made the occurrence of a secondary thunderstorm probable. Under such conditions, experiences show that an increase of the potential gradient close to the ground has to be reckoned with and hence, in this case especially increased over the vertical fin of the ship. Between ship and atmosphere, the occurrence of a brush discharge or St. Elmo's fire could be well conceivable. As a hydrogen-air mixture burns nearly without color, under the given circumstances the first ignition could have happened on the upper part of the vertical stabilizing fin and could have quickly spread to the leading edge of the fin on the ship's body.

As experiments in the D.V.L. and in Radio Telegraphic and Air-Electric Tests Station Grafelfing have shown, temperature discharges, which lead to an ignition of hydrogen-air mixture can fundamentally be created through brush discharges. The possibility of an ignition by St. Elmo's fire can therefore not be set aside, but it is premised on the presence of quite extraordinary gradients, unless assumptions are made which could hardly have been present in the case under question.

A further possibility for ignition could be given by gradient changes over a time period by the different electric conductivity values of the structural elements of an airship.

A Zeppelin airship is constructed from structural elements of widely different electric conductivities or different electric resistances.

The framework proper consisting in the main of duralumin, the field wiring, cable controls, etc. are metallic conductors with small resistance. Between them no appreciable potential differences can obtain. But the electric resistance of the gas cell fabric, the outer cover, the landing ropes made from Manila hemp, depends very much, as they all are semi-conductors, upon the water contents or the humidity. The lengthwise and crosswise resistances of such materials can have very high values.

If one wishes to discharge a charged condenser through such a high resistance, it always takes some time until the original charge is reduced to a certain fraction thereof. The higher the capacity of the condenser and the higher the resistance, the greater also is the value of this so-called time constant.

If the metal framework is considered the condenser against the earth, which is connected through the landing rope, the time constant varies between one-thousandth of a second and many minutes.

If on the outer cover fabric on the top of the ship there is assumed a limited wet spot caused by rain which has relatively good conductivity (the outside doping is water repellent so that such assumption can be made) then the capacity of this spot is connected over the resistance

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of the layered outer cover fabrid with the metal framework and one finds a time constant amounting in value to seconds, according to the size of the area.

In field changes of atmospheric electricity taking place quickly in point of time, between the wet spot which, as a conductor finds itself in that atmospheric electrical field part which extends by the girder construction of the airship from the outside to the interior, and the framework itself as also between the framework and the earth, potential differences occur, the equalization of which in time is prescribed by the respective time constants.

If the manila landing rope conducts relatively well, and the outer cover relatively less well, then with sufficiently large and speedy changes of the electrical gradient, the tension differences can be sufficient for the formation of an ignition spark through the outer cover fabric. Both conductors, airship structure and the layer of dampness find themselves within quite different conditions with external field changes. The free electricity of the influx charge of the airship can then flow down quickly to the earth and the airship assumes very quickly earth potential, but the free electricity of the humidity layer cannot as quickly flow off harmlessly; it jumps over to the framework in the form of a apark if the tension difference is high enough and starts the catastrophe in the presence of inflammable gas mixture. During the execution of model experiments in the Radio Telegraphic and Air-electric Test Station Graefelfing, during which the electric earth field was represented by an artificial one, and during which those conditions were logically re-created which probably were present during the landing, in many cases ignition of the hydrogen-air mixture could be produced.

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Besides the electric phenomena caused by the exterior field, other charge conditions also can appear on an aircraft. So it was previously proven by the Test Station Graefelfing and the D.V.L. that running gasoline engines effect a division of electricity. The one charge remains on the aircraft, the other flown off with the exhaust gases. As was to be assumed and as more recent investigations at the D.V.L. have proven, the charge of Diesel engines is considerably higher but still not sufficient for a probable explanation of the "Hindenburg" misfortune.

It may also be mentioned that under certain circumstances with the escape of lifting gas, electrical charges and ignitions are caused. In this case, the gas carries solid or fluid particles along the opening edge with sufficient speed. This phenomenon plays a role in the flow of compressed gas from high-pressure containers, but cannot lead to ignition during the exit from gas cells due to the low speeds of the flow.

Finally, the possibility was thoroughly discussed whether "ball lightning" could have caused a leak in a cell of the ship and at the same time ignition. The presence of ball lightning was indicated by the description of the first appearance of fire by several witnesses, who expressly emphasize that the first fire did not have the form of tongues of flames but rather had appeared like a barrel or a neon light. In the literature at home and abroad, ball lightning is similarly described. But since they mostly appear in connection with line flashes and the visible thunderstorm had passed over Lakehurst a longer period before, this explanation seems misleading.

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F. CONCLUSION.

The Investigating Commission has, in the present report, enumerated a number of possibilities, which could have caused the accident to the airship "Hindenburg" of May 6, 1937. In spite of thorough questioning of all the witnesses, in spite of a thorough-going inspection and search of the wreckage, and in spite of evaluation of all pictorial documents giving testimony of the sequence of the fire, no completely certain proof can be found for any of the possibilities cited above. In view of the fact that in the German Zeppelin airship traffic in an operation period of decades no accidents have occurred while utilizing hydrogen as lifting gas, and on the basis of all testimony of witnesses and investigations, the commission has gained the conviction, that everything had been done by all parties responsible for the frictionless execution of the airship traffic to forestall an accident. If therefore not any one of the previously-mentioned possibilities of criminal attack can be considered, the Commission can only assume as a cause of the airship fire a cooperation of a number of unfortunate circumstances in a case of force majeure. In this case, the following explanation of the accident appears as probable:

During the landing approach a leak developed in gas cell 4 or 5 in the rear of the ship perhaps through tearing of a wire, through which the hydrogen entered into the space between cell and outer cover. In this way an inflammable hydrogen-air mixture formed in the upper part of the ship astern.

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For the ignition of this mixture, two possibilities are conceivable.

(a) Due to atmospheric electric disturbances at the time of landing of the airship, the electrical gradient near the earth was so high that it led after grounding of the whole ship at the location of its highest increase, namely at the stern, to brush discharges and in that way to ignition.

(b) After dropping of the landing ropes, the surface of the airship's outer cover became less well grounded than the framework of the airship due to the lower conductivity of the outer cover fabric. At rapid changes of the atmospheric field, which are the rule during night thunderstorms and have also to be assumed in this present case, electric potential differences occurred between spots of the ship's exterior and the framework. In case these spots were sufficiently moist, which was especially probable in the region of cell 4 and 5 in consequence of the previous passage through a rain area, those differences could lead to equalization of tension by a spark, which possibly caused ignition of a hydrogen-air mixture present over the gas cells 4 or 5.

Of the two cited explanations the one under (b) appears to be the more probable one.

The German Investigation
Commission.

Signatures

Footnote 1 - Illustrations and the descriptive data pertaining thereto accompanied the German report but were not reproduced here because of the limitations of the printing process by which this combined report was duplicated. These were not believed essential to the purposes of this report.

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SECTION III

REPORT OF THE
UNITED STATES DEPARTMENT OF COMMERCE
ACCIDENT BOARD

SECTION III

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TO
THE HONORABLE
THE SECRETARY OF COMMERCE
WASHINGTON, D. C.

July 21, 1937

In an order, dated May 7, 1937, made by the Secretary of Commerce pursuant to the Air Commerce Act of 1926, as amended, relating to the investigation of accidents in civil air navigation in the United States, South Trimble, Jr., Solicitor, Major R. W. Schroeder, Assistant Director of the Bureau of Air Commerce, and Denis Mulligan, Chief, Regulation and Enforcement Division of the Bureau of Air Commerce, all of the Department of Commerce, were designated to investigate the facts, conditions and circumstances of the accident involving the airship HINDENBURG, which occurred on May 6, 1937, at the Naval Air Station, Lakehurst, New Jersey, and to make a report thereon.

Commander C. E. Rosendahl, U. S. Navy, Colonel C. deF. Chandler, U. S. Army, Colonel Rush B. Lincoln, U. S. Army, Colonel Harold E. Hartney, Technical Adviser to the U. S. Senate Committee on Commerce, Hon. Gill Robb Wilson, Director of Aeronautics for the State of New Jersey, and Hon. Grover Loening, Aeronautical Adviser to the U. S. Maritime Commission, were designated as technical advisers. General-leutnant Friedrich von Boetticher, German Military Attache, was selected by the German Ambassador at the invitation of the Secretary of Commerce, as an observer at the investigation.

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On the fourth day of the hearings, the members of the German Commission appointed to investigate the accident, including Dr. Hugo Eckener, Lieutenant Colonel Joachim Breithaupt, Professor Guenther Bock, Professor Dr. Max Dieckmann, Director Dr. Ludwig Duerr, and Staff Engineer Friedrich Hoffman, appeared and thereafter acted as observers and testified as witnesses. The U. S. Navy Board of Inquiry was represented throughout the hearing by an observer.

When the accident occurred, an aeronautical inspector of the Department of Commerce was present. Before midnight of the same day, other representatives of the Department reached the scene of the accident. After a preliminary inspection had been made, public hearings were held, from May 10th to May 28th, in the main hangar at the Naval Air Station, Lakehurst, New Jersey, in Asbury Park, N. J. and in New York City.

In addition to that provided by the Department's representatives, assistance was received from the U. S. Navy Department, Bureau of Investigation, Department of Justice, Weather Bureau, Department of Agriculture, Bureau of Standards, Department of Commerce, New York City Police Department, and the Bureau of Explosives. Aviation companies, newspapermen, newsreel representatives, and photographers, many of whom were eye witnesses to the event, and others, furnished valuable information.

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PART I. - THE ACCIDENT

The airship HINDENBURG was destroyed by fire at 6:25 P.M., E.S.T., May 6, 1937, at the Naval Air Station, Lakehurst, New Jersey.

Schedule

The airship was completing its first scheduled demonstration flight for the 1937 season, between Frankfort, Germany, and Lakehurst. It had departed from Frankfort about 8:15 P.M., G.M.T., Monday, May 3, and was due at Lakehurst on the morning of Thursday, May 6. It was due out of Lakehurst at 10:00 P.M. E.S.T., that night. Because of unfavorable winds encountered en route, its arrival at Lakehurst was deferred until 6:00 P.M., Thursday evening, and departure was to be postponed until midnight or later in order to reservice and prepare for the return voyage.

Ownership and Operation

The ship was owned and operated by the Deutsche Zeppelin Reederei, G.m.b.H., of Berlin, W. 8, unter den Linden, Germany. The flight, which was to have been one of a series to be made into United States territory during 1937, was authorized by a provisional air navigation permit from the Secretary of Commerce, and a revocable permit issued by the Secretary of the Navy to the American Zeppelin Transport, Inc., of 354 Fourth Avenue, New York City, as general United States agent of the Deutsche Zeppelin Reederei, G.m.b.H., for the use of the landing field and facilities at the Naval Air Station at Lakehurst.

Note: All times reported herein, unless otherwise indicated, are Eastern Standard Time (E.S.T.)

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Certificate of Airworthiness

In March, 1937, the German Government renewed the airworthiness certification of the aircraft, reporting that all of its safety devices had been inspected and found satisfactory.

Crew

According to the crew list (See Appendix I) furnished by the American Zeppelin Transport, Inc., the personnel on board, including officers, numbered 61, of whom 22 died as a result of the accident.

Passengers

The passenger list (See Appendix II), likewise furnished, shows that 36 persons besides the crew were on board. Of these, 13 died as a result of the accident. Other passengers and members of the crew sustained serious injuries.

Goods Carried

Total weight of the freight carried was 325 pounds and was stowed in the main freight compartment at Frame 125; 2 dogs were kenneled at Frame 92, and 3 packages were stowed in the control car. Mail was carried in a compartment on top of the control car. Of the freight and mail only a few pieces of mail were recovered.

Ground Crew and Facilities

The ground personnel consisted of 92 naval personnel and 139 civilians. Practically all of the ground crew had previous experience in landing airships. One member of the ground crew died as a result of burns received during the accident.

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Flight Across The Atlantic

Across the Atlantic from Germany to the United States, the flight had been uneventful, save for retarding winds which were not unusually turbulent. The route traversed by the ship on this side of the ocean was from Nova Scotia, via Boston, Providence, Long Island Sound, New York, and thence to Lakehurst. After passing over Lakehurst the first time, it proceeded to cruise along the coast for a few hours before retracing its course from Tuckerton, N.J., to the Naval Air Station.

PART II. - THE AIRSHIP

Design and Construction

The airship was placed in service early in 1936. It bore builder's number LZ 129 and had been constructed by the Luft Schiffbau Zeppelin of Friedrichshafen, Germany, an organization which had previously built 118 Zeppelin type airships. Briefly described, this type of design provides for a framework of duralumin metal girders with tension wires. There is division by frame wirings of the body into different compartments, into which the gas bags are placed to receive the lifting gas; a keel walkway to take certain loads; a framework with an outer cover of fabric to give form, and engine cars suspended from the frame outside the ship. The HINDENBURG was a Zeppelin type airship, having an axial corridor constructed longitudinally through the center of the hull.

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1936 Record

During its nine months of operation in 1936, this airship had made more than 55 flights; flown 2,764 hours, cruised 191.583 miles, crossed the ocean 34 times, carried 2,798 passengers and more than 377,000 pounds of mail and freight, all without mishap.

Dimension Capacities, Other Characteristics

Its length was about 803.8 feet; height, 147 feet; maximum diameter, 135 feet; fineness ratio (length over diameter), about 6; total gas volume, 7,063,000 cubic feet; normal volume, 6,710,000 cubic feet. Weight of ship with necessary equipment and fuel was 430,950 pounds; maximum fuel capacity, 143,650 pounds; total payload, 41,990 pounds, and total lift (under standard conditions) was 472,940 pounds. Its rated cruising speed was about 75 statute m.p.h.; its maximum speed was slightly over 84 m.p.h. Passenger space was entirely within the hull.

Controls

The control system was the conventional Zeppelin type control, with two rudders acting as a unit for horizontal control, and two elevators acting likewise for vertical control. Emergency elevator and rudder control wheels were installed in the stern of the ship. An electrical gyroscopic device attached to the forward rudder wheel provided automatic steering.

Outer Cover

The outer cover consisted of cotton fabric on certain parts of the frame; on others, linen, depending upon stresses to which it was exposed. The exterior

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surface of such fabric was treated with several coats of cellon and a mixture containing aluminum powder. As protection against ultra violet rays, the inner surface of the fabric on the upper part of the ship was coated with red paint.

Gas Cells

In each of the sixteen compartments of the ship was a gas cell containing the lifting gas, hydrogen. The middle cells were separate, whereas the two bow and the two stern cells were intercommunicating. The gas cell material consisted of a film placed between two layers of fabric. Nettings were provided to prevent all sharp edges from damaging the gas cells. It was stated that the amount of gas leakage through this fabric approximated a maximum diffusion rate of about 1 liter per square meter per 24 hours.

Gas Valves

Fourteen automatic and an equal number of manually operated or maneuvering valves were affixed to the cells. A single maneuvering valve was affixed to cells numbered 1 and 2 and cells 15 and 16. Gas could be released from the cells by manual operation of the valve controls located in the control car, and hooked up with the valves by a series of wires and pulleys. This was done under the supervision of the captain or the watch officer in charge. The automatic or emergency valves were provided to reduce the pressure of the gas in the cells under certain circumstances. The cells were numbered from stern to bow, from 1 to 16. The maneuvering valves of cells No. 3, 4, 5, 6, 7, 8, 9, 10, 11, 13 and 14 were connected to a master wheel in the control car which operated all of them as a unit, and there also were independent controls for the separate maneuvering valves so that the gas in them could be released as desired.

Cell Fullness or Pressure Indicator

Electrically actuated gas fullness or pressure units were connected to the gas cells to indicate visually by sensitive meters in the control car the pressure and hence the relative fullness of the gas in the cells. These units were located in the ship's axial corridor, or walkway. The accuracy or sensitivity of this system was not definitely established. An appreciable amount of gas might have been able to escape before such escape would show on the visual indicator unless that indicator was kept under close observation. According to Witness Eckener, a cell could lose at least 200 to 300 cubic meters of gas before the indicator would show such a loss. Such an amount is only a very small proportion of a cell's content.

Gas Shafts

Between every two cells a gas shaft was provided into which gas could be valved directly from the cells. The shafts extended vertically from the lower walkway through the axial walkway to the top of the ship for

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ventilation purposes. On the top they came in contact with the outside air under the protection of specially designed gas hoods or ventilators.

Propulsion

Four Daimler Benz diesel engines, type LOF-6, each having a maximum rating of 1100 hp. were used to propel the airship. They were contained in four outside engine cars, or gondolas, and were suspended laterally on the ship's hull by struts. Engine-room telegraphs provided communication between the control room and the individual engine cars. The fuel used by the engines was a diesel oil.

Propellers

The four-bladed propellers attached to each engine were of wood and 19 feet, 9 inches, in diameter. The blades were armored with brass sheathing about $1\frac{1}{2}$ inches in width, on the leading edge, from about the 43-inch radius to the tip of the blade. The sheathing was bonded to the ship's structure through the engine. Tests were made with the prototype of the propellers used on the ship. They were tested to loads 50% in excess of the thrust to which the propellers would be subjected at take-off, which was three times greater than the thrust which would be imposed at cruising speed. They also successfully withstood the block tests. They were limited to 1400 r.p.m. in forward rotation and 1120 r.p.m. in

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reverse rotation. These revolutions were below the fluttering speeds of the blades.

Electrical Power Plant and Installations

The electrical power plant of the ship consisted of two 50 hp. diesel-driven generators with switchboards and distribution system. These generators were independent of the outside propelling engines. The electric generators and principal members of the system were located amidships on the port side of the keel. Current was generated for purposes of lighting, cooking, radio and steering. There were two circuits, one of 220 volts, the other of 24 volts. The ship's electric wiring was of copper and was installed in accordance with the rigid regulations governing the German Mining Societies. The lead to the stern light, which was on a 220-volt circuit, using a very heavy cable protected by a special fuse, extended from the electrical power plant along the lower walkway and thence to the light. No electric wiring extended above the equator except in the extreme nose of the ship.

Ropes and Cables

The main mooring steel cable was fixed to the tip or nose end of the ship. The port and starboard bow trail ropes were attached to the ship at frame 244.5. These trail ropes were about 413 feet in length. It is understood that in landing the ship, it was the practice to approach the ground mast from leeward and drop the

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wire cable and the two trail ropes. The main cable was then coupled to a mooring mast cable leading through the top of the mast. By means of a winch, the cable was then reeled in, pulling the mooring cone on the ship's nose into the corresponding cup on top of the mast. The trail ropes were coupled to ground ropes and led out to the sides to keep the ship headed into the wind and towards the mast and to prevent it from over-riding the mast structure. In the stern, at ring 47, an after mooring cable was in practice let through a metal fair lead. At ring 62 a port and starboard spider was let out at landing. Besides those enumerated, the ship was provided with other mooring or landing tackle, for such use as circumstances warranted.

Ballast Arrangements

Water was generally used for ballast. The emergency ballast was contained in fabric containers, four of which, of 500 kilograms of water, were suspended in the bow and an equal number in the stern. To the right and left of the lower walkway were suspended a number of other ballast tanks, some of 2500 liters each and others of 2000 liters each. The ballast tanks could be emptied partially or totally by the elevator men by means of control wires connected to a ballast stand in the control room. Several of the fuel tanks could also be used for

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ballast purposes.

Radio Equipment

The radio-room was located above the after end of the control car. Its equipment provided for two-way radio telephone and telegraph communications. It included a short wave and a long wave transmitter, each with 200-watt antenna capacity; two all-wave receivers and two direction finders. The frequency of the short wave transmitter was 4160 to 17,500 kcs. The frequency of the long wave transmitter was 120 to 500 kcs. The frequency range of the recenvers was 12 to 20,000 kcs. Power for the transmitters was obtained from a 220-volt direct current supply generated by the ship's electric power plant. The receivers obtained their high voltage from batteries, and power for their filaments was obtained through a series resistor from the 24-volt ship's generator. For the short wave transmitter, there was a trailing antenna of 26 meters length. For the long wave transmitter, a trailing antenna of about 90 meters length was used. These trailing antennas were located directly below the transmitters and ran through an aperture in the keel of the ship. There was a fixed antenna extending from the control car about 15 meters toward the stern. The fixed antenna was used only for receiving purposes. In addition to this equipment, there was located in the bow an emergency transmitter and receiver, current for which was obtained from a generator driven by

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pedal power. This emergency set employed a trailing antenna about 20 meters in length.

Lifting Gas

The ship was inflated with hydrogen. According to the evidence adduced, this gas has the following characteristics: It is colorless, odorless and tends to diffuse in all directions. The only way that hydrogen could be detected by smell would be due to the presence of impurities as a result of the process by which it was produced, or contamination from some source such as rubberized fabric. Hydrogen, for lifting purposes, has a density of approximately 5 pounds per 1000 cubic feet, depending on the temperature and pressure. Its lifting power is the difference between the density of air and its own density. The density of air is about 75 pounds per 1000 cubic feet. Assuming pure hydrogen, its lifting power would therefore be about 70 pounds per 1000 cubic feet. An opinion was advanced that the general order of pressure of the gas within the cells of the ship was somewhere between half an inch and one inch of water pressure. It was stated that the density of hydrogen corresponds to air at a temperature of 5000° F. and that the chimney effect of its escape through the gas shafts of the ship was so very great that there was no possibility of its moving down the shafts into the lower parts of the ship.

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The flammable limits of a mixture of hydrogen and air are probably between 4.5% and 62% of hydrogen. Other experiments have shown variances from 8 - 9.8% to 66%. The temperature at which chemical activity between hydrogen and oxygen takes place is between 507° to 557° Centrigrade. This temperature range is dependent upon the amount of hydrogen present. The range of activity of combustion will be from the lower limit of 4.5%, at which there will probably be an invisible union without evidence of flame. A combustible mixture would be more hazardous in an atmospheric condition of 98% relative humidity, and temperature 60° Fahrenheit, than in dry air with relatively low humidity, since dry hydro-oxygen is more difficult to ignite and its ignition temperature is higher. In an explosion the flame propagates in all directions in the combustible range between 15 to 45% of hydrogen. These figures were arrived at experimentally with glass or metallic apparatus which did not have effect upon the combustion temperatures. Catalytic metals having absorption properties would be likely to affect the combustion at lower temperatures. Finished duralumin would not be expected to have material catalytic effect upon hydrogen.

Bonding

The whole metallic structure of the craft was bonded.

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PART III. - THE LANDING MANEUVER

Meteorological Conditions

With respect to the meteorological conditions in which the landing was conducted, a summary of the general weather is given as well as the local conditions prevailing at Lakehurst at the time of the accident.

General

The 7:30 A.M., EST. U. S. Weather Bureau map of the vicinity, including the northeastern tier of states, shows a disturbance over central New York and northeastern Pennsylvania, with a cold front extending from this center southwestward to West Virginia. This front separated neutralized polar air to the east of the cold front which had become warmer and more moist and neutralized colder air to the west of the front. The warmer and more moist mass of air covered the Middle Atlantic states, southeastern New York and southern New England.

The cold front advanced eastward during the day from central Pennsylvania at a rate of 12 to 15 m.p.h., passing Lakehurst shortly after 3:30 P.M. There was not quite sufficient surface heating during the early afternoon to set off a thunderstorm at Lakehurst, and it was not until the front passed and some slight lifting of the air mass occurred that a thunderstorm began. The records of the Naval Air Station show that the thunderstorm began at 3.40 P. M. and ended at 4:45 P.M.

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Telegraphic reports indicate, the thunderstorms in and to the west of New Jersey were not severe; nor were they of a well defined squall character. Between 12 P.M. and 1:30 P.M. E.S.T., these storms extended in a definite belt over the region of Harrisburg, Pa., northeastward to Bear Mountain, N.Y., and New Hackensack, N.Y. Between 1:30 and 2:40 P.M. none was reported. Between 2:40 and 3:40 P.M., Camden and Fort Monmouth, N.J., only reported thunderstorms. Between 3:30 and 4:30 P.M., Lakehurst, Mitchell Field, N.Y. and Floyd Bennett Field, N.Y., reported them. Between 4:40 and 5:40 P.M. none was reported; and between 5:40 and 6:40 P.M., Floyd Bennett only reported one. Summarized, the thunderstorms in eastern New Jersey were of a local character and not severe.

The New York Weather Bureau office bulletin issued at 1:20 P.M., May 6th, follows:

> "1800 G.C.T. Moderate wind shift with increasing and lowering clouds possible thundershowers New York and vicinity expected in middle or late afternoon Stop New York scattered cumulus and small cumulo nimbus approaching from west - visibility excellent surface wind south 12 miles - barometer 29.68 falling steadily - temperature 66."

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Local

With the passage of the front at Lakehurst, the wind shifted to the northwest with gusts up to 20 knots, and was accompanied by slight increase in barometric pressure, decrease in temperature, heavy showers and several thundershowers. Then there followed a rapid decrease in the velocity of the wind and its direction became variable. The wind at Lakehurst at 6:10 P.M. went into the southeast and remained there for about 45 minutes, shifting again, and then it became mostly southerly. The front, after passing about 3:30 P.M. E.S.T., apparently slowed down to a rate of approximately 7 miles an hour and was in the vicinity of Atlantic City, N.J. at 8:00 P.M., its direction being north northeast-southwest, clearing rapidly after 8:00 P.M. During the afternoon cumulo nimbus and cumulus clouds developed locally and with the approach of the front there appeared a well-defined mild squall line in the west, which moved slowly over Lakehurst and apparently became stationary between it and the shore line until about 5:30 P.M., when it continued eastward. Several heavy showers occurred between 5:00 and 6:00 P.M., with accompanying thunder. Visibility was reduced during these showers. At 5:12 P.M. the thunderstorm then over the field was moving north, and it was believed that by the time the ship arrived at the station the storm

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would have moved away from the station. The ship at this time was out of sight because of low visibility and the ceiling, in the direction from which it was expected to approach, was not more than 500 to 600 feet.

Conditions at the time of the approach were: Ceiling between 2000 to 3000 feet; clouds .7 stratus; very light rainfall; sky showed signs of clearing to the westward; barometric pressure 29.72; temperature 60° F.; relative humidity 98; surface wind light, variable and shifting and at the precise moment of the beginning of the landing was southeast 1 knot. It was expected that the surface wind direction would go into the west or perhaps the northwest. Reports from Trenton and Camden, N.J. indicated that the wind was westerly and that at Camden it was about 18 knots just previous to the landing of the ship. Wind at top of the weather tower on the field was west 6 knots. The approach level of the ship was about 200 feet above the ground. The top of the tower is 186 feet above sea level (ground elevation at place of landing was about 90 feet above sea level). The inversion condition was 60° at the lower level, 59° at the second, and 57° at the third level, being temperature readings at various levels from the top to the bottom of the weather tower. As the ship was approaching the landing area, occasional lightning was visible from the distant south and southwest, but none was observed over the field at this time. When the headway of the ship was stopped, a pronounced shift of wind was felt on top of the mooring mast, from southerly to southeast or south-southeast. This wind was colder than the previous wind had been.

Communications, Radio

Regular reports from the ship were received as scheduled at the Naval Air Station, Lakehurst. At one stage in the latter part of the flight the static was bad but it did not prevent communications between the ship and ground stations. Shortly before arrival at Lakehurst, direct communication was maintained by the ship with the Naval Air Station.

At 1:55 P.M., E.S.T., the station received a message from the commander of the Ship stating that he would depart from Lakehurst as soon as possible after arrival. At 4:42 P.M., the commander of the station radioed the ship: "Conditions still unsettled recommend delay landing until further word from station advise your decision." At 4:52 P.M., the commander of the ship replied: "We will wait till you report that landing conditions are better." At 5:12 P.M., the commander of the station advised the ship: "Conditions now considered suitable for landing ground crew is ready period thunderstorm over station ceiling 2000 feet visibility five miles to westward surface temperature 60 surface wind west-southwest eight knots gusts to 20 knots surface pressure 29.68." At 5:22 P.M. station commander radioed ship: "Recommend landing now." At 6:00 P.M. station transmitted to ship: "Overcast moderate rain diminishing lightning in west ceiling 2000 feet improving visibility surface wind west-southwest four knots gusts under 10 knots surface temperature sixty-one pressure twenty-nine seventy." At 6:08 P.M. station commander sent last message: "Conditions definitely improved recommend earliest possible landing." This was acknowledged by the ship.

Prior to the accident all of the ship's trailing antennas had been reeled in. No high frequency transmissions were being conducted when the trail ropes were dropped from the ship. Both transmitters were turned to the "off" position at that time and remained so thereafter. The radio dynamotors had also been shut off. The last message transmitted over the ship's radio was shortly after the landing station signal had been sounded, about 15 minutes before the fire. It was sent on the long-wave transmitter to Lakehurst at 6:10 P.M., E.S.T. During the landing, watch was kept on the long-wave receiver. No landing report was transmitted from the ship to Germany while it was over the field at Lakehurst. One of the ship's radiomen stated that atmospheric disturbances had been encountered during the afternoon of May 6, but that such condition improved toward evening and continued to improve during the last 30 minutes of the flight. No difficulty was experienced during that period in sending or receiving either on the short or long-wave transmitters or receivers. Witness Herbert Dowe, ship radio operator stated that he was on watch and actually listening to the radio until the fire started and that he did not notice any interference which could have been caused by improper bonding or shielding and that he did not receive any interference such as might have been transmitted by local station.

There was no oral communication between persons in the ship and on the ground during the maneuver.

The sequence of actions in bringing the ship up to the landing point is in part revealed pictorially by the track of the ship over Lakehurst, drawn on map of the Naval Air Station, with notes on the maneuver by Witness H. W. Bauer (See Appendix III). Among other data the map provides information respecting successive altitudes, speed, operation of engines, released of ballast and valving of gas.

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Operation of Engines

About 10 minutes before dropping the bow trail ropes, the engines were running full cruising speed ahead; the ship's speed about 33 meters per second (approximately 73 m.p.h.). The altitude of the ship, according to its altimeter, was then about 180 meters (590 feet). About 8 to 9 minutes prior to the release of the ropes all engines were idled ahead; altitude 150 meters (492 feet); ship's speed falling off to 15 meters per second (approximately 33 m.p.h.). Then, in fairly rapid order the after engines were idled astern and then put full astern to reduce the speed to 12 to 13 meters per second (approximately 27 m.p.h.); after which all engines were idled astern; altitude at this time was 120 meters (393 feet). About 2 minutes prior to dropping of the bow trail ropes all engines were put full astern for a period of about one minute to stop the ship; after which the forward engines were idled ahead and the after engines were idled astern. When the trail ropes had been dropped the forward engines were given a short burst ahead; then idled ahead.

Release of Ballast

Starting at a point about three-quarters of a mile from the landing point 300 kilograms (661 pounds) of water ballast was dropped from ballast bag at Frame 77. Then in rapid order, from the same frame, at about intervals of 1000 feet, ballast was dropped twice again, the second time, 300 kilograms (661 pounds) the third, 500 kilograms (1,100 pounds). This release of 1,100 kilograms (2,420 pounds) of water ballast took place within a period of 2 to 3 minutes before the trail ropes were dropped.

Valving of Gas

According to Witness H. W. Bauer's sketch, gas was valved on the wheel for 15 seconds approximately 10 minutes before dropping the bow trail ropes; ship proceeding at full cruising speed. About 8 minutes prior to dropping of ropes, gas in Cells 11 to 16, first five forward cells, was valved for 15 seconds; ship then proceeding at 15 meters per second (approximately 35 m.p.h.). Approximately 4 to 6 minutes before dropping the ropes, gas in Cells 11 to 16 was again valved for 15 seconds; speed of ship 12 to 13 meters per second. (Approximately 27 m.p.h.). About 2 minutes prior to dropping of ropes, gas in Cells 11 to 16 was valved for 5 seconds.

Crew as Ballast

According to the elevator man who had taken over the elevator helm in the landing approach, the ship was still slightly tail heavy after dropping water and valving gas, consequently six men of the crew were sent forward to the bow in order to equalize the weights. He was unable to account for the tail heaviness of the ship after the ballast

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had been dropped.

Tail Heaviness

The ship was weighed off to the west of the field and was found a little light. There followed the trimming operations that have been described in the preceding paragraphs. There is evidence to show that the tail of the ship was heavy during the maneuver. Witness Albert Sammt, second in command of the ship, accounted for this condition by saying that it was due to the consumption of fuel; that it gave him no concern because it was very little. There was diversity of opinion advanced regarding this condition of the ship. Witnesses H. W. Bauer and C.E. Rosendahl considered it to be normal. The latter stated that the ship's tail heaviness had been logically accounted for. Under the circumstances in which it landed in a light wind with little air flow on the tail surfaces and consequently little aerodynamic lift, 120 pounds midway from the tail of the ship would be felt by the elevator man and be noticed by those in the control car who were watching the inclinometer for that very thing; that the condition did not exist from the time of the dropping of the bow trail ropes during the 4 minutes intervening before the fire broke out.

To other witnesses the ship appeared heavy in the stern, among them Witnesses Benjamin May, in charge on top of the mooring mast, and W. A. Buckley, Assistant Mooring Officer. Witness Hugo Eckener indicated, according to his

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information, that while the ship may have remained in satisfactory trim from the time the trail ropes were dropped until it burned, such interval was a short period of time. He did not think that a hydrogen leak would have been so large that in such a relatively short time it could have been noticed. He mentions the testimony of Witness H. W. Bauer, relating to the trimming operations in which a very short time before the accident 6 men had been ordered forward. From this he infers that shortly before the ship reached the landing position it was necessary to trim ship by putting weight forward, and that the elevator man could hardly have noticed anything during this interval because the ship had no more forward speed. He further stated that careful calculation showed that the trimming moment effected by these operations amounted to at least 70,000 to 80,000 meter kilograms (506,391 to 578,933 foot-pounds) of trimming effect; when this effect is compared with the trimming moment that could be obtained aerodynamically at full cruising speed by the use of the elevator controls in the order of 150,000 to 200,000 meter kilograms (1,085,124 to 1,446,820 foot-pounds), then it became clear to him that the ship was very badly out of trim.

Witness Eckener also testified that witnesses in the control car had reported that the out-of-trim condition originated approximately one-half hour before the landing maneuver after going through the rain clouds; that the ship became tail heavy by running through heavy rain because the weight of the rain is greater in its effect on the horizontal fins, which are behind the center of gravity. There is also another apparent effect of rain upon the ship. That is the tail would seem to be heavy to the elevator man while the ship was running through rain, because it automatically has a tendency to nose up since the center of aerodynamic pressure moves aft. This effect, however, disappears very rapidly after passing through rain and in the present instance must have disappeared quickly because the ship as a whole was light. The ship, ten minutes after passing through heavy rain clouds, should have again been in good trim. In the opinion of Witness Eckener, however, it appeared so tail heavy that it became necessary to apply a trimming effect of some 70,000 meter kilograms (506,391 foot-pounds). Furthermore, he indicated that if the ship had been as tail-heavy before it proceeded through the rain clouds, it would not have been operated without the release of ballast. As no testimony was given that the ballast had been dropped before the ship moved into the rain clouds, Witness Eckener believed that some unusual condition in the ship might have

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developed prior to the ship's landing.

With regard to the amount of rain that the ship had been exposed to during the landing maneuver, there appears to be some difference of opinion. Witness Sammt, stated that there was a little rain as the ship crossed the field at the beginning of the maneuver, not heavy enough to weigh the ship down as much as 500 kilograms (1100 pounds); that was the only rain experienced during the last two hours of the flight because they had avoided the rain carried in the weather front. As the ship took a final bearing on the field it made a wide turn into quiet weather, returning to the field in this condition. According to him, the front had passed and the weather was favorable for landing. The sky was overcast but without disturbances or squalls. Witness Nelson Morris, a passenger, stated that a very light rain fell exactly as the ship came over the field the last time, but until that time there had been no rain. Witness Anton Wittemann, who had commanded the airship GRAF ZEPPELIN, stated that when the HINDENBURG approached for its landing maneuver and as it passed through the front, the weather conditions as seen from the ship were entirely favorable; the thunder storm had passed into ordinary rain. The ship entered somewhat

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heavy rain which became much lighter when closing in on the station. At the approach there were no cumulus clouds; there was a clear-cut stratus layer from which light rain was falling. Witness H. W. Bauer, second watch officer of the ship, said that about 20 minutes before the landing approach the ship passed through a heavy rain and through stratus clouds containing rain before making the approach. It did not pass near any lightning.

Altitudes at Landing

When the ship was brought to a stop over the landing point, its altitude was about 180 feet above the ground. It rose to about 200 feet when the bow port landing ropes checked its further upward rise. Thereafter, it descended to about 135 to 150 feet when the accident happened.

Electric Installations

According to Witness Philipp Lenz, Chief Electrician of the ship, no fuses blew nor did any circuit breakers operate just prior to the fire. The several circuits of the ship were intact, the interior ship lights and the navigation lights were burning as usual.

Rudder

Two witnesses testified that the top and bottom rudder did not appear to be working in unison when the ship came over the field. From other testimony it appears that the rudders were functioning normally.

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PART IV. - THE FIRE

Ground Log

It was the practice at the Naval Air Station to maintain a log of event in connection with the landing of the HINDENBURG. The log of its last landing reveals that the first approach of the ship in landing maneuver was sighted at 6:15 P.M., E.S.T., May 6, approximately over the Officer's Quarters on the station. At 6:21 P.M., the bow trail ropes were dropped, on a bearing of 30 degrees from the mooring mast, first the starboard rope, followed immediately by the port rope. Ship was first observed afire at 6:25 P.M.

Description of Landing

The landing made on this occasion has been described as a high landing or flying mooring, a method of landing which is occasionally employed. Some qualified witnesses stated that it was normally conducted in every respect. Among these were Witnesses Rosendahl and A. F. Heinen. Others indicated that the approach seemed hurried; that the ship made what seemed to be a fairly short turn and approached the mooring circle fairly rapidly. Based upon the statements of other witnesses, Witness Eckener expressed the view that the ship must have proceeded in a sharp turn to approach for its landing. Witness Sammt said the turns were normal.

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Incidents before the Fire

Before the fire broke out, the ship was being held by the bow port trail rope which had been coupled to the port yaw line and a strain had been taken on this rope around the niggerhead of the ground winch. The bow starboard trail rope had not been coupled to the ground line, but was being handled by the starboard bow landing party. At no time during the approach did the ship come closer to the mooring mast than 700 feet. The main bow cable of the ship at this time had been let out about 50 feet, but neither it nor any of the cables or ropes in the stern had reached the ground before the fire started. After the trail ropes in the bow had been dropped, the ship no longer had any forward speed. It began to move up and astern and also to swing slowly to starboard. Then a light gust was felt from port.

Fluttering of Outer Cover

Witness R. H. Ward, in charge of the port bow landing party, a couple of seconds before the fire, had his attention attracted by a noticeable fluttering of the outer cover on the top port side between frames 62 and 77, which includes cell No. 5. No smoke or other disturbance accompanied the flutter when he first saw it. It was a wave motion. In his opinion the motion of the surface was not due to the slip stream or resonance effect of the propeller. It was entirely too high from the propeller. It appeared to him to be more like an action of gas inside pushing up, as if gas was escaping. He apparently had seen this action occur in other aircraft. The ship had no perceptible forward motion the time he observed the flutter; its engines were idling in forward rotation. The fabric had not opened up when he first made the observation. The flutter was followed by a ball of flame approximately 10 feet or so in diameter; then came an explosion. On a diagram this witness indicated that the first appearance of fire was near the top of the ship and above the point where he saw the flutter. With respect to this testimony, Witness Eckener said that a leak in a gas cell, permitting the escape of 40 to 50 cubic meters of gas per second, would be sufficient to cause a flutter in the outer cover which could be observed as reported, but probably would not be enough to draw the attention of those in the control car to a loss of buoyancy aft. Witness R. W. Antrim, who was on top of the mooring mast, also stated he saw that the fabric behind the after port engine was very loose and fluttering. It extended rearward and upward from the after port engine to a quarter of the way to the tail.

Strain on Port Trail Rope

The drift of the ship to starboard, according to the mooring officer, Witness Tyler, was finally checked by means of the port trail rope. This rope was hauled up taut on the winch. The starboard trail rope was being handled by the manpower of the starboard bow party. Witness Albert Stoefler, one of the ship's cooks, who was looking down from a window in the ship, stated that he "saw how the landing crew came running up, and how they loosened the knot of that rope and fastened it to the lower lines on the ground. Then I saw how the ropes took tension and at the moment I felt a very strong detonation of the ship, vibration of the ship.*** I did not notice any explosion. I only noticed that vibration I was speaking about before." He thought the ship was striking the mooring mast. Witness H. W. Bauer stated that after the landing rope had been fastened, he went from his position to the port window in the control car and observed the tensioning of the landing ropes. At the time of that observation, there was a strong shock in the control car and his first assumption was that the landing rope had broken. Witness Max Zabel, ship's third officer, stated that he observed the bow trail ropes being dropped; that the port trail rope became rather tight. He saw the ends of the ropes which were tied together whirl around and tighten. Immediately after this landing rope had become tight, an explosion was heard and the destruction of the

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ship occurred. He described the vibration that was felt in the control car as an extraordinary one. Witness Dowe, ship radioman, testified that while watching one of the landing ropes being handled by the ground crew there suddenly was some tearing in the ship, a metallic tearing. A passenger reported, "and then as that rope was getting taut, I heard a detonation***".

Sensations Within the

In describing their nervous reactions at the beginning of the accident, some of the persons within the ship, in addition to such descriptions as are provided in the preceding paragraph, spoke, in effect, as follows: Witness Severin Klein - When the ship was almost standing still, it gave a sudden jolt. Witness Xavier Maier - First he heard detonation; then he noticed the vibration, the shock, and fell on his back. Witness Heinrich Kubis - First heard or felt an explosion approximately at the time that the ship took a sharp inclination. Witness Lenz - The sound that he heard he thought might have been a landing rope breaking. Witness Claus Hinkelbein - The jerk and the sound of the detonation and the sight of the fire or the reflection of fire were all simultaneous. Witness Kurt Bauer - Noticed a cracking shock which originated in the rear. Witness Wittemann - When he heard dull detonation, thud, his first idea was that rope had parted. Witness Walter Ziegler - Saw how the port landing rope was hauled tight; shortly thereafter he heard a dull thud or detonation and a heavy shock went through the ship. Witness Kurt Schoenherr - It was a strong shock he sensed after hearing a rather dull detonation. Witness Sammt - His first intimation that something was out of order was a heavy push, about the same shock as if the ship had been pushed to the side and the landing rope had broken. Neither prior to nor after the push did he hear a muffled explosion. He did not associate the push with anything that might have occurred in the after part of the ship.

Appearance of Fire

Numerous expert and lay witnesses on the field testified as to where they first observed the fire on the ship. There was great diversity in this testimony for reasons that are very apparent. Among the most important of these reasons were the extreme rapidity with which the fire spread, the different positions of the witnesses with respect to the ship, the size of the ship, more than one-sixth of a mile in length, and an over-all height, equivalent to a twelve story building, and the fact that at the time of the fire it was still daylight. It is estimated that the interval between the first glimpse of flame and the impact of the main body of the ship with the ground was 32 seconds. The great majority of the ground witnesses who testified as to the first appearance of fire were looking at the port side of the ship.

After carefully weighing the oral evidence and transcribing to a master diagram the numerous diagrams on which the ground witnesses indicated their first observations of fire, we conclude that the first open flame, produced by the burning of the ship's hydrogen, appeared on the top of the ship forward of the entering edge of the vertical fin over Cells 4 and 5. The first open flame that was seen at that place was followed after a very brief interval by a burst of flaming hydrogen between the equator and the top of the ship. The fire spread in all directions, moving progressively forward at high velocity with a succession of mild explosions. As the stern quarter became enveloped, the ship lost buoyancy and cracked at about one-quarter of the distance from the rear end. The forward part assumed a bow-up attitude, the rear appearing to remain level. At the same time the ship was settling to the ground at a moderate rate of descent. Whereas there was a definite detonation after flame was first observed on the ship, we believe that the phenomenon was initially a rapid burning or combustion — not an explosion. From the

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observations made, it appears that there was a quantity of free hydrogen present in the after part of the ship when the fire originated.

A brief resume of the observations made within the stern of the ship shows that Witness Helmut Lau, who was standing on the ladder leading up to the lower catwalk from the lower vertical fin and was looking up facing the port side of the fin, heard above him a muffled detonation and saw from the starboard side, down inside the gas cell, a bright reflection on the front bulkhead of Cell No. 4. He saw no fire at first, but a bright reflection through and inside the cell. The cell suddenly disappeared because of the heat. Then Cells 3 and 5 caught fire. This witness said he did not see the center of the origin of the fire, but it must have been further up since he saw the reflection of fire through the cell wall material. It was the same type of explosion that one hears when using a kitchen gas range, when first lighting the flame or turning it off. Witness Lau did not smell any hydrogen at the time he made these observations. Witness Hans Freund was letting out the after mooring cable at Frame 47 and had let out a few meters of it when he heard a muffled detonation. Fire was simultaneous with the explosion. He was surrounded by fire immediately. Witness Rudolph Sauter, who was stationed in the keel of the lower vertical fin, first heard a dull detonation, then saw fire in Cell No. 4, a

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big fire, which he identified as a hydrogen fire. None of these witnesses in the stern of the ship felt any unusual vibration or heard any breaking of structures prior to the detonation or the sight of fire or reflection of fire. None of the other members of the crew or passengers on board the ship observed fire or reflection of fire until after feeling an unusual vibration or shock or hearing the detonation.

PART V. - THE COMBUSTIBLE MIXTURE AND ITS IGNITION

Having retraced the course of events and circumstances surrounding the accident, we come to the question, why did the fire occur? As yet, with the few exceptions to be noted, no more has been provided than a hypothetical approach to the answer. We have weighed the several theories that have been advanced.

Sabotage

The possibility that the cause is to be explained by premeditated or willful act has received active attention. Sabotage has been examined under two classifications; the first - external, including the use of incendiary bullet, high powered electric ray, and the dropping of an igniting composition upon the ship from an airplane; the second classification - internal - including the placing within the ship of a bomb or other infernal device. To

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date, there is no evidence to indicate that sabotage produced the grim result.

Accidental Causes

In a consideration of accidental causes, two factors must be found together. There must be present (a) a combustible mixture of hydrogen and oxygen of the air; and (b) sufficient heat to ignite such mixture. In the analysis of the evidence the mixture and its ignition are treated separately.

Presence of Combustible Mixture of Hydrogen and Air

Accumulation through Diffusion or Osmosis

While it is conceded that the fabric of which the cells were made is slightly permeable to the diffusion of the contained hydrogen, it is not our opinion that this characteristic of the cell walls, under the circumstances prevailing would account for a combustible accumulation of gas and air within the ship; the normal rate of seepage being, as was indicated under description of the cells, about one liter per square meter per 24 hours.

Failure of Valve Mechanism

According to the testimony, only one valve failure had occurred on the ship. This happened when the ship was new; as a consequence, certain changes had been made in the construction of the mechanism. In any event, the failure noted occurred to an automatic or pressure relief valve which would not have been functioning at the time of this accident. However, because the valves were mechanical devices, it was possible that there might have been a defect or failure in them, but no testimony appears to show that this possibility was a likely one.

Decreased Ventilation

Another query regarding the presence of such mixture presented itself. Could it have been due to the reduced scavenging of the gas by the ship's ventilation system during the last minutes of the craft's existence when its speed eventually had been reduced to a full stop, combined with the last valving operation, about six minutes before the fire? This theory seems improbable because of what was said about the efficiency of the ventilation system and because of the fact that the chimney effect created by the 6 knot wind that was blowing at the ship's elevation during the last four minutes prior to the fire, should have evacuated practically all of the gas from the shafts. The forward speed of the ship, reported to have been from 15 to 20 knots per hour, when the last valving operation was performed, should have been ample, it was stated, to have cleared the gas rapidly from the ship. A further argument made with regard to the scavenging of gas was that immediately after the last reported valving the ship's engines were backed down hard, and that this deceleration should have tended to move the gas in the ship toward the bow and out through the forward gas shafts.

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In considering the production of such mixture by the rupture of a cell or cells, there are at least several avenues to explore.

Entry of Piece of Propeller

One of these might be laid to the failure of a propeller and the throwing of one of its fragments through the adjacent part of the hull into a cell. To this possibility there was devoted an extensive examination by experts of our staff and those of other agencies. The condition of the propeller of engine car No. 2 attracted our attention. Witness F. W. Caldwell, one of this country's foremost propeller experts, was quite certain that the propeller of the after port engine did not break in flight but was shattered at the time the car struck the ground. He said that there was no indication of the separation of the sheathing from the blades except as the result of shattering on impact. Witness Deutsche, machinist in the after port engine car, indicated that the propeller of his car was still rotating when it struck the ground; that he did not feel any unusual vibration of the engine before the crash.

Fracture of Hull Wire

One other significant possibility must be discussed while the question of cell rupture is being examined. It was suggested that, while in flight, a tension wire might have ripped a hole in a cell and thus permitted a quantity of gas to escape. Coupled to this possibility is the

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testimony of Witness R. H. Ward, digested briefly in the statement of facts; that he saw a fluttering in the outer cover above the equator between rings 62 and 77 and believed that this fluttering was caused by gas escaping into the space between the adjoining cell and the outer cover. A shear wire in one of the panels at the place from which the gas was escaping could have snapped while the ship was turning during the landing maneuver. Witness Eckener stated that such turns generate high stress in the after part of the ship, especially in the center section close to the stabilizing fins which are braced by shear wires. The gas thus accumulated between the cells and the outer cover must have been a rich mixture. Such a mixture, enclosed in a space between the outer cover and the gas cells, would, if ignited, burn with relatively slow speed until gas in greater volume was released by the burning through of the cell walls. Witness Rosendahl recalled that in the early years of operation with naval aircraft, shear wires had broken with varying effect, causing no serious damage, however.

Major Structural Failure

Consideration has been given to the possibility that a major structural failure in the stern of the ship caused the hydrogen to be liberated by rupturing a cell and forcefully breaking an electric lead or metal part, thus

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producing a spark. The fire broke out when the port trail rope, which held the ship to the ground, became taut. It was reported by some persons that at, or about, the time they observed the fire they heard a cracking sound from the stern of the ship. An examination of the wreckage disclosed that the rivets, by which the after end of the axial corridor was connected, through a fitting to the hull, had pulled out; that all of the radial wires in the small frame nearest the stern had broken in tension; that only a few of the small tabs of metal from the periphery of the frame, which had been pulled off the bight formed where the radial wires hooked on to the frame, were found on the ground below where the frame struck. The shearing of the rivets and the condition of the wire and the frame might be explained by the force with which the rear end hit the ground; or by the torsional or other stresses which the tail suffered in its last moments in the air. It has also been pointed out that the ship was stressed for greater loads than the tensional strength of the bow trail rope, and that the rope had not parted. Furthermore, it was observed that the eye through which the trail rope was attached to the ship and the longitudinal member to which the eye was affixed, were intact after the accident. The four members of the crew in the stern of the

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ship testified that they did not hear or see any such structural failure prior to the fire.

Ignition of the Mixture

Many of the theoretic aspects of the ignition of the combustible mixture were dealt with at great length by a number of experts. Only a summary of this phase of the investigation is related in this report.

Mechanical

If there had been enough heat generated by the friction of wires or other members of the ship coming forcibly into contact with each other, due to structural failure or breaking, a sufficiently hot spark might have been produced to set off such mixture. There is insufficient evidence to sustain a conclusion based upon this theory.

Chemical

As has been stated, there are metals which have a catalytic effect upon a mixture of hydrogen and air and would materially lower its ordinary ignition temperature, but it does not appear that any such metal was in that part of the ship where the fire was first observed.

Under the title of chemical possibilities there has also been suggested that a flame might have been produced by spontaneous combustion. The evidence is inadequate to support this theory.

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Thermodynamic

In the examination of thermodynamic possibilities much time at the outset of the investigation was given to the possibility of such mixture being ignited by the sparks from the engine exhausts. It was suggested that sparks or larger particles of carbon thrown out from the diesel engines might have been carried into the openings in the lower part of the hull or have been blown over the exterior of the stern and there have ignited such mixture. While the circulation of the exhaust gases, set up by the direction of rotation of the propellers just before the accident (the after engines idling in reverse and the forward engines idling ahead) was different from that produced while under way, it was maintained by the German experts that this circumstance would not result in sparks or carbon particles reaching the interior of the hull, and, furthermore, that the sparks would not have been able to ignite such mixture on the top of the ship at least 165 feet away from the after exhaust outlets. Witness Ludwig Duerr testified that very extensive experiments respecting this possibility had been conducted by the builders and the results had been reassuring. When the engines are delivering 1100 to 1200 hp. the temperature leaving the piston before it enters the exhaust stack is 500° to 530° centigrade. The temperature

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of the exhaust is lower. The engines ordinarily develop 800 to 850 hp. At this output the temperature of the exhaust gases is 450° to 480° back of the cylinder. With a mixture of air sucked in, the temperature is reduced to 230° to 250° centigrade. Visible sparks have a temperature over 500° centigrade but lose their heat rapidly as they are impelled through the air.

Had this been the cause of the ignition, it is believed that it would have come into play before the elapse of the four-minute interval between the dropping of the trail ropes and the accident.

That the heat of the exhaust gases caused the havoc is also improbable. If ignition had happened at the exhaust it would have been necessary that the temperature of the band of air between the outlets and the place of the first flame would have had to be about 507° centigrade. According to Witness Duerr, the temperature at the exhaust outlets was much lower than 507° C. With the Hindenburg and the Graf Zeppelin, no difficulties had been experienced from this quarter.

Electrical

Under the classification of electrical sources of ignition several were considered. A combustible mixture of air and hydrogen could have been ignited by the overheating of wires carrying current within the ship, e.g., by

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a short circuit. Barring the possibility previously alluded to, of a substantial failure in the stern structure of the ship, which might have produced a sudden breaking of such wires in the aft end of the ship, it is thought to have been only remotely possible that the mixture was fired by a defect or failure of the ship's electrical wiring.

According to Witness Lenz, who was stationed in the electrical power plant at the time of the accident and had most of the ship's electric indicators, fuses, and circuit breakers, under observation, the various circuits were functioning normally just prior to the conflagration. No fuse blew or circuit-breakers operated at that time. It was also observed that the cable carrying the current to the stern light was very sturdy and was installed so as to provide plenty of slack to compensate for expansion and contraction of the frame of the ship.

Spark in Gas Fullness or Pressure Indicator

A theory introduced by Witness Heinen was that the cause of the fire was due to the ignition of such mixture in one of the gas fulness or pressure electric meter actuating units fixed to the axial corridor in the vicinity of cells No. 4 and 5. He believed that a small pocket of gas accumulated in the folds or ridges of the cells surrounding the corridor and found its way into the

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inner recesses of the meter and was there ignited by an electric spark; that the fire thus created traveled up along the radial wires to the space between the cells and the outer cover igniting the free hydrogen collected along the longitudinals at the top of the ship on the inner surface of the outer cover; that the relatively slow burning of such free hydrogen would account for the peculiar manifestations of illumination described by certain witnesses; that the fire in the second sequence then destroyed gas cell No. 4, as seen by Witness Lau.

With regard to the presence of gas in one of the meters it was estimated that in one hour the seepage in the axial corridor would have amounted to one-fortieth of one per cent of the volume of the corridor; that even in the motionless condition of the ship, the corridor would have been well ventilated due to the chimney effect created by a wind of six knots blowing over the gas shafts; that the ventilation in the corridor would have prevented pockets of hydrogen from forming because the air current through the corridor was not laminated but was made up of whirls and eddies. However, if it could be shown that a rent occurred in a cell below the axial corridor, then it is possible that some free hydrogen might have found its way into one of the meters.

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In regard to the ignition of such mixture within a gas pressure, or fullness, meter the following is quoted from a report of the Bureau of Standards, relating to Exhibit 74, one of the meters taken from the ship:

"It is evidently intended for measuring and giving a remote indication of small gas pressures by electrical means. The gas pressure acts on a diaphragm in opposition to a helical spring. A plunger attached to the diaphragm carries a coil of wire which has a resistance of 100 ohms. Two rollers, connected in parallel, make contact with the sides of the coil. Two flexible connections run to the ends of the coil. The change in the relative resistances of the two parts of the circuit between the contact rollers and the ends can cause suitable electrical indicating instruments in the control cabin to indicate the position of the coil and diaphragm and hence the pressure.

"All electrical parts are enclosed in a cylindrical metal box. The only openings into this box are (1) the hole, 10 mm in diameter at the top through which the operating rod passes with a clearance of not over 0.05 mm and (2) the opening at the bottom which is completely filled by the 3-conductor cable (covered with metallic braid) which connects to the rest of the circuit. The conical housing surrounding the metal box is well ventilated.

"The device seems to be excellently designed and constructed from the standpoint of safety, and there appears no way by which it could with any reasonable probability have caused a fire.

"An overheating of the device by short-circuit seems impossible. A short-circuit external to the device would impose on it only the full voltage

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(24 volts) of the circuit and produce a rate of heat dissipation of less than 6 watts. A short-circuit inside the device would not draw more than the 1 milliampere fixed by the external instruments. A simultaneous short-circuit both inside and out would blow a fuse, if one was present, before a dangerous temperature was reached. Good practice requires such fuses on all such circuits, and one was probably used.

"The normal operation of the device should produce no sparks. Deterioration of the contact rollers or of the coil, or a breaking of a wire inside the metal box might produce a spark inside. It seems impossible that hydrogen should be present inside as it could get there only by diffusion down the narrow clearance between the operating rod and its guide tube, 50 mm long. A spark could be produced outside the box only by the breaking of the 3-conductor cable.

"This cable is strengthened by the metallic braid and runs in a protected location along the structural member. It could not be determined whether or not the cable was definitely anchored to the member, nor whether the metallic braid was originally clamped to the metal box, because of damage in the fire."

In the light of all the available evidence on this point we believe that the possibility of igniting such mixture by the means just described was very slight.

Resonance Effect - High Frequency Inductance

An attempt was made to discover if the ignition of such mixture could have been laid to spark emission due to resonance effect upon metal parts of the ship's interior caused by received radio waves of high frequency.

There was on the field at Lakehurst, a localizer beam radio transmitter of low power, maintained by an air-

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line company, the on-course portion of which was so situated as to pass through the space occupied by the ship at the time it took fire. This transmitter was at that time about 1800 feet from the ship. Its power output was 15 watts; its frequency 278 kilocycles. The maximum field strength authorized for this type of station is 1500 microvolts per meter at one mile, which represents fifteen ten-thousandths of one volt, per meter measured at one mile on the on-course portion of the range which, incidentally, is the area of weakest radiated power. The strength of this field is so low that it has been compared to the power of a fly. So far as could be determined, this localizer was the only transmitter that was operating at Lakehurst at the time in question. It is not believed that other high-frequency stations, at some distance from the field, could have had inductive effect upon the airship.

Witness Dieckmann, of the German Commission, stated that he and his colleagues had been particularly interested in the possibility of ignition through high-frequency radio induction, especially after hearing the testimony of Witness Freund who was engaged in paying out a length of the stern cable at ring 47 when the accident took place; that this part of the cable might have received impulses and thus electrical energy would have been conveyed into the inside of the ship. However, it appears that

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if such result was to occur due to inductive effect, a transmitter relatively close to the ship and of considerable power would have had to be operating at the time of the event. These conditions were not present.

Resonance effect due to high-frequency generation within the ship was impossible because all the ship's transmitters had been shut down before the appearance of fire. Furthermore, once inside the ship in the form of oscillations in the structure no damage could have been done, because the structure itself was so large and so complex that there was no possibility of a small amount of energy setting the whole ship in oscillation and that oscillation in separate parts, which perhaps contained high resistance, would be short-circuited by other parts of the ship. In view of the facts and the expert testimony given on this possibility, it may be said that in such inductance there was only the remotest chance that it was responsible for the elusive spark.

Electrostatics

Under this designation of electrical possibilities there is now to be considered a group distinguishable from current electricity and known as electrostatics. In this group, there is first mentioned a possibility due to the nature of the materials employed.

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In the older type of cell fabric, containing a rubberized element, it was apparently possible to create a static spark by tearing the fabric. The cell fabric used in the HINDENBURG as far as we could learn, did not include material possessing this characteristic. Since virtually all of the cells were consumed by the fire, no test could be made of the cell fabric.

The two bungees in the stern of the ship connected to the horizontal members of the tail, contained some rubber, but as far as we know the bungees had not been damaged until after the fire had broken out.

Before proceeding further with the subject of electrostatics, it is to be remarked that an airship as a body is regarded as carrying an electric charge, the nature and extent of which depend upon the circumstances. In motion it may accumulate a charge either through friction with the air or perhaps by means of charged water drops such as may be found in clouds or mist. It may accumulate a charge of either positive or negative sign. Thunder clouds may carry a positive or a negative sign. According to the evidence in this instance, the ship is assumed to have carried a positive charge on its outer surface, which is a semiconductor. This phenomenon is due to the fact that an airship in flight is within the atmosphere which is electrified. A few of the more interesting features of this phenomenon are; that the earth ordinarily is charged negatively; that in the atmosphere there is an electrical field measured in volts per meter (potential gradient) which in fine weather amounts to 100 volts per meter, becoming higher as the weather grows more disturbed; that the tendency is for an equalization current to pass from the atmosphere to the ground; that the electrical conductivity of the atmosphere is greater when the atmosphere is humid.

Other facts and assumptions are that the total outer surface of the ship has a uniform potential, that the electrostatic effects on the outside of the ship are separate and apart from those on the inside; that a number of conditions tend to equalize the potential of the ship with the surrounding atmosphere; among these is the dissipation created by the exhaust gases and by the movement of propellers, the edges of the latter being metallically connected with the ships structure; that the landing ropes would serve as conductors of the ship's charge and equalize the potential of the ship with that of the ground. When the ship is held by the landing ropes the electrostatic picture is such that the surface of the ship after a brief interval, so to speak, becomes a piece of the ground elevated into

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the atmosphere.

The potential differences measured vertically to the earth are called the potential gradient. This gradient is higher over those areas of the ship where the edges or points project into the atmosphere, especially over the bow and stern of the ship. It may be increased in the presence of charged clouds.

The principal protection against an electrostatic discharge which might serve to ignite an inflammable mixture in or about the ship is the bonding of the ship. Briefly, such bonding is the connecting up of the many parts of the ship so that electrically it becomes one complete metallic whole. A possible test of the state of this bonding could have been made by detecting through the radio receivers the characteristic noise associated with interference created by imperfect bonding. In the present instance, as had been noted, the receiving system of the ship did not give indication that any injury had occurred to the ship's bonding prior to the accident.

We have also considered the possibility that due to a discharge between parts of the ship having different potentials, a spark might have been created. Whether such a discharge occurred we cannot say. According to the testimony, the ship was bonded in keeping with the best known practice.

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There was one fixture of the ship in this respect, that received more than passing notice - the unbonded electric wires at the stern electric lamp of the airship.

Witness Dieckmann indicated that there might have been a static charge produced by this tail light wiring at the light bulb since the wiring within it was the only part of the ship which did not have the same potential as the remaining surface of the ship, a very small difference, however. Whether such a small electrostatic capacity as the lamp terminal would have been able to produce a spark is highly questionable. Another reason to regard it as improbable is that no one reported having seen the origin of the fire at the extreme rear end of the ship.

Ball Lightning

A reading of the record reveals that some space is given to another manifestation of electrostatic discharge; namely, to the possibility that ball lightning might have accounted for the ignition of the mixture.

Ball lightning is supposed to be one of the peculiar species of lightning discharges that have been observed from time to time. One of its features is that like a drop of oil on water it spreads and splits into segments, some of which segments continue for a distance along objects on which they alight.

Although some authorities have disclaimed the existence of ball lightning, we have considered the idea

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for what it might be worth. It does not very well explain the slow burning that some of the witnesses described as having taken place at the beginning of the action. Moreover, the theory as applied in the present instance, would appear to have little substance since no one testified to having observed any form of lightning.

For the same reason any other claim made on the ground of lightning as a cause would also seem to fail because none of the witnesses who testified stated that they observed any lightning flashes in the vicinity of the ship or heard an accompanying clap of thunder at the time of the accident.

Brush Discharge, or St. Elmo's Fire

In order to develop the next possibility to be considered, viz., ignition due to brush discharge, or St. Elmo's fire, a few additional remarks are necessary upon the subject of electrostatics and the conditions that actually prevailed at the time and place of the accident.

It will be recalled that the bow port trail ropes first made contact with the extremely wet ground, 4 minutes before the fire. When they left the ship they appeared to be quite dry as dust was observed to fly from them as they descended. These ropes were made of hemp. The atmosphere at the time and place of landing was humid and the ship had absorbed moisture. It was, therefore, reasonable to suppose that in the interval the ropes continued to absorb moisture and their conductive qualities increased. Therefore, their contact with the ground under the circumstances would discharge the static accumulated on the ship. Laboratory tests were made by the National Bureau of Standards of the electrical conductivity, at various humidities, of a section of the bow port trail rope, to determine whether the static discharge accumulated by the airship was or was not discharged when such rope made contact with the ground. Under the varying conditions employed in the tests, it was found that the airship would be 90% discharged in a period of from 0.6 seconds to 170 seconds after such rope came in contact with the ground.

With respect to the potential gradient existing in the atmosphere in which the ship was standing, witness F. W. Reichelderfer, naval aerologist, indicated that conditions were favorable to a steep potential gradient due to the existence of a thunderstorm condition. Witness Eckener also believed that a high potential gradient existed at the time and place of the accident. He apparently based his opinion upon the following: - that a thunderstorm front had just passed over the station; that the heavy rain had become a light drizzle, thus reducing the potential gradient materially and that from his information the appearance of the sky showed a light stratus ceiling. He proceeded to

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say that if one closely examined the current registrations of winds, temperatures, and pressures, then one might recognize that the first thunder front must have had a smaller, lighter one, following it, that the wind turned back to the southeast. Winds of the higher altitude remained westerly. The barometer curve showed a slight falling off of pressure and relatively the temperature started to rise again. That is, after the temperature had been brought down appreciably, by the breaking in of the cold air, the temperature remained constant for one-half hour before the landing maneuver to one-half hour after the landing maneuver. Then the temperature again started to decline rapidly and the wind slowly turned back to the northwest.

This, according to the witness, the sensitive instruments show, and that if this was not noticed at the field it was quite natural because attention was focused on the landing maneuver and on the handling of the ship. (For registrations made by the sensitive instruments, referred to by witness Eckener, see Appendix 4 containing graphs made at the Naval Air Station, Lakehurst, N.J., May 6, 1937, including anemograph, thermograph and microbarograph traces - correct within five minutes).

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He stated confidently that there was a small tail-end to the first thunderstorm that passed by, which most likely created a steeper potential gradient than would otherwise be expected. Whether this stronger gradient could have generated sufficient potential between the air ship and the air masses above the ship so that an equalization of the gradient took place, either by St. Elmo's fire, or by a spark, he was unable to decide.

That the ignition was not effected by such a static equalization spark immediately after the landing lines had been dropped was because they then were dry, hence poor conductors. They slowly became damp in the light drizzle that was falling; and in such condition their conductivity became greater. Therefore, he believed that the potential between the ship and the ground was slowly equalized and afterwards the potential gradient between the ship and the overlying air space was sufficient to generate these static sparks.

Witness Whitehead in commenting upon these views respecting the potential gradient said that if a secondary storm was present in sufficient intensity to cause a spark of lightning of any character that it would have been visible or audible. At any rate it would be reasonable to suppose that probably because of the preceding thunderstorm

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the potential gradient at the time and place of the accident was somewhat greater than normal.

Witness F.A.L. Dartsch, aerologist at the Naval Air Station appeared to have a somewhat different opinion. He stated that previous to the landing there had been heavy showers which could have produced a strong potential gradient but whether that still existed at the time of the accident when only a light rain was falling with just the clouds above, he could not definitely say. He did not believe that the potential gradient then existing was dangerous to the ship but he had no way of verifying his view. In answer to the question, "After the thunderstorm had disappeared, and the wind and rain had decreased, were there any signs or indication of a new small depression or squall?" Witness Dartsch said that the only indications they had had was the temporary shift from southeast to southwest with the slight - about one hundredth inch - rise in pressure. However, no distinctive clouds of precipitation occurred with this change.

Brush discharge ordinarily is seen only after dark. It is manifested particularly from sharp points or projections of any material object that is charged to a sufficiently high electrostatic potential so that the charge dissipates. The effect is produced by particles of the material substance or by ionization of the gases of the atmosphere from impacts or stress. The ignition of a combustible mixture of gases in such a discharge is due to transformation of kinetic energy into heat from impacts of ions or particles. The brush discharge appears either reddish or bluish depending upon the electrical sign of the charge.

During the course of the public hearings, the question of whether a brush discharge would produce sufficient heat to ignite an inflammable hydrogen air mixture, was dwelt upon to a considerable extent. Since that time, further experiments have been made in the High-Voltage Laboratory of the National Bureau of Standards and it has been found possible to ignite hydrogen by a brush discharge by using somewhat more intense discharges than those previously tried with a somewhat slower velocity of the gas passing the needle point.

In this consideration of the possibility of brush discharge it is to be noted that no witness testified that a visible indication of it was present. This, however, may be accounted for by the fact that darkness had not yet fallen at the time of the accident.

Witness Whitehead was of the opinion that the continuous presence of brush discharge, sufficient to cause the ignition, would require a greater current intensity than could have been possible through a dry rope.

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Another argument against the brush discharge theory advanced by Witness Whitehead was that there was much evidence that the first sign of fire was through the translucent skin at the point well away from the tip of the fin.

Witness Dieckmann in elaborating on this phenomenon stated that a one-hundredth or one-thousandth part of a watt, perhaps less, was all that would be necessary to ignite a mixture of air and hydrogen; that it was difficult for him to believe that brush discharge was responsible for the ignition; that none of the witnesses testified to its presence. He remarked upon the testimony as to the presence of glowing reflections of fire which had moved from the stern forward but stated that such references to reflections were peculiarly indefinite and uncertain.

Of related interest to brush discharge was the opinion of Witness Earle that in an atomosphere of high humidity, static electricity could be attracted to the top points of the ship when the ship's mooring ropes came into contact with the ground sufficient to cause a spark to jump across the mixture of hydrogen and air, saying that such would be possible if the ship was in relatively slow motion, while gas was being valved, placing a layer of gas between the ship and the damp atmosphere. The concentrated atmosphere between the cloud and the ship would reduce

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resistance to sparking and if the potential of the ship was the same as that of the ground there would be a possibility of sparking across; that it is easier to spark through hydrogen than through air.

The meteorological records and related data of the investigation were made available to Dr. W. J. Humphreys of the United States Weather Bureau. He has concluded after making a study of such material that, "a brush discharge, or several of them, very well might have occurred on the ship after, not before, the landing ropes came into contact with the ground; that this brush discharge would have continued for some time; that it would have been invisible (being in daylight); that such a discharge likely would have ignited any adequately rich stream of leaking hydrogen that reached it; and that from the point of ignition the flame would have shot back to the leak, there quickly would have burnt a larger opening and set going a conflagration of great violence and rapidity".

CONCLUSION

The cause of the accident was the ignition of a mixture of free hydrogen and air. Based upon the evidence, a leak at or in the vicinity of cell 4 and 5 caused a combustible mixture of hydrogen and air to form in the upper stern part of the ship in considerable quantity; the first appearance of an open flame was on the top of the ship and a relatively short

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distance forward of the upper vertical fin. The theory that a brush discharge ignited such mixture appears most probable.

Respectfully submitted,

South Trimble, Jr., Solicitor

R. W. Schroeder, Asst. Director,
Bureau of Air Commerce.

Denis Mulligan, Chief, Regulation and
Enforcement Division, Bureau
of Air Commerce

Approved

Daniel C. Roper,
Secretary of Commerce.
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APPENDIX I

Officers and Crew on board the Airship HINDENBURG on its departure from Frankfurt-am-Main, Germany, on May 3, 1937, were as follows:

*Captain Ernst Lehmann
Captain Max Pruss, Commanding

Watch Officers

Albert Sammt
Heinrich Bauer
Walter Ziegler

Navigators

Max Zabel
Franz Herzog
Christian Nielsen
Kurt Bauer

Radio Officers

*Willy Speck, Chief Radio Operator
Herbert Dowe
*Franz Eichelmann
Egon Schweikard

Engineering Officers

Rudolf Sauter, Chief Engineer
Eugene Schaeuble
*Wilhelm Dimmler

Elevatormen

*Ludwig Felber
*Ernst Huchel
Eduard Boetius

Helmsmen

*Alfred Bernhard
Helmut Lau
Kurt Schoenherr

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Electricians

Philip Lenz, Chief Electrician
Joseph Leibrecht
*Ernst Schlapp

Mechanics

*Walter Bahnholzer
Eugen Bentele
*Rudy Biallas
August Deutschle
Jonny Doerflein
Adolf Fischer
*Albert Holderried
Richard Kollmer
*Robert Moser
*Alois Reisacher
Theodor Ritter
Raphael Schaedler
*Willy Scheef
*Joseph Schreibmueller
Wilhelm Steeb
*Alfred Stoeckle
German Zettel

Riggers

*Ludwig Knorr, Chief Rigger
Hans Freund
*Erich Spehl

Stewards

Heinrich Kubis
Wilhelm Balla
Fritz Deeg
Max Henneberg
Severin Klein
Eugen Nunnenmacher
*Max Schulze

*Frau Imhoff, Stewardess
Dr. Ruediger, Ship's doctor

Cooks

Xaver Maier, Chief Cook
*Richard Mueller
Alfred Stoeffler

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Cooks (Contd.)

Alfred Groezinger
*Fritz Flakus
Werner Franz, Mess Boy

Observer

Captain Anton Wittemann

*Indicates those who died in accident.

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APPENDIX II

Passengers on board the Airship HINDENBURG on its departure from Frankfurt-am-Main, Germany, on May 3, 1937, were as follows:

	Adelt, Gertrude	Berlin, Germany
	Adelt, Leonhard	" "
*	Anders, Ernst Rudolf	Dresden, Germany
	Belin, Peter	Washington, D. C.
*	Brink, Birger	
	Clemens, Carl Otto	Bonn, Germany
*	Doehner, Hermann	Mexico City, Mexico
*	Doehner, Irene	" " "
	Doehner, Matilda	" " "
	Doehner, Walter	" " "
	Doehner, Werner	" " "
*	Dolan, Curtis	France
*	Douglas, Edward	New York
*	Erdmann, Fritz	
	Ernst, Elsa	Hamburg, Germany
*	Ernst, Otto C.	" "
*	Feibusch, Moritz	Lincoln, Nebraska
	Grant, George	London, England
	Heidenstamm, Rudolf von	
	Herschfeld, George	Bremen, Germany
	Hinkelbein, Claus	
	Kleeman, Marie	
*	Knoecher, Erich	Zeulenroda, Germany
	Leuchtenberg, Wm.	New York
	Mangone, Philip	
	Mather, Margaret	
	Morris, Nelson	
	O'Laughlin, Herbert	
	Osbun, Clifford	Chicago, U.S.A.
*	Pannes, Emma	New York
*	Pannes, John	" "
*	Reichold, Otto	Vienna, Austria
	Spaeh, Joseph	
	Stoeckle, Emil	
	Vinholt, Hans	Copenhagen, Denmark
	Witt, Hans	

* Indicates those who died in accident.

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