REPORT OF THE R. 101 INQUIRY

Presented by the Secretary of State for Air to Parliament by Command of His Majesty, March, 1931

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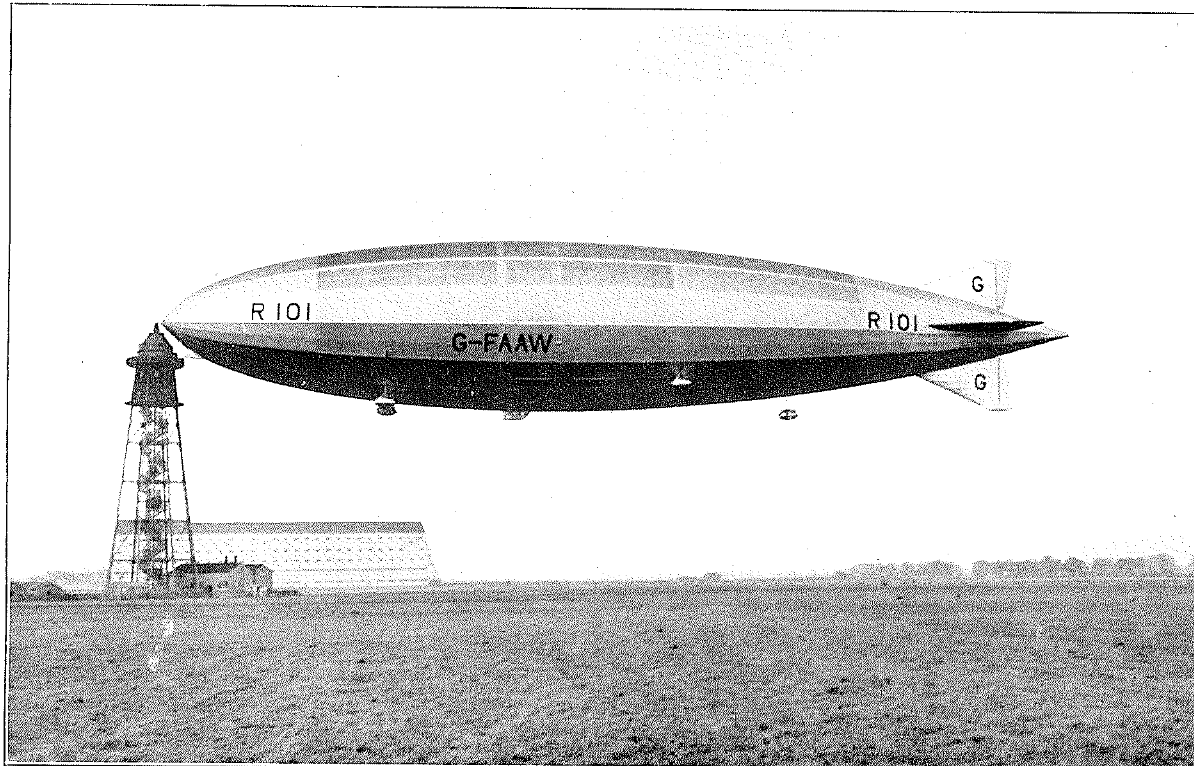

Airship **R101** at the mooring tower, Cardington.

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THE AIR NAVIGATION ACT, 1920.

THE AIR NAVIGATION (INVESTIGATION OF ACCIDENTS) REGULATIONS, 1922 TO 1930.

ORDER dated the 22nd October, 1930, made by the Secretary of State for Air under the Air Navigation (Investigation of Accidents) Regulations, 1922 to 1930.

WHEREAS an accident arising out of or in the course of air navigation occurred on the 5th October, 1930, near Beauvais, France to the airship R.101.

AND WHEREAS the said accident is an accident to which the Air Navigation (Investigation of Accidents) Regulations, 1922 to 1930, apply; and it appears to me that it is expedient to hold an investigation of the said accident, and the causes and circumstances thereof.

NOW THEREFORE I, the Right Honourable William Warrender Lord Amulree, G.B.E., one of His Majesty's Principal Secretaries of State, in pursuance of the said Regulations and of all other powers enabling me in that behalf, hereby order and direct an investigation of the said accident and the causes and circumstances thereof to be held:

AND I appoint the Right Honourable Sir John Allsebrook Simon, one of His Majesty's Counsel, to hold such investigation and to report thereon.

(Sgd.) AMULREE,
Secretary of State for Air.

AIR MINISTRY,
LONDON.
22nd October, 1930.

The Secretary of State, by subsequent Orders, appointed Lieutenant-Colonel, J. T. C. Moore-Brabazon, M.C., and Professor C. E. Inglis, F.R.S., to act as assessors for the purposes of the investigation.

To
The Right Honourable
The Lord Amulree, G.B.E.,
Secretary of State for Air.

My Lord,

I was appointed, under the Order of October 22nd, 1930, made by you under the Air Navigation (Investigation of Accidents) Regulations, to hold an investigation into the causes and circumstances of the accident which occurred on October 5th, 1930, near Beauvais in France, to the Airship R.101, and to make a Report on the matter. Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., and Professor C. E. Inglis, F.R.S., O.B.E., were appointed to act as Assessors for the purposes of the said investigation.

I now have the honour to transmit the Report, together with a corrected copy of the shorthand notes of the evidence.

The Inquiry, over which I presided, was held in public at the Institution of Civil Engineers. It was opened on October 28th, 1930, and lasted in all for 13 days. The Attorney-General (Sir William Jowitt, K.C.), the Solicitor-General (Sir Stafford Cripps, K.C.), and Mr. Wilfred Lewis, appeared at the Inquiry on behalf of the Crown, and Mr. P. L. Teed appeared on behalf of the widow of Flight-Lieutenant Irwin, Captain of the R.101.

The sittings of the public Inquiry were divided into two periods, the first occupying ten days' hearing and ending on November 10th, 1930. The Court then adjourned till Wednesday, December 3rd, when three more sittings were held, ending on December 5th. In the interval, Professor Bairstow undertook, at the request of the Court, a special investigation for the purpose of supplying further calculations which would help in analysing the cause of the accident. In order to assist these further calculations, an exact model of the R.101 as she was finally shaped, was constructed, at the National Physical Laboratory, and a number of valuable experiments were made by the staff there, which have been of great assistance. I desire to express my deep obligation to the authorities at the National Physical Laboratory for the help they thus rendered, and also for further investigations specially made at the request of the Court after the Inquiry had concluded, which are referred to in para. 106 in the Report, and also in Appendix VI.

In the course of the Inquiry 42 witnesses were examined. Their names will be found in Appendix I of the Report.

The authorities at the Air Ministry and the Staff at Cardington throughout rendered the fullest assistance to the Inquiry, and a full disclosure was made of official records. It may be confidently asserted that all available information of any material value was placed before the Court and everything possible has been done by officials, experts, and private persons to make the Inquiry complete. The Court desires to put on record its special obligations to Professor Bairstow, who has devoted himself with constant assiduity and skill to assisting the investigation. Without his conclusions and explanations it would have been impossible to appreciate the scientific and theoretic aspect of the questions raised by the disaster.

It is a matter of great satisfaction to me, as it will also be to yourself and to the public, that my two Assessors, Lieut.-Colonel Moore-Brabazon and Professor Inglis, find themselves in agreement with me on all points in the Report which I am presenting. I may be permitted to express my deep sense of obligation to them both for assistance and guidance without which the Report could not have been written. The document may therefore be taken as our joint work and opinion.

Lastly, my Assessors join with me in putting on record our deep appreciation of the constant devotion and exceptional skill exhibited throughout the Inquiry by the Registrar of the Court, Mr. L. F. C. Darby, and the Assistant-Registrar, Squadron-Leader A. H. Wann. The mass of documents to be digested and arranged was very large, and the evidence to be analysed and brought together was extremely voluminous. Whatever of clearness or completeness the following Report may possess is largely due to their efforts.

I am, My Lord,

Your obedient Servant,

JOHN SIMON.

27th March, 1931.

REPORT.

1. At six thirty-six on the evening of October 4th, 1930, the R.101, the biggest airship in the world, on the design and construction of which so much care had been lavished for several years past, left her base at Cardington, near Bedford, and set out on a maiden voyage to India via Ismailia. She carried, besides officers and crew, her designer Colonel Richmond, the Director of Airship Development Wing-Commander Colmore, the Director of Civil Aviation Sir Sefton Brancker, the Secretary of State for Air Lord Thomson, and other officials specially associated with airship construction and navigation.

About seven and a half hours later, shortly after two o'clock in the morning of October 5th, she came to earth 216 miles away, in undulating country south of the town of Beauvais in France, and immediately became a blazing wreck. Of the 54 people on board, all but eight perished instantly in the flames; two of these eight died of their injuries shortly after the disaster. The six survivors—five engineers and the electrician—were called as witnesses at the Inquiry.

It is the cause and circumstances of this tragedy that the Court is required to investigate.

PART I.—EARLIER HISTORY OF BRITISH AIRSHIPS.

2. In order to appreciate the technical evidence and to form a just conclusion on matters immediately relating to the accident, it is necessary to provide a sketch of the course of airship development before the construction of the R.101 was undertaken. Down to the outbreak of the War, the airship as a means of transport had made more advance than the aeroplane. Between 1910 and 1914, five German airships had carried 42,000 passengers in 2,000 flights without mishap to any passenger. On the other hand, the first successful aeroplane flight from London to Manchester was not performed until 1910, and this was without carrying any passengers.

By the end of the War, the relative position of aeroplane and airship was reversed. The technical progress of the aeroplane was definitely in advance of that of the airship. The vital part played in the War by aeroplanes as military instruments and the constant increase in the number of purposes to which they were applied, produced a service in which the heavier-than-air machine became more and more important. Rapid development on the technical and engineering side kept step with a numerous and highly skilled personnel engaged in aeroplane flying, while airships fell into the background. The theoretic problems connected with flight are, no doubt, to a considerable extent, common to both types of aircraft. But the intensive research organised and carried on by the Advisory Committee for Aeronautics, and the aeronautical investigations carried out at the National Physical Laboratory and at various experimental stations, were inevitably directed, for the most part, to securing improvements in aeroplanes. The experience of German Zeppelins seemed to show that the large rigid airship could not successfully operate in the face of organised aeroplane attack and anti-aircraft defence, though airships of the Zeppelin type carried out during the War many noteworthy operations, including a continuous flight by the German L.57 in 1917 to East Africa and back, covering a distance of 4,200 miles in 96 hours. The rigid airships built in England during the War—*e.g.*, R.33 and R.34—were practically copies of Zeppelin airships, and though later designs were evolved from earlier ones, no complete examination of aerodynamical problems was adequately made in connection with airship construction and behaviour until a later date.

In June, 1919, the British airship R.34, on returning from a reconnaissance flight over the North Sea, encountered a gale of such severity that although flying through the air (with her after-engine entirely out of action) at 40 knots, she was actually going astern over the sea for eight hours. Nevertheless, she returned to her base successfully after 57 hours of continuous flight.

In the following month the R.34 flew to America in 108 hours; remained moored there for four days; and then flew back to England in 75 hours, thus covering a total distance of 6,400 miles in 183 hours.

Among the performances of foreign airships in the years following the war may be noted that of the German "Bodensee" in the latter half of 1919 (103 flights covering 32,000 miles and carrying 2,450 passengers); the "Los Angeles," which flew in October, 1924 from Friedrichshafen to Lakehurst in the United States in 80¾ hours; and the Italian "Norge," which in the summer of 1926 flew with Amundsen over the North Pole between Spitzbergen and Alaska.

Previous Airship Accidents.

3. In connection with this record of post-war achievement in various parts of the world three serious airship accidents must be borne in mind.

The French "Dixmude" met with destruction in the air in 1923; the facts of the accident are exceedingly obscure, and the French Court of Inquiry attributed the disaster to lightning.

The United States "Shenandoah" (inflated with helium gas), which had successfully fulfilled a programme of American flights between places as far apart as Texas, California, Illinois, and New York, was carried up to a great height and broke up in the air on September 2nd, 1925. The ship came to the ground in several portions and of its complement of 43 persons 14 were killed outright, 2 were hurt, and 27 escaped uninjured. The American Court of Inquiry found that her destruction "was due primarily to large unbalanced external aerodynamic forces arising from high-velocity wind currents."

Earlier in point of date than either of these disasters was the misfortune which overtook the British R.38 on August 24th, 1921. British rigid airships up to and including R.37 were little more than copies of Zeppelins, and the later Zeppelins had been evolved from earlier types by a process of slight but continuous variation without resorting to the fundamental research work which has since been pursued. The R.38 represented a departure from the older types, but in this case also the design was based rather on empirical knowledge than on fundamental research. She broke in two when at a great height in the air during a trial flight, and the two halves of her came to earth separately, the fore-end catching fire and descending into the Humber. A Report made by the Aeronautical Research Sub-Committee established that the accident was due to structural weakness, and the Committee found that the calculations which had been made about the strength of the R.38 were confined to statical conditions, qualified by a factor of safety which was thought to be adequate, and had not paid regard to the aerodynamic forces to which the airship would be subjected in motion through the air. The factor of safety was 4, i.e., it was assumed that if the strength of the R.38 was sufficient to withstand four times the static strain, this would be sufficient to cover adequately the additional stresses due to dynamic action.

Static and Aerodynamic Forces.

4. This distinction between static and aerodynamic forces is so important in itself, and has led to so valuable an enlargement of theoretical investigation, that it is desirable to explain the matter in simple terms at this point before going further.

The first sort of calculation, which is purely statical, is made by imagining the ship to be constructed according to its design and to be poised in the air motionless, with no wind operating upon it, and exposed to no strains or stresses except those which are due to the distribution of weights in the structure, and to the amount and distribution of the lift of the gasbags. On this assumption, the lift of the gas must necessarily be equal to the weight of the ship, and the object of this first set of calculations is to ascertain whether the distribution of weights and the strength of different parts of the structure are such as to make it quite certain that in this condition of rest no part of the airship would buckle or break. A factor of safety was chosen which was believed to be suitable in connection with each calculation, and the assumption was that if the design was found to satisfy those conditions the airship might be regarded as sufficiently strong for the work it had to do in the air. It will be observed, however, that if reliance is placed upon statical calculations alone, no attempt will have been made to measure the wholly different strains and stresses to which the machine will be exposed when it is propelled by its engine-power through the medium in which it floats. All that will have been done is to provide empirically against these further forces, known as aerodynamical forces, which necessarily exert themselves only when the ship is in flight or is no longer free to float in and with the medium like a jellyfish floats in and with the tide. These aerodynamical forces require to be most elaborately calculated; they depend, amongst other things, upon the rate at which the ship is passing through the air and, indeed, increase with the square of the speed. Not only so, but on passing from the hypothesis that the airship is at rest to the assumption that she is travelling under engine power, bending moments in some of the ship's members may be actually reduced, though in other cases pressure of the resisting wind will cause them to be greatly increased. The resultant effect will, in many cases, vary according to the angle which the ship takes up with reference to the air stream, and very great changes will be brought about by different positions of the elevator or the rudder. Aerodynamical factors, therefore, have to be considered as well as purely statical factors, though it is necessary here to emphasise that neither of these sets of calculations do anything more than provide a guide for securing that the airship and every part of it will have sufficient structural strength. The question of how she will *behave* in the air in various assumed conditions, in what circumstances she will retain her stability, and at what point she may become unstable, is a yet further enquiry which must be distinguished from both the statical and aerodynamical calculations to which reference has been made.

In view of the disaster to the R.38 in 1921, the Aerodynamical Research Sub-Committee which investigated the accident reported that research by both model and full-scale experiment was essential to determine and verify the aerodynamical forces to which a given airship would be subjected and that "in the construction of such an airship, reference to first principles of design is necessary; and for progressive development of airships in size and speed, it is not sufficient to place exclusive reliance on a comparison with existing ships, using the routine methods adopted for R.38."

The Two Panels.

5. Hence arose two bodies, upon whose Reports and Memoranda the more scientific construction of later airships in this country largely depends. Each of these bodies was appointed by the Aeronautical Research Committee, of which Sir Richard Glazebrook has been Chairman throughout. The first of them was

known as the "Airship Stressing Panel," and over it Professor R. V. Southwell presided. The main work of this Panel was to consider methods of calculating the strains and stresses which would arise in various parts of the structure of an airship from aerodynamic forces. Its Report, dated August, 1922, contains a mass of highly technical information on this subject and urges the importance of model experiments as a check on the theoretical results which had been reached.

The other body, known as the "Airworthiness of Airships Panel," was presided over by Professor L. Bairstow, who gave most valuable evidence at the Inquiry.

The Report of the Airworthiness of Airships Panel was published in October, 1924, and recommended a number of factors of safety which the Panel considered appropriate for various conditions—that is to say, it fixed how many times stronger the airship must be than would be theoretically just sufficient to bear the strain put upon it under different circumstances. In constructions which have not to sustain their own weight by lifting power, a generous factor of safety is often consistent with good design, but, as is pointed out in the Report of the Airworthiness of Airships Panel "it would be easy to stipulate figures which would hamper design without approaching the factors of safety used in engineering practice: however, the standpoint has been taken that such factors are inadmissible and that success in airship design requires a more thorough knowledge of principles and data than the older engineering applications: full use must, therefore, be made of this new knowledge by designers and a high standard of workmanship is required." In other words, the condition that airships must not be too heavy to fly makes it impossible to provide so wide a margin for uncertainties as might be possible in the case of a bridge. The importance of the results of theoretic conclusions proving correct in practice is thereby greatly increased. The factors of safety laid down by Professor Bairstow's Committee were, as will be seen later, taken as the basis for certifying the airworthiness of the R.101. The Report added that the factors of safety which it laid down "necessitate consideration of the stability of the ship, and of the amount of available control through the elevators and rudders. Information on the effect of gusts is so scanty as to be valueless for calculations, and the Panel has followed the lead given by the Accidents Investigation Sub-Committee in assuming that the worst conditions in a natural wind will not be more severe than those contemplated in certain extreme cases set out in the schedule."

The 1924 Programme.

6. In the meantime, however, the reduction of expenditure which was called for in 1920 had compelled the Air Ministry to close down the Airship Branch of the Royal Air Force. By the end of 1921 there was a possibility that airship operations in this

country would be stopped and the airships and stations disposed of. In 1922 and 1923 much consideration was given to a scheme of airship development urged by Commander Burney (now Sir Dennistoun Burney), and in 1924 the former Government of Mr. Ramsay MacDonald appointed a Cabinet Committee to reconsider the position. This Inquiry went to show that if airship development was to proceed upon a sound technical basis, it was inevitable that the Government should undertake the research and experiment which the disaster to R.38 had shown to be necessary, and His Majesty's Government, therefore, decided to adopt the experimental programme of airship development which was in course of being carried out when the loss of the R.101 occurred. This experimental programme was to extend over three years, and was at first calculated to cost £1,350,000. Events were to prove that both the period and the cost were underestimated. The programme was designed to test the capacity of modern rigid airships as a standard means of long distance transport, and to this end it was resolved to set on foot a thorough scheme of research and investigation in preparation for two practical operations—

(*a*) The construction of two airships with such improved speed, range, and load-carrying capacity as would enable them to make long voyages overseas with a substantial margin of lifting power ; and

(*b*) The carrying out of flights to and from an overseas' terminal in order to test whether the airships were suitable for the work for which they were designed.

The Memorandum prepared by Sir Samuel Hoare as Secretary of State for Air, and laid before the Imperial Conference in 1926, in explaining the nature of this experimental programme, went on to say—

> "It was held that once this programme had been successfully carried out the further developments of airships would be assured, and it was recognised that the practical progress of the experimental programme might well prove to be of decisive importance in the history of airship development. It was, therefore, decided to develop the programme in a spirit of scientific caution, holding considerations of prudence and safety to be of paramount importance. Two airships were to be built, one by the Air Ministry (R.101) and one by the Airship Guarantee Company (R.100). This ensured competition in design and provided that a purely accidental failure of one ship should not terminate the whole programme. Elaborate researches and experiments were to be made ; new sheds and masts were to be erected in England, Egypt, and India ; and the weather conditions of the route were to be carefully investigated in their application to airship navigation. During the last two years work has been proceeding under this programme."

Model and Full-scale Experiments.

7. The course of research contemplated by the 1924 programme was carried out with great thoroughness and care. Reference has already been made to the recommendation that both model and full-scale experiment was essential, and accordingly a series of model experiments was carried out in the wind tunnels of the National Physical Laboratory to determine, or to assist in determining, the best shape for the two new airships. These experiments eventually led, in 1926, to the selection of a shape of hull which differed substantially from that of the older airships, and which was found to give for a given volume a much lower resistance. Whereas the R.33 was 645 feet long and 78 feet in diameter, the R.101, as originally designed, was 732 feet long with a diameter of 132 feet. The ratio of diameter to length is described as the "fineness" of an airship, and both the R.100 and the R.101 had a lower fineness ratio—*i.e.*, are "thicker" in comparison with their length—than either the Zeppelin type or the earlier British airships. The following table illustrates this contrast :—

Name of Ship.	Length in feet.	Diameter in feet.	L. over D.	Capacity, cubic feet.
R.38	694·5	85·5	8·1 to 1	2,724,000
Graf Zeppelin	776·9	100	7·7 to 1	3,708,000
R.100	709·2	133	5·3 to 1	5,000,000
R.101 (as originally designed).	732	132	5·5 to 1	5,000,000
The R.101 (as altered)	777	132	5·9 to 1	5,508,800

In addition to the model experiments in the wind tunnels of the National Physical Laboratory, full-scale experiments were made in accordance with the policy laid down in 1924. R.33 was re-conditioned and carried out a series of full-scale flights to accumulate data for the acquisition of which full-scale facilities had not previously been available. Further, a full-scale section of the future R.101 was constructed for strength tests before the construction of the airship itself was put in hand.

After the R.33 had been re-conditioned, and while she was moored to the mast at Pulham in April, 1925, before the full-scale experiments could be carried out, a gale, which reached 45 miles an hour, tore her from the mast and carried her out over the North Sea. Although she had a severely damaged bow with two gasbags in her nose partially deflated, she withstood the storm for 30 hours and returned safely to Pulham, showing that a well-built airship with a good Commander and crew could withstand the most severe conditions without having to make a forced landing. This incident also proved the practical value of meteorological information. The R.33 throughout her flight was sent forecasts as to the probable course and duration of the gale, and her Commander was, therefore, able to gauge his capacity to weather the storm and to return to his base on its cessation.

Conditions to be fulfilled by R.100 and R.101.

8. The above account of the course of British airship development down to the time when the building of the R.100 and the R.101 was contemplated and taken in hand will show how important was the new stage which was to be represented by these two air vessels. The next part of this Report will contain a more detailed account of the design and construction of the R.101, but before entering upon technical matters it will be well to summarise the main features aimed at as the new objective. Not only were the R.100 and the R.101 to embody designs and methods of construction which were based on a far more thorough programme of experiment and research than had hitherto been undertaken, but the ships themselves were to be much larger in size than any previously existing airship, and the intention was that each of them should satisfy the following general requirements :—

(i) *Capacity.*—To be 5 million cubic feet, giving with hydrogen gas about 150 tons gross lift, i.e., nearly twice that of any airship previously constructed in this country, and more than a third as much again as the largest existing Zeppelin.

(ii) *Strength.*—To afford certain definite factors of safety (particularly with regard to aerodynamic forces) laid down by the Aeronautical Research Committee in 1924—a condition never before imposed on any airship in this country.

(iii) *Speed.*—The full speed to be not less than 70 miles an hour and the cruising speed 63 miles an hour.

(iv) *Accommodation.*—Passenger accommodation, including both sleeping and eating accommodation, to be provided for 100 people.

(v) *Weights and useful lift.*—The structure weight, including power plant, but excluding fuel, not to be more than 90 tons, giving a useful lift of 60 tons, or 40 per cent. of the gross lift of the airship.

(vi) *Power plant.*—To be operated on fuel which could safely be carried and used in sub-tropical or tropical climates.

Modification in Original Conditions.

9. As will be seen hereafter, some of these projected requirements were not persisted in or finally secured. Requirement (vi) really meant that both the R.100 and the R.101 were to be fitted with heavy-oil engines instead of petrol engines, but in the end the R.100 was propelled by Rolls-Royce petrol-burning engines of the " Condor " type, and accomplished its journey to Canada

and back† by means of this motive power. If, therefore, the condition implied in (vi) is insisted upon, the type of engine used in the R.100 makes that ship inappropriate for a journey to India. The R.101, on the other hand, was fitted with a specially designed heavy-oil engine built by Messrs. Beardmore.

Another serious departure from what was originally contemplated arose, in the case of the R.101, at any rate, in connection with requirement (v). For when this vessel as originally designed and constructed was inflated, it was found that instead of 90 tons out of her gross lift of 150 being needed to carry fixed weights so as to give a useful lift of 60 tons (40 per cent. of the gross lift), the fixed weights amounted to 113·6 tons out of a gross lift of 148·6 tons, thus giving a useful lift of only 35 tons, about 24 per cent. of the gross lift. It is out of this so-called "useful lift" that provision has to be made, not only for crew, passengers, stores and water, but for the weight of fuel with which the vessel starts. As will be seen hereafter, this was so serious a diminution in the original lift which had been prescribed and estimated, that the R.101 could not contemplate attempting a voyage to India without undergoing changes which would increase its balance of lifting power, and hence arose two alterations of which much was heard at the Inquiry—the insertion of an additional "bay" or section in the middle of the ship, and the re-arrangement of the gasbag-wiring so as to increase the capacity of the gasbags. In addition, some reduction in weight was secured by cutting out certain conveniences and other details which could be dispensed with.

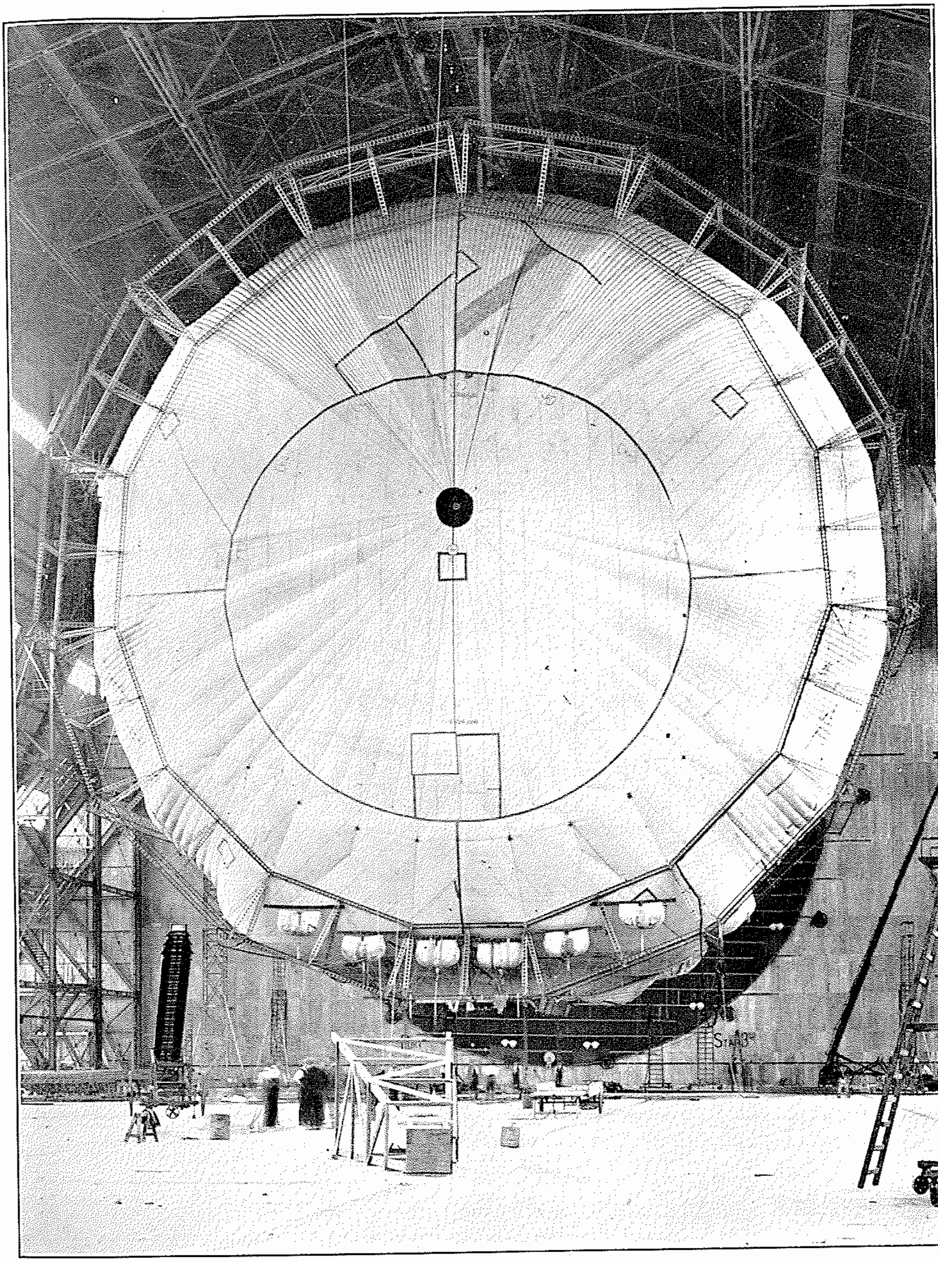
Bigger Mooring Towers.

10. One other matter needs mention before entering upon a description of the nature of the design and the course of the construction of the R.101. Airships of the size contemplated could not undertake distant journeys without the previous provision of a system of mast-mooring suitable for vessels of such large dimensions. Such mooring towers must be established at both ends of the journey and at any necessary intermediate points. The system of mast-mooring which had been evolved at Pulham, in 1921, was suitable for airships of two million cubic feet capacity or less, but it was now necessary to provide mooring-masts on a scale and of a size which would be suitable for airships of five million cubic feet and upwards. One was erected at Cardington. The Canadian Government erected a suitable mooring tower at Montreal, which was successfully used for the R.100 on her Canadian flight. For the R.101, mooring towers were prepared at Karachi and also at the intermediate station of Ismailia, on the Suez Canal. The question was considered by the authorities

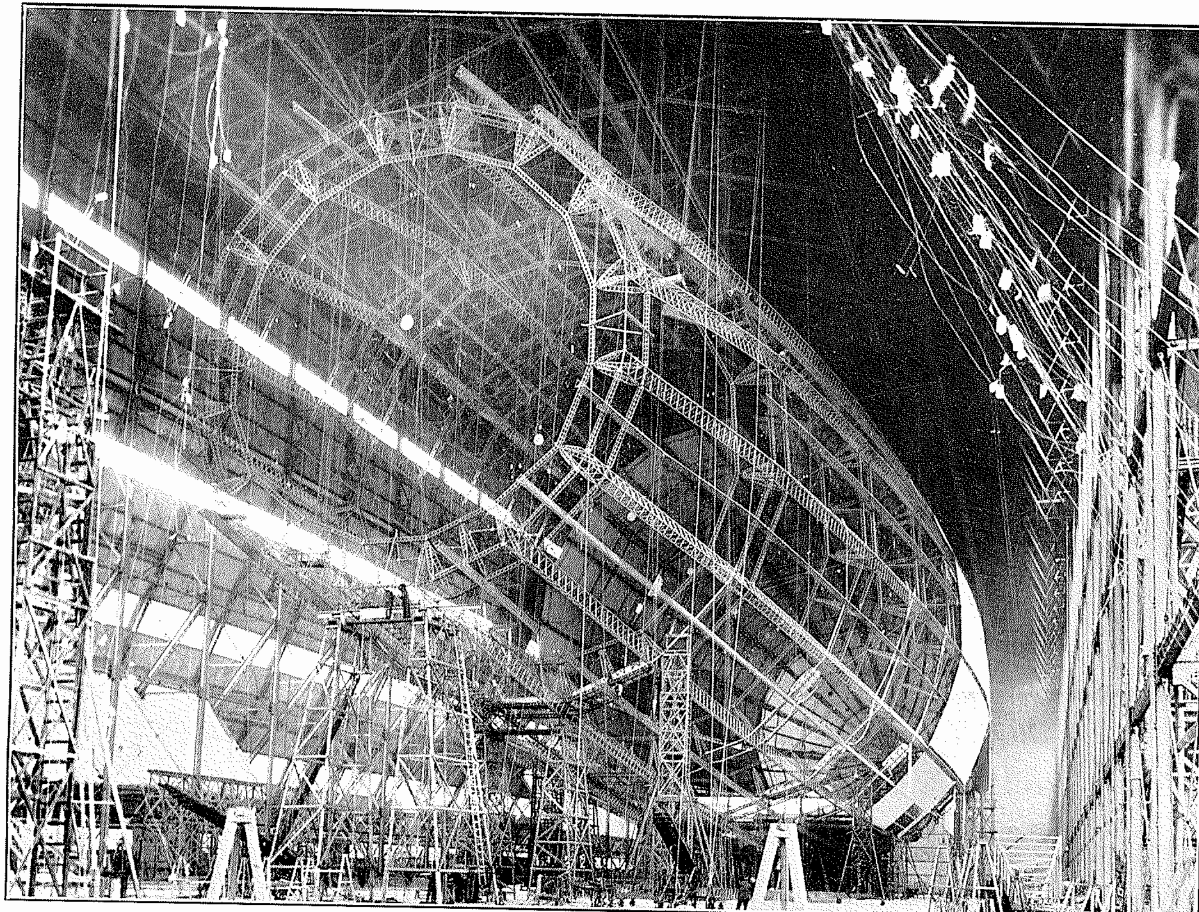
† The R.100 left Cardington for Canada on 28th July, 1930, and reached Montreal in 79 hours; she returned to Cardington from Montreal on 16th August after a flight of 57 hours.

whether it would not really be necessary, or at any rate highly advantageous, to have intermediate towers at other points, but the decision was reached that this, which would involve further expense and delay, could not be authorised in advance of the first attempt to reach India, while matters were still so largely in an experimental stage.

Unhappily, the disaster to the R.101 while crossing France has meant that the mooring towers at Ismailia and Karachi, which between them have cost £105,000, have never been used at all.



Airship R101—Test Bay and Gasbag.



Airship R101—Interior construction.

PART II.—DESIGN AND CONSTRUCTION OF R.101.

11. In the construction of the R.101, the designers broke away almost completely from conventional methods and in every direction an attempt was made to improve upon standard Zeppelin practice. Some of these inventions were a natural consequence of the great size of the airship, while others aimed at securing interchangeability of component parts. These novelties in design, however, were not confined to the general anatomy of the hull, but extended to many important details such as gasbag-wiring, relief valves, steering mechanism, and even included the adoption of a novel design of heavy-oil engine.

Originality and courage in design are not to be deprecated, but there is an obvious danger in giving too many separate hostages to fortune at one time. Indeed, the only effective security against the risk of trying many new experiments in design simultaneously is a prolonged series of trials designed to test out the airworthiness of each new feature in turn. During the construction, and in the early trial flights of the R.101, this policy of cautious experiment at each step was admirably fulfilled ; but in the later stages, when it became important to avoid further postponement and the flight to India thus became urgent, there was a tendency to rely on limited experiment instead of tests under all conditions. The programme of trials as at first submitted to Major Scott by the Captain of the R.101 was far from being completed as originally intended (*see* below, para. 73), and, as will appear in Part IV of this Report, the R.101 started for India before she could be regarded as having emerged successfully from all the exhaustive tests proper to an experimental stage.

Shape Adopted for the Hull of the R.101.

12. As stated in paragraph 7, an extensive series of aerodynamic experiments, more complete than anything previously attempted in connection with airship design, were initiated in 1924, and carried out at the National Physical Laboratory during the following two years. Two hull forms were tested for drag, lateral forces, yawing moments, and damping coefficients.

These forms, designated by A.M.3a and A.M.3b, are shown in Fig. 1 on the following page. A.M.3a was of circular section throughout. A.M.3b was identical with A.M.3a so far as the part forward of the maximum diameter was concerned, but its tail was fish-shaped and non-circular in section.

On the completion of these tests, the results were forwarded to the Royal Airship Works and, at a meeting between representatives of that establishment and of the National Physical Laboratory, it was decided to adopt form A.M.3a, and a further set of experiments was planned for determining the most efficient shape and size of the fins. After two preliminary experiments,

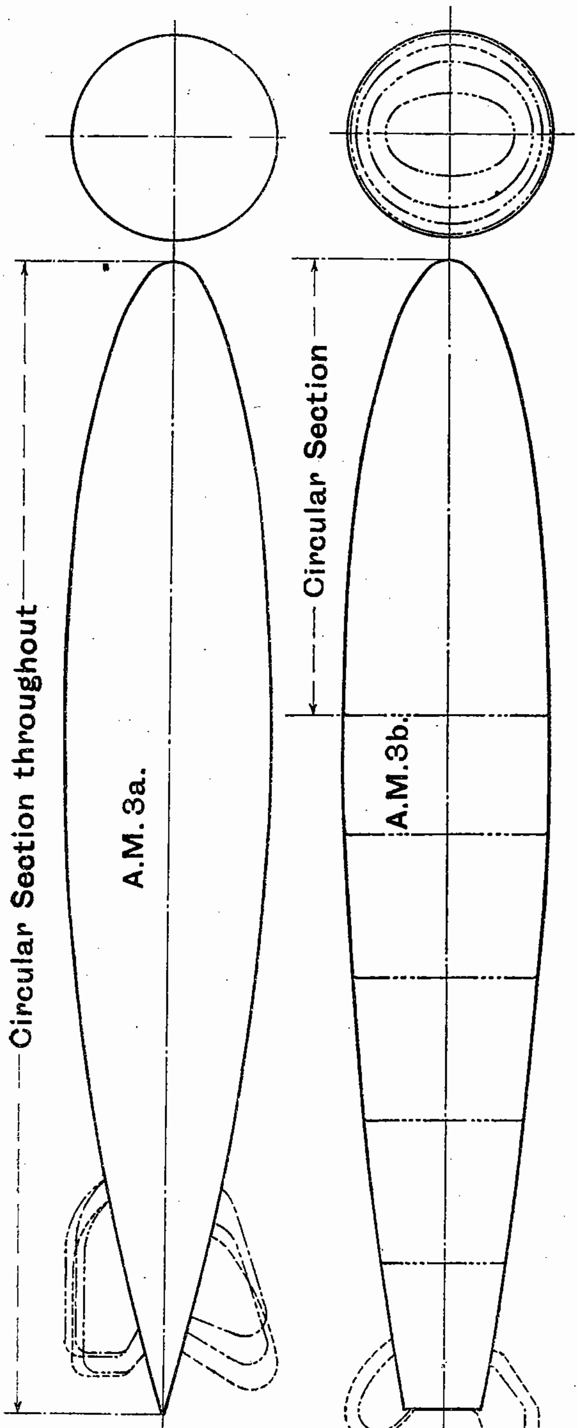


FIG. 1.

the type of fin and control surface shown in Fig. 2 was found to be highly satisfactory, in that it combined adequate stability with a remarkably low drag coefficient.

The general shape of the R.101 which in its original form is shown in Fig 3 is one of lower fineness ration (5·5) than had been employed in previous rigid airships, *i.e.*, the R.101, like the R.100, was " fatter " in proportion to length. This formation had the great advantage of giving a very low resistance or drag to longitudinal movement through the air, this resistance being little more than 2 per cent. of the resistance of a circular plate of the same diameter as the maximum diameter of the hull.

Particulars of Fins.

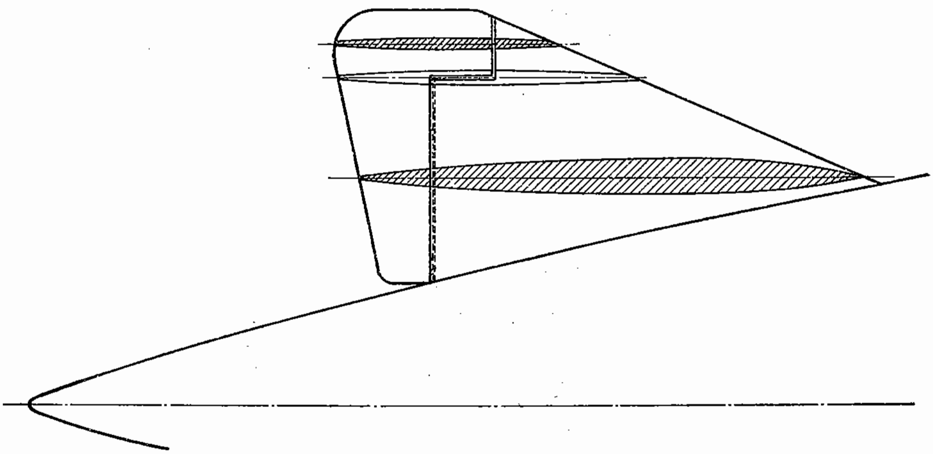


FIG. 2.

No length of the hull as originally designed was of uniform section, and the longitudinal members between the frames were shaped to give continuity of curvature, decreasing progressively from bow to stern.

As originally designed the hull was 732 feet long, with a maximum diameter of 132 feet, and its gas capacity was expected to give it a lift of approximately 150 tons gross. At a later stage its length was increased to 777 feet by the addition of a bay in the region of maximum girth and the extra gasbag accommodation thus provided, together with other alterations, brought the gross lift up to about 167 tons.

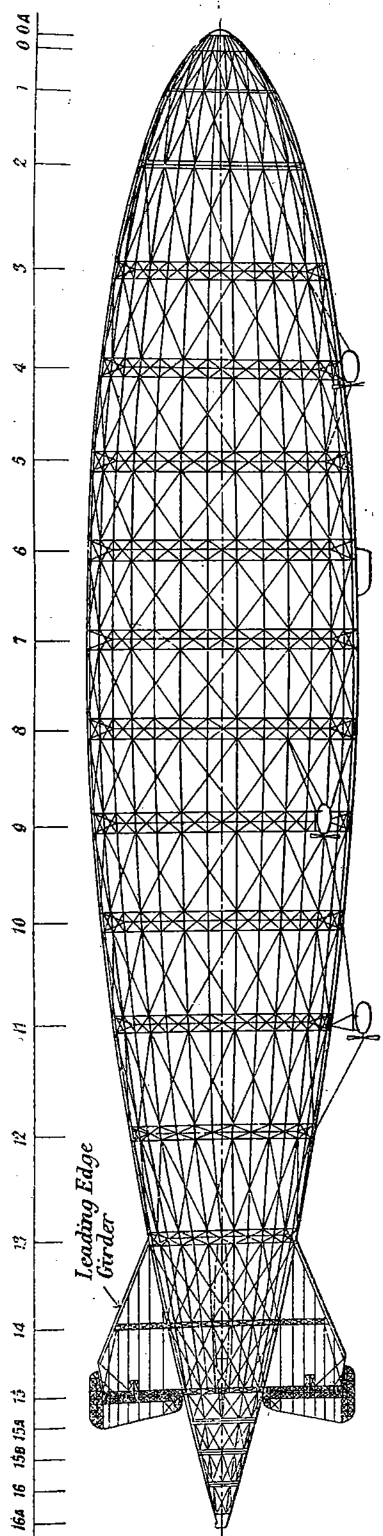

0 0A
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
15A
15B
16
16A
Leading Edge Girder

FIG. 3.

General Structure of Hull.

13. The general anatomical structure of the hull before it was lengthened is shown in Fig. 3. It consisted of a number of ring-shaped transverse frames joined together by 15 continuous main longitudinal girders. In order to prevent the gasbags which were situated between the frames being too unequal in size, the frames were not spaced equally apart but in the regions of large girth were brought somewhat more closely together.

Frames 3 to 13 were of novel design, in that the rings were devoid of spokes or radial bracing. This construction is illustrated by Fig. 4. The inner perimeter of the ring was a single member; the outer consisted of two parallel members about 10 feet apart, so that the cross-section of the ring was triangular.

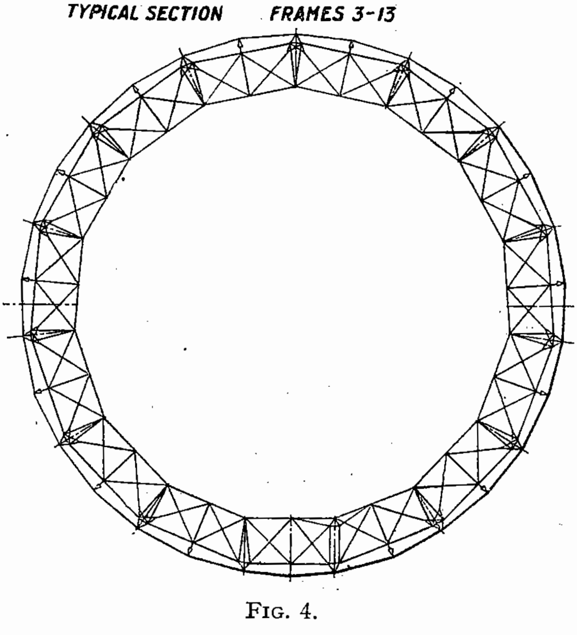


FIG. 4.

The main longitudinal members, also triangular in section, were attached to the outside of the transverse frames.

The outer cover was stretched over the main longitudinal girders, but to reduce the tension in the fabric, 15 intermediate longitudinals known as "reefing girders" were provided, and in consequence the external surface of the ship became thirty-sided.

These reefing girders in no way contributed to the stiffness of the structure as a whole. Reefing girders running between adjacent frames were provided with intermediate flexible joints which shielded these girders from indeterminate bending moments and also from longitudinal stress arising from slight relative displacements of adjacent frames.

The attachment of the reefing girders to the transverse frames was effected by telescopic " kingposts " which were designed so that they could be jacked out radially and thereby produce any desired degree of tension in the outer cover.

Bending moments in the hull structure were resisted by the main longitudinal girders. Resistance to shear was provided for by the system of diagonal wires indicated on Fig. 3, these wires joining up the corners of the rectangular panels formed by adjacent frames and diagonals. For the transverse frames and longitudinal girders, high tensile stainless-steel tubes were employed, while considerable use was made of duralumin for joints and attachments. For additional protection against corrosion, the stainless-steel was coated with lacquer and all duralumin was given anodic treatment.

The light reefing girders were of a type usual in Zeppelin construction, being built up of duralumin members having a trough section.

Method of Erection.

14. Apart from the fact that the unprecedented size of the R.101 made it possible and even desirable to depart from conventional methods of construction, the novelty of the design was mainly dictated by considerations of ease of erection and the possibility of subsequent repair or replacement of members. The various component members were delivered at the erecting shed at Cardington fully machined and complete with every necessary attachment. All that had to be done on the site was the linking together of these component parts with accurately fitting bolts. The work of assembly was in consequence reduced to a minimum.

This policy, of course, entailed a vast amount of preliminary work in computing the dimensions of the various parts to a very high degree of accuracy. It also involved an extensive use of jigs, and the machining had to be carried out to tolerances ranging from 0·015 of an inch in girders 11 feet long, to 0·030 of an inch in girders 30 feet long. That this high degree of accuracy was attained reflects great credit on the makers.

The R.101 may be said to have been machine-made, in contradistinction to having been constructed by hand, and those responsible for the policy doubtless had in view the saving of time and cost which would be effected in the event of repeat orders being placed. For a single ship, the time occupied in the vast amount of preliminary work which had to be performed more than counterbalanced the time saved in erection, and this largely accounts for the striking fact that some four years were spent in connection with the design and construction of the R.101.

In connection with the evolution of the various types of girders, where exaggerated factors of safety could not (from considerations of weight) be permitted, an immense amount of mechanical testing was carried out to verify the validity of stress calculations, both in connection with component parts and in connection with completed girders. In addition, a complete full-sized bay was set up with a gasbag in position, and the strains in the various members were measured by recording strain-gauges.

The care taken in this preliminary experimental work is beyond all praise, and its comprehensive character can be estimated by the fact that approximately a hundred separate girders were tested to destruction. It is probably no exaggeration to say that never before in the history of structural engineering has so much care been taken to explore the strength of a structure before it was used, and to check the stress calculations by actual measurement.

15. The main credit for the general character of the design and methods of construction of the R.101 must be given to the late Lieutenant-Colonel V. C. Richmond. His powers were almost autocratic. He kept the work of design centralised in his own hands, though he was always open to receive and adopt suggestions which seemed to him helpful, and in doing so, he never omitted to acknowledge the help he had received. Although the general design, stress calculations and geometrical computations were carried out under Colonel Richmond's supervision at Cardington, there remained the formidable task of designing and manufacturing the innumerable structural details of the hull, in order to carry into effect the general plan laid down. This work was wholly entrusted to the firm of Messrs. Boulton & Paul, and Colonel Richmond was unsparing in the praise he bestowed upon this firm and the Chief Engineer, Mr. J. D. North, for the admirable way in which this very difficult and responsible task was performed.

Gasbags.

16. It will be understood that an airship of the type to which the R.101 belonged, derives its lift from a row of gasbags of suitably graduated dimensions which are attached to its structure and enclosed within its outer envelope.

Though the gasbags of the R.101 were of unprecedented size, their construction was in close accordance with standard Zeppelin practice.

In the lengthened ship there were seventeen such gasbags, and the largest of these, which was situated in the new bay, had a capacity of no less than 510,300 cubic feet and gave a gross lift of about $15\frac{1}{2}$ tons. The total gasbag capacity was 5,508,800 cubic feet, corresponding to a gross lift of 167·2 tons.

The gasbags, which completely filled the spaces between longitudinal girders and adjacent cross frames, were made of cotton fabric lined with gold-beater-skin, these two components being united by a special kind of glue.

Although constant experimental work has been carried out in the hope of finding a satisfactory substitute, gold-beater-skin has up to the present remained the best material for rendering fabric bags gas-tight. The skin is a fine membrane forming the outer coat of part of an ox's intestine known as the *cæcum*.

Lengths of 25 to 30 inches are freed from fat by washing in warm water and scraping with a blunt knife. In gasbag manufacture, the first process is to assemble skins so as to form large continuous sheets ready for glueing to the cotton fabric. A double layer of skins in their wet state is laid out on smoothly stretched canvas, which merely serves as a background on which the skins are assembled. As the skins dry out they adhere together and can then be readily peeled off from the canvas in one continuous sheet resembling thin transparent parchment. No adhesive of any kind is employed to make the individual skins unite in a continuous sheet, though, in order to keep the membrane pliable, glycerine is added to the water in which the skins are soaked before assembly.

After a sheet of gold-beater-skin has been thus prepared, it is ready to be glued to the inner side of the cotton fabric, which in its turn is built up by glueing together strips of the fabric with an overlap of about one inch.

In all bags (except the one in the additional bay) these panel seams were taped with cotton fabric $1\frac{1}{4}$ inch wide. This was done to guard against the danger of a seam lifting, but experience showed that this precaution was unnecessary.

All fabric seams in a finished gasbag, both longitudinal and circumferential, were overlapping glued connections as above described, while gold-beater-skin formed one continuous membrane on the inside of each bag. To improve its waterproof qualities the bag was given a coating of oil-varnish on its inner skin face, and on the outer cotton face the same varnish was used with the addition of some beeswax and aluminium powder.*

Tests on glued seams were carried out on pieces 3 inches wide and 8 inches long, and the specification required that these test pieces should stand a load of 20 lb. per inch run of seam. These tests were applied under various conditions of humidity. These requirements of strength would appear to have been ample to meet the stresses which were developed in the gasbags under normal conditions. Such stresses were relatively small, being of the order of 1 lb. per inch run. But in this connection it should be observed that if a tear of any considerable length is started, the concentration of stress at its two ends is so great that it must almost inevitably extend, like a tear in the sail of a ship. This

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* Three types of cotton fabric were employed in the R.101, varying slightly in weight and strength, the final (and presumably the best), which was used for the additional gasbag, having the following specification :—

Weight not more than 57 gms. per square metre (unoiled).

" " " 64 " " (oiled).

Threads per inch—135 in warp and weft.

Strength—30 lb. per inch run in warp and weft.

danger could be guarded against by using a fabric with additional diagonal fibres, and it is understood that in some at any rate of the Zeppelin airships, fabric of this variety has been employed.

17. At every stage, the materials and workmanship of the R.101 gasbags were under the closest possible scrutiny both by the Works Inspectors at Cardington, and by the Inspectors of the Aeronautical Inspection Department of the Air Ministry. The gasbags when incorporated in the airship were doubtless as perfect and free from defects as it was humanly possible to make them. But after the ship had been through some of its preliminary trials, and particularly after an increase in the size of the gasbags had caused serious chafing against the frames of the ship, leakage of gas through holes in the bags developed to an abnormal and indeed alarming extent. But although holes in gasbags are very far from being desirable, it must be borne in mind that the escape of gas from a small hole even at the top of a bag is relatively small in comparison with the whole contents of the bag. The gas pressure is only of the order of one ounce per square inch, and, unless small holes are very numerous, the resulting loss of gas is not a matter of serious consequence.

It is further to be remembered that if a rent occurs in a gasbag, the gas which escapes through the rent is that which is below the orifice: the rest of the gas, which is higher than the rent, remains in the bag. Consequently, to get anything approximating to the sudden deflation of a whole gasbag, the opening which lets the gas escape out of it must not only be of considerable size, but must be at the top of the bag.

As an indication of the rate of discharge of pure hydrogen from a gasbag, if may be mentioned that under a pressure difference of one ounce per square inch, the velocity of discharge is 327 feet per second, and assuming a coefficient of discharge of 0·6, the volume which will escape through a circular orifice 1 foot in diameter is 9250 cubic feet per minute.*

Gasbag-Wiring.

18. The gasbag-wiring for the R.101 was of entirely novel, and extremely elaborate, construction. It formed the subject of a patent taken out in December, 1927, conjointly by Lieut.-Colonel V. C. Richmond and Squadron Leader F. M. Rope, both of whom perished in the disaster.

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* The gasbags were numbered from bow to stern. Nos. 1 and 2 were connected and, taken together, contained 136,300 cubic feet; No. 3 contained 311,800 cubic feet; No. 4, 416,600 cubic feet; No. 5, 474,100 cubic feet; No. 6, 496,500 cubic feet; No. 7, 478,500 cubic feet; No. 8, 476,000 cubic feet; No. 8 (a) (the additional one in the new bay), 510,300 cubic feet; No. 9, 501,300 cubic feet; No. 10, 490,200 cubic feet; No. 11, 437,500 cubic feet; No. 12, 358,700 cubic feet; No. 13, 233,200 cubic feet; No. 14, 116,300 cubic feet, and in the extreme tail in the neighbourhood of the after fins, No. 15 and No. 16 (which were connected) contained between them 71,500 cubic feet.

Some system of wiring is essential for the double purpose of reinforcing the gasbags to resist gas pressure, and for transmitting the upward lift to definite points on the framework of the airship. The wiring in this case consisted of two independent systems intersecting at right angles. One system formed circumferential girdles round the bags in planes at right angles to the axis of the ship, and the other system ran longitudinally around the curved side of the bags and terminated in rings at the centres of the flat ends as shown in Fig. 5 (*a*).

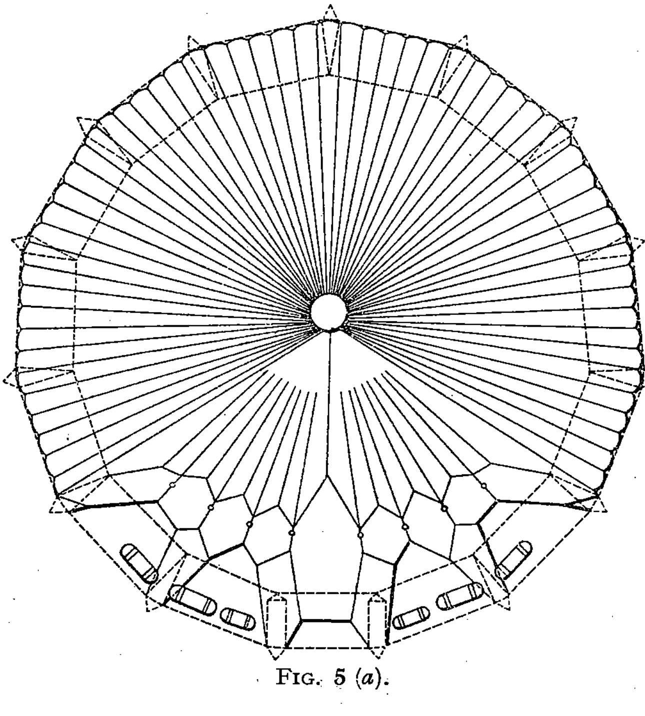

FIG. 5 (*a*).

About 50 per cent. of a gasbag lift was tapped off from the circumferential wires, this lift being transmitted to suitable points on the transverse frames by means of " bridles," one of which is depicted in the centre of Fig. 5 (*b*).

The longitudinal wires, running right and left across the circumferential surface of the bag, start from a sort of chain of wire (called in the Specification a " catenary chain ") held midway between adjacent frames by means of " bridles " leading to the main joints as shown in Fig. 5 (*b*). This system of wires may accordingly be likened to a pair of parachutes, their crowns being the rings to which the wires converge, and their edges being the chain. One duty of this longitudinal system of wires was to control the axial displacement of the bag arising from pitching or from its neighbour becoming deflated. If adjacent bags are equally inflated, the intervening bulkhead of radiating wires remains flat, but, in the event of the bag on one side becoming deflated, pressure on the wire bulkhead becomes unequal and it curves in the manner shown on the left-hand side of Fig. 5 (*b*).

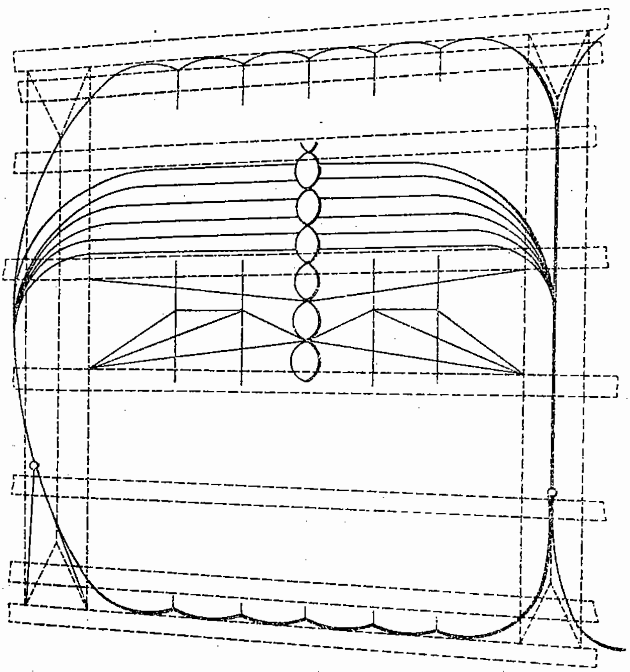

FIG. 5 (*b*).

Another duty of the longitudinal wires was to transmit the remaining 50 per cent. of the upward lift of the gasbag to the frame of the ship. This was done by means of tapping wires, which connected some of the bulkhead wires to points on the lower portion of the corresponding transverse ring, as indicated on Fig. 5 (*a*). In the Patent Specification one of the advantages claimed for this system of gasbag wiring was that the gasbag was "kept from touching the longitudinal girders." However, in the later stages of the evolution of the R.101, in view of the urgent demand for increased lift, the wiring system was let out to such an extent that the gasbags in some places came into contact with the longitudinal girders and projecting corners of the transverse frames. The danger of attrition and of consequent holing was sought to be minimised, as will be seen hereafter, by the padding of numerous points.

19. The above description is necessarily technical, and it may assist in comprehending it and in understanding the attached diagrams if a rough analogy is suggested. Imagine 17 immense regimental drums of the ordinary shape set up on their rims in a row. The drums are of graduated size, the biggest in the middle. Round the circumference of each drum will be wound a large

number of wires each forming a circle at right angles to the axis of the drum. These wires correspond to the first of the two systems referred to. Now imagine that just outside the centre of each of the parchment ends of each drum there is a circular ring of metal, and that an immense number of strands of wire radiate out from each ring and pass over the barrel of the drum where they meet corresponding wires from the other side by being connected to a wire chain running round the barrel. If either end were looked at from the side, it would present an appearance corresponding to Fig. 5 (*a*). This series of radiating wires would obviously cross the circumferential wires at right angles in their passage from one side of the drum to the other, and it is this series of wires which constitute the second system of wiring referred to above. The analogy would be more complete if each drum were imagined to have one end somewhat smaller than the other, for each gasbag in the series was designed so as to fit into its place in the ship with due regard to the taper of the envelope.

Each drum-shaped gasbag was therefore contained within a complicated network involving many hundreds of wires and points of junction, planned so that the strain upon each wire at every point should be suitably distributed and transmitted. The radial wires running from each ring towards the circumference were, as to the first portion of their length, common to the contiguous surfaces of each pair of adjoining gasbags, but before these radial wires reached the circumference they forked into two, so that one wire would run round the end of one gasbag towards its other side, and the other followed a corresponding course to enwrap the neighbouring bag. In other words, the system of radial wires spreading from each ring as a centre formed a sort of reticulated bulkhead which separated each gasbag from the next. And the whole construction constituted a cage within which each inflated gasbag was confined and was prevented from expanding further. It will be appreciated, therefore, that if the vessel when in flight pitched or rose suddenly, the tendency of the gasbags to surge or sway fore and aft was resisted, (though it was not entirely prevented), by the system of wiring.

It only remains to bring home to the reader some appreciation of the size of the gasbags which were thus confined within the meshes of this wiring system. The largest of them, when fully inflated, measured from the crown to the bottom 126 feet, i.e., it would extend from the floor of Westminster Hall well above the roof. The whole row of them could not be accommodated within the extreme length of Westmister Abbey.

Gas Valves of R.101.

20. Like the gasbag-wiring, the gas valves of the R.101 were of entirely novel design. In order to make clear in what the novelty consisted and how delicate a mechanism was involved, it is first

necessary to appreciate the functions which gas valves have to discharge and the methods hitherto ordinarily adopted for fulfilling those functions.

21. As an airship ascends, the fall in atmospheric pressure causes the gas in the bags to expand. To prevent avoidable loss of gas, the bags, when the ship is at its mooring mast, are not usually inflated to their full extent and it is only after the airship has risen to, say, 1,000 feet, that the expanded gas fills the bags completely. To permit the ship to rise above this " pressure height ", provision must be made for an escape of gas, and this provision takes the form of relief valves which blow off when the gas pressure in the bags slightly exceeds the normal. Change of gas volume may likewise be brought about by changes of temperature, but expansion due to this cause is not likely to be rapid, and relief valves of large capacity are mainly needed to deal with the possibility of the ship being caught up in a rapidly ascending current of air and thereby elevated several thousand feet in a very short space of time. The American airship " Shenandoah "—(*see* para. 3 above)—experienced a phenomenon of this character, for she was caught in an up-current of air which was estimated to have attained the extreme velocity of 50 miles per hour. The destruction of the " Shenandoah " was attributed primarily to external aerodynamic forces, but in any case her experience illustrates the reason why relief valves should have sufficient capacity to deal with sudden changes of altitude.

With the care which characterised the specifications for the R.101, gas valves were called for which could deal with a vertical rise of 4,000 feet per minute (45·5 miles per hour). Though even more violent upward currents may occasionally be found in the heart of a severe thunderstorm, they are very rare, and meteorological reports would probably enable an airship to steer clear of any such extreme disturbance. In any case, weather conditions at the time and place of the R.101 disaster entirely rule out an explanation of it based on this class of consideration.

22. In former airships the usual practice was to fit a spring-loaded automatic relief valve at the bottom of each gasbag, so that the gas would " spill " out of the bottom of the bag as soon as the pressure within overcame the pressure of the spring. These automatic valves rested on cages when the bags were full, but moved upwards with the bottom of the bag when it became deflated. In addition to an automatic relief valve of this character, former practice usually prescribed the use of " manœuvring valves " which were fitted on the top of each gasbag. These latter valves are in no sense automatic, but are worked by controls from the control car if it is desired to discharge gas in order to decrease buoyancy.

Both types of valves—the automatic relief valve at the bottom and the manœuvring valve at the top—were in fact used in the R.100.

23. In the R.101, however, an entirely new and very ingenious arrangement was employed by which the functions of the automatic and the manœuvring valves were combined in the same piece of apparatus. On either side of a gasbag, at its midway height, a valve of this new pattern was fixed in position, so designed that its opening or closing did not depend upon any spring mechanism. Two sizes of valves were employed, of 30 inches and 40 inches diameter respectively, the smaller valves being used for the smaller bags.* The rate of discharge, under normal pressure, if a bag had both of its 40-inch valves open, was calculated to be 72,000 cubic feet per minute.

In Appendix III to this Report will be found a description of the construction and working of this new type of valve.

24. It will be observed from this description that the valves installed in the R.101 are extremely sensitive. They are more easy to inspect than manœuvring valves placed at the top of a gasbag would be, though, as they are half-way up the side of the gasbag, they can only be approached by climbing. So long as they operate as designed, though they open under very small extra pressure, they close again automatically as soon as that pressure falls to normal. On the other hand, if by the intervention of some unexpected cause a valve sticks open, it would be necessary after discovering the defect, for a rigger to climb up to rectify it, since there is no quick alternative method of bringing the valve back again on to its seating. The loss of gas in these circumstances from the lower half of the gasbag might be very serious.

In the trial flights, these valves appear to have given general satisfaction, though it cannot be claimed that the weather conditions encountered, or the changes of altitude attempted, were at any time sufficiently severe to constitute an exhaustive or conclusive test. Owing to the very small force with which the valve face is pressed against its seating, the valves have a tendency to open slightly when the ship rolls through an angle of 5° or somewhat more, and if the ship were to roll from side to side through a larger angle it would seem that there might be a temporary opening of valves on the port and starboard side alternately with an intermittent loss of gas resulting. A further reference to this subject will be found in para. 47 below.

Other Features of Construction.

25. The special features of construction already mentioned are far from exhausting all the novelties introduced into the R.101 by the ingenuity of its designers. But it does not seem necessary, having regard to the purpose of this Report, to describe other matters in equal detail.

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* Gasbags 2, 14 and 15 had one 30 inch valve; gasbags 1 and 16, being connected with their neighbour, had no valve.

As regards the outer cover, the experiment was tried of doping the fabric before it was placed in position. By this means, some reduction of weight might have been achieved and, by the employment of tensioning devices in which the pull applied to the fabric was recorded on spring gauges, it was hoped that a definite state of tension could be assured. Owing, however, to subsequent absorption of moisture, this pre-doped fabric was apt to shrink and to develop long tears (*see* para. 41), and in consequence it was decided to discard the original pre-doped cover and to replace it with fabric which was doped after it had been stretched in position.

To maintain equality of air pressure between the inside of an airship and the surrounding atmosphere, inlets and outlets for air must be provided in the outer cover. For example, when the ship is rising rapidly, air inside the cover must be allowed to escape freely, and conversely, when the ship is descending, unless air is given sufficient opportunity to enter, a partial vacuum will be developed in the interior. If the R.101 was to be able to rise with safety at a rate of 4,000 feet per minute (*see* para. 21), very full provision of outlets was necessary. She was provided with an ingenious arrangement of inlet and outlet holes for this purpose, supplemented by a series of slots arranged on a circumferential ring in the region of the maximum diameter. There is no need to describe these arrangements in detail, but it should be stated that they appear to have been excellently designed to serve the purpose already mentioned, as well as for the ventilation of the ship and for permitting the escaping of gas which might accumulate between the gasbags and the outer cover.

Control Mechanism.

26. A most important part of the design, which also contained features of novelty, was the mechanism for controlling the flaps hinged to the vertical and horizontal tail fins which constituted the rudders and elevators of the vessel. These four control surfaces were identical in shape and area; each flap had a span of about 44 feet. They were operated by a very ingenious yet simple mechanism invented by Squadron Leader F. M. Rope, which is illustrated by Figs. 7a, 7b, and 7c.

The tiller consisted of a triangular framework ABC, AB and AC being tubes projecting into the interior of the fin to which the flap was hinged. The member BC, as shown in Fig. 7b, was set obliquely across the flat end of the flap facing the fin, and the triangular tiller ABC was free to hinge about this oblique axis BC. The apex A of the tiller, as indicated in Figs. 7a and 7b, was constrained by rollers to run along the mid-longitudinal section of the fin. As A was displaced above or below its mean position, as shown in Fig. 7a, B was forced to move to the left or right respectively, and C was equally displaced in the opposite direction. Consequently, a movement of A along its sector caused the flap to turn about its hinge in a perfectly definite manner.

The control car was placed amidships below the main body of the airship, and in the control car two men on duty would operate the rudder and elevator respectively. At the side of the elevator-coxswain were an altimeter and an inclinometer, and variations in height were secured, so far as the movement of the elevator was concerned, by turning a spoked wheel. The cable actuated by this wheel ran round a drum and thence to pulleys connected with the mechanism located in the lower vertical fin, and at first

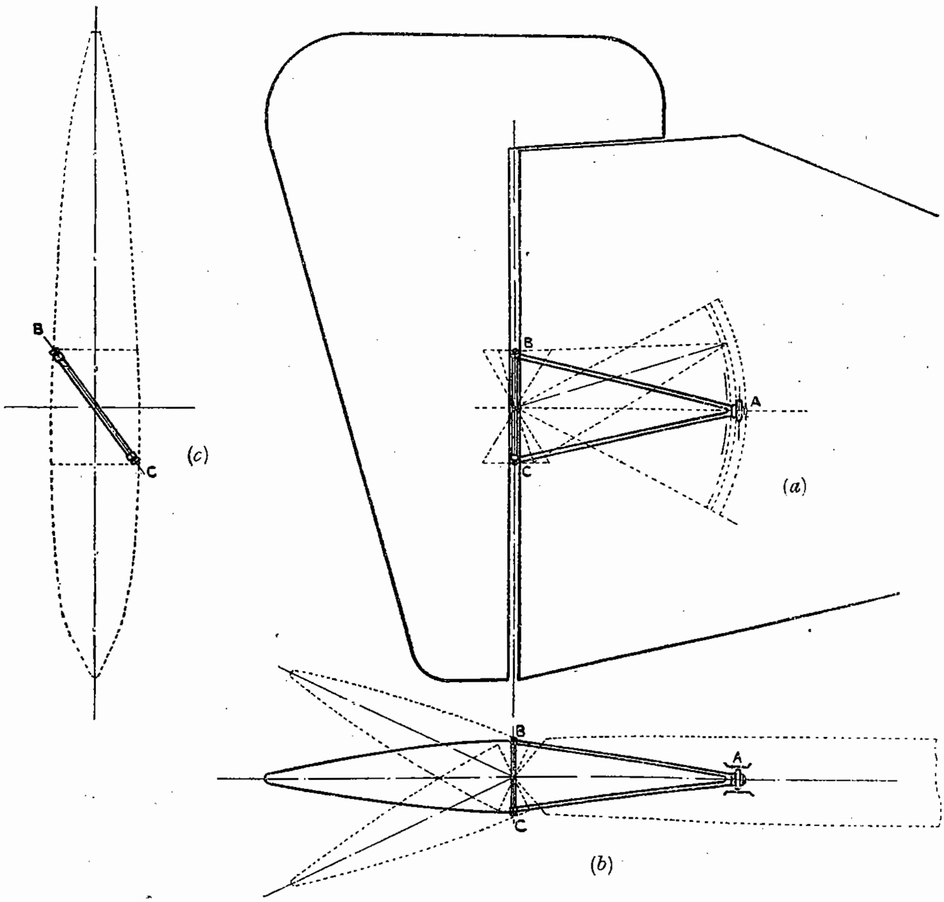

FIG. 7.

the movement of the controls was assisted by "servo" gear actuated by oil pressure which helped to rotate the drums. Later on this "servo" mechanism was removed in connection with arrangements which were made to reduce the weight of the ship. But it would seem that this auxiliary power was found to be unnecessary and that man-power was quite adequate for the operation of steering and elevator controls. For small angles of movement no great effort was required, but to put the elevators hard over through their extreme range of 25° up to 25° down called for a considerable expenditure of energy. To move the elevator from the middle to its extreme position would require many turns of the wheel and the time occupied would be about half a minute. It may be noted here that the number of turns of wire on the drum was an indication of the position of the elevators, and consequently, after the disaster occurred, it was possible to infer with certainty that the elevators were hard up at the instant when the ship struck the ground.

Motive Power.

27. In view of the fact that the organisation of an airship service to India was from the first an essential feature in the Government's programme of airship development, it was considered desirable to use some fuel less volatile than petrol, in order to minimise the risk of fire in sub-tropical regions. With this end in view, it was decided that the R.101 should be equipped with engines burning heavy oil on the compression ignition system, thus obtaining the advantages of a comparatively cheap and safe fuel, and furthermore reducing the risk of fire by the avoidance of electrical ignition. As might have been expected, the production of a new type of engine to satisfy the required conditions proved to be a matter of considerable difficulty and, both in respect to weight and horsepower developed, the power units fell short of the standard it was hoped to reach. It was originally hoped that each engine would be able to maintain 700 b.h.p. at 1,000 revolutions per minute, whereas the result eventually achieved was a continuous full power of 585 b.h.p. with a possible maximum of 650 for a brief period.

The weight based upon the continuous full power worked out at 8 lb. per b.h.p., and, though this figure was a great improvement on previous engines of a somewhat similar type, it was considerably in excess of the figure anticipated.

Each of the five engines consisted of eight cylinders of 8¼ inches diameter with a 12-inch stroke, arranged vertically in line. Oil was injected into each cylinder shortly before the position of maximum compression, when the temperature and density of the compressed air were sufficient to produce rapid burning, approximating to an explosion. The length of time during which fuel was pumped in could be varied, and this constituted the only means for controlling the power of the engine. The type was known as the Beardmore Tornado Engine, and they were designed and manufactured by Messrs. Beardmore, though in their evolution and development Wing Commander Cave-Browne-Cave played a prominent part.

The design necessitated a long crankshaft, and, in the engine as first constructed, the torsional flexibility of this long shaft, associated with the periodic impulses due to eight cylinders, developed such violent torsional oscillations in the crankshaft at a critical resonance speed of about 950 revolutions per minute, that continuous running in the neighbourhood of this critical speed was a practical impossibility. This resonance phenomenon was the greatest stumbling block encountered in the evolution of this new type of engine.

Without a complete redesign of the engine it was not possible to keep clear of all critical resonance speeds, but by an increase of certain dimensions of the crankshaft, which could be effected without a drastic reconstruction of the whole engine, the major critical speed was raised well above the normal speed of running. The excess in actual weight over what had been anticipated was in part due to the necessity for this more robust and stiffer crankshaft, but it was mainly caused by the very substantial character of the crank-chamber, which in the absence of torsional oscillations could have been lightened to a very considerable extent. With the experience gained, there is reason to believe that in the future a similar engine could be designed which would weigh only 4 lb. per brake-horse-power, thus making the weight comparable with airship engines of the petrol variety, though how far such an engine would be comparable in length of life and durability is a question which only prolonged experience could answer.

28. As installed, the total weight of the power installation of R.101 (including auxiliaries) amounted to 17 tons, in comparison with under 9 tons for R.100 and 7 tons for the Graf Zeppelin. But the comparatively heavy weight of the R.101 power installation is, for long voyages, largely compensated for by the reduction in fuel which has to be carried. Thus for a range of 2,500 miles, under still air conditions, R.101 required only about 17 tons of fuel oil at a cost of about £5 per ton as against a consumption of 23 tons of petrol, costing about £23 per ton, in the case of R.100.

The five engine units were carried in separate power cars attached to the outside of the hull, the propellor thrust in each case being transmitted to the frame of the ship by a thrust-wire leading from a bearing carried on the outer face of the airscrew hub.

Two of the power cars were near the bottom of the hull on either side of frame 4, in the forward part of the ship. Two others, somewhat higher up, were attached on either side of frame 9, and the fifth was placed centrally under frame 11 towards the stern of the ship, where it would give a good flow of air to the rudder, even when the ship was approaching its mooring mast at low speed.

Each engine was directly coupled to its airscrew, 16 feet in diameter, without any reduction gearing. Originally it was intended to use a form of hub by which the pitch of the propellors could be altered while in motion, and thereby enable them to give either ahead or astern thrust. These hubs, however, failed under a test in which they were exposed to excessive torsional oscillations, and it was considered advisable to substitute ordinary wooden propellors with fixed hubs. As originally engined, the vessel had four engines which propelled her only ahead, and the remaining engine worked only astern. Later, all five worked ahead, but since astern thrust is necessary to check the forward way of the airship as she approaches the mooring tower, the two forward engines were provided with a valve gear mechanism whereby they could be restarted to run in a reverse direction.

The main engines were started by auxiliary engines which developed 40 h.p. at 2,000 revs. per minute and transmitted rotation to the main engines by a 20 to 1 reduction gear. These starting engines used petrol, though it was hoped in the future to replace them with engines of the heavy oil compression-ignition type, and in fact one of them had been so replaced when the R.101 started on her final flight. These auxiliary engines, in addition to starting the main engines, were available for driving electrical generators and air compressors. Two power cars carried electrical generators, and, as an alternative to the petrol engines, power for these auxiliaries could be provided by constant speed windmills, which came into operation for airspeeds in excess of 40 m.p.h. and developed 10 to 15 horse-power.

During a flight, each power car was manned by a mechanic, who received his orders from the control car by means of an engine room telegraph dial. The main engines were water-cooled by an evaporative system, by which the steam which accumulated in the head of the separator was condensed in honeycomb radiators.

Fuel and Ballast.

29. Most of the fuel storage tanks were of 224 gallons capacity each, though in certain positions it was more convenient to provide two tanks of half this capacity which were used as a single unit. From the storage tanks, fuel was led by gravity to transfer tanks from which it was pumped to feed tanks above each engine car. The storage tanks could accommodate about 29 tons of oil, which left a reasonable margin on the fuel requirements for a voyage to India, with a halt at Ismailia for refuelling, assuming that the weather conditions were not too unfavourable.

Certain of the storage tanks were fitted with jettison valves, by which their contents could be released very rapidly in cases of emergency. The stream of oil thus released quickly broke up into fine drops, and, if released from a height of 1,000 feet or thereabouts, it eventually assumed the form of a very fine rain whose presence on the ground could hardly be detected.

The discharge of jettison tanks was in most cases operated from the control car, and the time taken to complete the process of emptying a tank was only three seconds.

Disposable water ballast to the amount of eight tons was carried in half-ton bags or tanks which could be released, in some cases, instantaneously from the control car, and in other cases locally by the execution of orders given from the control-car to members of the crew. In addition, provision was made for another seven tons of water ballast in storage tanks similar to those used for fuel.

30. The above account of the main features in the design and construction of the R.101 has been for the most part compiled for the Court by Professor Inglis. It is based partly on verbal evidence directly supplied to the Court, partly on descriptions published in the technical press, and to a considerable extent on papers which have appeared in the Journal of the Royal Aeronautical Society, particularly two communications from Wing Commander Cave-Browne-Cave and Lieut.-Colonel V. C. Richmond, published in March, 1929, and August, 1929. respectively.

PART III.—PRELIMINARY TRIALS AND RECONSTRUCTION.

31. More than two years were spent on the elaborate investigations and calculations on which the design of the R.101 was based, and in 1927 actual erection began in the huge shed at Cardington prepared for the purpose.

The process of erection occupied two more years, and by the end of September, 1929, her construction, according to the design and dimensions originally intended, was complete. Before she left the shed, a "lift and trim" test had to be undertaken. As regards lift, when the gasbags were fully inflated it was found that instead of having a "useful lift" of 60 tons, as had originally been intended (*see* paragraph 8 (v) above), her fixed weights amounted to as much as 113·6 tons which, when subtracted from her gross lift only gave a useful lift of about 35 tons (*see* paragraph 9 above). It had, of course, been appreciated, as the process of construction proceeded, that the sum total of fixed weights which she would have to lift would be greater than what had originally been hoped for, viz., 90 tons. In particular, her engines when delivered and installed in the five engine cars, were heavier than estimated, though it was not the extra weight of the engines which chiefly explained the excess. So serious a reduction in useful lift was mainly due to additional weights in the main structure. It was soon realised that an airship with a useful lift of only 35 tons could not undertake the voyage to India, and hence arose the changes which were made in the R.101 at a later date by rearranging the gasbag-wiring so as to increase the capacity of the gasbags (paragraphs 37 to 41 below), and ultimately by inserting an additional "bay" (paragraph 51).

Launch and First Two Trials.

32. These alterations, however, were not at once resolved upon or undertaken. The next stage in the story is the bringing of the R.101 out of her shed for the first time and the mooring of her to the tower at Cardington (October 12th, 1929), followed by two preliminary trials (October 14th and 18th respectively). The *First trial flight* lasted for 5½ hours, and the *Second* for 9½ hours. On the first occasion only two engines were working for a great part of the time. On the second occasion four engines were used—the fifth at this stage was a reversing engine only. These two trials took place in daylight and in calm weather; no written reports were made of them; but Colonel Richmond's diary records that he was well satisfied with the stability of the vessel and her response to control. No speed tests had as yet been attempted.

33. The late Lord Thomson was a passenger on this second flight. The Court was informed by an official from the Air

Ministry that at the conclusion of this flight the Secretary of State was interviewed by press representatives, and announced his hope that he might be able to travel to India in the ship at Christmas of that year. But it is important to add that he emphasised that his policy was "safety first," and that as long as he was in charge no pressure would be brought to bear on the technical staff to undertake any flight until they were ready and satisfied that all was in order.

Four more Trial Flights.

34. The next incident was a warning from the Meteorological Department that a storm was approaching Cardington which threatened to cover a large area, and it was thought prudent to put the ship back in her shed (October 21st), where she remained until she was brought out again on November 1st. The *Third Trial Flight*, lasting for $7\frac{1}{4}$ hours, took place on this date. On the next day the R.101 for the first time attempted night flying. This *Fourth Flight* lasted from 8 p.m. on November 2nd until 10.0 a.m. on November 3rd; the ship cruised in the direction of the Isle of Wight, returning safely to her tower at Cardington. An attempt was made to carry out a speed trial with the four engines that worked ahead, but one of them gave out before the course was completed. The *Fifth* and *Sixth* trials were short flights of three hours each in the early afternoon of November 8th and November 14th. A further flight was projected for November 16th, when it was proposed to take as passengers a large number of Members of Parliament who assembled at Cardington for the purpose. Weather conditions were, however, unfavourable, and this flight did not take place.

The Court had before it written reports made at the time as to the behaviour of the vessel on some of the flights referred to in this paragraph. Wing Commander Colmore had drawn up an elaborate schedule of Functioning Tests, covering details of engine working, the fuel and ballast systems, gas valves and gasbags, controls, instruments, and many other matters. The duty of making reports on these various matters was assigned to different officers of the ship according to the Department in which they were specially expert, and at a later date reports dealing with the behaviour of the vessel were collected and submitted to Major Scott, who was in charge of flying operations.

It is well to say at once that these documents evinced the greatest thoroughness and care in every department. Naturally, many minor defects or difficulties were noted for the purpose of subsequent correction, and one or two matters of greater importance must be referred to hereafter; but there can be no doubt that, in general, the behaviour of the vessel in these early trials gave general satisfaction, and thoroughly justified the confidence which those responsible for her design and navigation undoubtedly felt in her.

The R.101 Rides out a Gale.

35. More impressive, perhaps, than the satisfactory performance of the R.101 in these calm weather trials, was the fact that on November 11th, 1929, she rode out a severe gale while attached to the tower. It was well known beforehand that strong winds might be expected, and the decision to leave the ship where she was indicates the confidence felt in her ability to withstand them. There were frequent gusts of over 70 miles per hour ; the average wind speed during the afternoon was 55 m.p.h. and a maximum gust of 83 m.p.h. was recorded. Wing Commander Colmore's Report to the Air Ministry points out that the load on the nose-coupling, which at one time amounted to 15½ tons, was successfully withstood, and that even with this maximum load the ship had an ample margin of strength. The observed results corresponded closely with theoretical calculations previously made. He added :—

> " throughout the period, the ship rode comfortably at the tower and without violent movement. There was, however, a slow rolling motion at the higher wind speeds, reaching a maximum of 6°. The ship was at all times well under control . . . Beyond the entry of rain and a certain amount of chafing of the gasbags due to the roll, no damage whatever was sustained."

Another report, made by Mr. G. W. Hunt (who was Chief Coxswain on the voyage to India) must be quoted in full :—

> " 11th and 12th November, 1929.
>
> 1st Officer R.101.
>
> During Storm Routine of the above dates whilst looking round it was observed that in the case of Nos. 3 to 14 bags inclusive, a very considerable movement from side to side was taking place on each flat end, as much as 3″ to 4″, and at times the surge of the bags in a forward and after direction was considerably more.
>
> Owing to the combined two movements, where the bags were touching or nearly touching the radial struts round main frames, especially at C and D longitudinals, the plates on top of the radial struts rubbed and chafed the bags, and in places such as No. 8 starboard fore end tore the bag 9″ in a jagged tear. No. 8 thus became deflated to 60% and on inspection taking place it was noticed that on every roll the valves opened to the extent of ¼″ to ½″. The valves were lightly stopped back until the bag was gassed to 95%.
>
> The holes on top of No. 14 bag were caused by the bag bearing hard on O girder, where several nuts project and combined with the movements of the bag caused punctures.
>
> G. W. Hunt."

The " O " girder is the topmost girder in the structure ; girder C is just above and girder D just below the centre line of the ship.

It is noteworthy that, whatever repairs had to be effected, the vessel undertook further trials after this exacting experience, without first being taken back to its shed.

Endurance Flight.

36. Next came a much longer Trial Flight, the *Seventh* in the series (November 17th and 18th). This was an "Endurance Flight." The flight instructions issued by Wing Commander Colmore indicated that the duration of the flight was to be 36 hours, with the possibility of an extension to 48 hours. In fact the flight lasted for 30 hours and 41 minutes, from half-past-ten in the morning to about five o'clock on the following day, and in the course of it the vessel travelled over 1,000 miles, passing over much of Scotland and Ireland as well as making an extensive tour over English towns, usually at a height of 1,000 to 1,500 feet.

This is much the longest continuous flight which the R.101 ever accomplished. The performance gave much satisfaction to Major Scott and to the Captain, Flight-Lieutenant Irwin. In the course of this flight the vessel executed various "turning trials" with success; she encountered bumpy conditions without serious discomfort, and after flying for the last hour or more above fog, made a good descent to the mast as darkness was closing in. Just prior to landing one of the "bridles" by which the lift of a gasbag is transmitted to the frame, broke; but this seems to have been due to the small size of the pulley round which the bridle worked: at a later stage larger pulleys were substituted, and chain bridles were used instead of wire.

The R.101 remained at the Cardington tower until the end of the month, but on November 30th she was taken in and remained continuously in her shed until June 23rd of the following year. She had thus, in the course of the seven weeks which had elapsed since she was first launched, flown for over 70 hours; and though these flights were in good weather and did not include any long trial at full speed, she had behaved well and had given officers and crew valuable experience of her capabilities. Moreover, in the storm of November 11th, she had proved her ability to withstand a severe buffeting, while attention had been directed to the risk of chafing of the gasbags when she rolled. A report made on December 23rd dealt with this last matter in the following terms:—

> "There appeared to be a good deal of movement of the gasbags and gasbag wiring when the ship was rolling at the tower, the hull appearing to roll round them. This caused a fair amount of chafing on the bag all round the inner ridge, and a lot of padding will be necessary here. There is a clear mark on each bag where this has taken place, and it may be worthy of consideration as to whether the bag should not be slightly reinforced at this point. . . . The gasbags held gas remarkably well and maintained a steady purity. The success of the new valve and its position on the bag largely contributed to this."

Need to Increase Useful Lift.

37. The time had now arrived when it was urgently necessary to reach a decision for surmounting the outstanding difficulty that the R.101, as at present designed and constructed, had too

small a " useful lift " to make it possible for her to undertake a voyage to India. For such an enterprise she would need to carry some 25 tons of fuel oil, and this would not leave sufficient margin unless her lift was increased. Thus, alterations for the purpose of reducing her fixed weight or increasing her lift were inevitable.

This problem was the subject of the fullest and most careful consideration during the winter of 1929–30. The Air Ministry at the Inquiry produced to the Court all the Minutes that passed on the subject, including elaborate memoranda by Wing Commander Colmore, and Sir John Higgins, who was at the time Air Member for Supply and Research. Two possible courses were suggested—

(1) To remove from the ship various fittings which could be dispensed with, such as the " Sevro " gear which supplemented steering by hand, the look-out position on the top of the ship, the heavy glass in the windows of the promenade, certain unnecessary tanks, and a number of passenger sleeping cabins and other conveniences. By such means as these it was estimated that the fixed weights might be reduced by nearly three tons. At the same time it was proposed to enlarge the gasbag wiring so as to enable the inflated gasbags to fill more space and thus to increase the lift by over three tons. The total improvement in the " useful lift " which would be secured by these alterations would thus amount to about six tons.

(2) To increase the total length of the airship by inserting an additional middle section or " bay," thus providing space for an additional gasbag which it was at first estimated would add another nine tons to the useful lift. This, of course, would require a re-calculation of the strains, both static and aerodynamic, which the reconstructed ship would have to sustain. Moreover, this second change necessarily involved a further delay before the R.101 could attempt its Indian voyage.

38. It was proposed to put in hand the first group of changes as soon as the R.101 was put back into its shed at the end of November, 1929, and the Secretary of State was informed that this work might be completed by the following February, and that the ship might be ready for what was called " the demonstration flight to India " by the second week in March. On the other hand, it was realised that the adoption of this first set of changes alone might not be sufficient to secure that the vessel could get further than Egypt and that if regular operations on the Indian route were desired, the extra bay was also necessary. During the hot months of the summer, conditions for such a flight were more adverse, and the choice, therefore, was between making the first set of alterations alone and attempting a flight

along the Indian route in the spring, or delaying the first attempt to the late autumn of 1930, by which time the additional bay could also be inserted.

39. These alternatives were put before the Secretary of State, Lord Thomson, in a full and careful Minute by Sir John Higgins on November 21st, 1929, and a week later the Secretary of State replied as follows :—

"A.M.S.R.

I am of opinion that no good, and quite possibly some harm, might be done by a flight to India in the early months of 1930. The best course would I think be :—

(*a*) To make the various alterations you suggest in para. 3 of your minute.

(*b*) To insert the extra bay.

(*c*) To make every effort for a flight with 55 tons disposable load to India and back at the end of Sept., 1930.

28.11.1929. T."

(The alterations referred to by Lord Thomson in (*a*) were those described under (1) in para. 37 above.)

Lord Thomson's Decision.

40. Lord Thomson thus determined to adopt the course of prudence even at the expense of further delay. The first set of changes were taken in hand during the spring of 1930, but it was decided not to cut the ship in two and insert the extra bay until after she had been again brought out of the shed and submitted to further tests in the course of the summer. In a letter to the Treasury dated December 12th, 1929, the Air Council announced that they had had under consideration the question whether the R.101 should carry out a flight to India and back in the following March with the minor improvements already referred to, or whether it would be better to delay the flight in order to increase the lift of the airship further. The letter went on to state that the Air Council believed that with these minor modifications the R.101 could fly to India without difficulty in March or April, but that the return flight would be less easy owing to the fact that conditions on the flight from Karachi to Ismailia were more adverse, and to the further fact that the lift of an airship is necessarily lower at Karachi than in this country, and that this loss of lift is heaviest during the summer months. The Air Council stated that they had therefore decided that,

"in order to avoid running any unnecessary risks it is better to postpone the flight to India until the lift of R.101 has been increased, by the addition of a section in the middle of the airship. No mechanical or aerodynamic difficulty is anticipated as the result of this alteration in the airship; but the Council propose to have the calculations and drawings examined by Professor Bairstow and Professor Sutton Pippard, as was done with the design of the main structure."

The total cost of both sets of alterations was estimated at £21,000 for direct labour and material, together with approximately £2,500 for the gasbag, and £1,000 for the additional outer cover. The letter added :—

> " The Council contemplate that R.101's flight to India should now take place in September next, and, to enable this to be done the additional bay should be inserted by the end of July. If, however, the work is to be completed by this date, the preliminary design work and the ordering of material must be put in hand as soon as possible."

Treasury sanction was duly obtained for the carrying out of this scheme, and the Indian authorities were informed of the change of timetable. It is to be noted that the Air Ministry at this time undoubtedly contemplated that further flying trials would be necessary after the new bay was inserted, for Sir John Higgins' letter of December 27th, 1929, to Sir Geoffrey Salmond who was commanding the Air Force in India concluded by saying —" Accordingly, in order to increase the lift of the airship still further we are proposing to put in another bay during the summer and then to carry out the first flight along the Indian route *after the airship has done some further flying trials with the new bay fitted*." Indeed, a Minute prepared for the Secretary of State by Sir John Higgins on December 6th, while setting out the good results already attained by the R.101 in previous trials, added— " Before she gets a full Certificate of Airworthiness, R.101 has yet to do a 48 hours' endurance flight. There has hitherto been no suitable opportunity for this, as we cannot run the risk of an endurance flight finishing in a gale."

Damage to Outer Cover.

41. The minor alterations having been completed, including the very important change of enlarging the gasbag-wiring so that the gasbags had more room to expand, the R.101 was again brought out of its shed early on the morning of June 23rd, 1930, and was moored to the tower. The wind was light but there was much humidity in the atmosphere, and almost immediately a disturbing incident occurred. The outer cover, between panels A and B on the starboard side of the ship, developed a split which extended to a length of about 140 feet. As meteorological conditions indicated that the wind was likely to rise, in which case the ship could not be got back into her shed, it was decided to mend the tear in place, and by working all day, in spite of gusts and heavy rain, a weather-tight repair was completed by 5.30 p.m. A second but shorter split occurred next day on the topmost part of the cover, but this was similarly repaired in a few hours. Such ripping of the outer cover would of course be extremely dangerous if the vessel was in flight, and much consideration was given to the best way of preventing its recurrence. It was decided to abandon the idea of using a " pre-doped " cover, *i.e.*, one which was made of fabric which had been treated

before being stretched round the structure, and to substitute, when the vessel next returned to the shed, a new cover which would be doped after being fixed to the ship. This latter method was the practice previously followed in other airships, and the new system had been adopted as an experiment in order to gain the advantage of some reduction in weight (*see* para. 25 above). In the meantime, it was decided that by reinforcing the repaired cover with some strengthening bands, it would still be possible for the ship to fly at the R.A.F. Display on Saturday, June 28th, which was the immediate reason for bringing her out of the shed at this time.

R.A.F. Display Flights in June 1930.

42. Accordingly, three more flights took place on successive days—the *Eighth* on June 26th (undertaken for testing the repaired cover and lasting for 4½ hours), the *Ninth* on June 27th (undertaken as a rehearsal for the next day's Display and lasting 12½ hours), and the *Tenth*, again for some 12½ hours when the vessel successfully performed her part of the programme at Hendon. Apart from the Report on these flights made by Flight-Lieutenant Irwin, to which reference is made below (*see* para. 47), evidence was given at the Inquiry by several witnesses who, either as officials from Cardington or as members of the crew of the R.100, flew in the R.101 on one or other of these occasions. The most important of these was Squadron Leader Booth, Captain of the R.100. This officer, when asked his impression of the flight on the 27th of June, said :—

> " On the 27th of June we left the mooring tower at 8 o'clock in the morning, and landed again in the evening. The conditions during the day were rather bumpy, and there was a clear sky with cumulus clouds and intermittent sunshine. We were only flying at reduced speed, 40 and 42 knots, and she appeared to be bumping rather a lot, which I attributed to the slow speed of flying. Also during the day I noticed that she was getting heavier than seemed to be consistent with the temperature and the height at which we were flying. During the day we had to let go some ballast, in the afternoon, as the height coxswain reported that she was difficult to keep at the flying height of 1,000 or 1,200 feet, and I think for the whole day we expended nine tons of ballast, and, assuming that we used about two tons of fuel, that makes up 11 tons of ballast that we expended. At the time, I remarked on this to Flight-Lieutenant Irwin, and he, I think, was under the impression that the gas valves were giving trouble owing to the slackness of the outer cover."

Flying " Light " and " Heavy."

43. Squadron Leader Booth's reference in the above quotation to the R.101 " getting heavier " makes this a convenient place to explain what is meant by saying that, in navigating an airship, she may be either " flown heavy " or " flown light." If a body is going to float in a medium without either falling or rising, it is obvious that its weight must be exactly equal to the weight of the medium it displaces. Sea-water, for example, is about 800 times heavier than air, and this is, of course, the reason why

a vessel which displaces sea-water will float, though it is 800 times heavier than a vessel of the same size which floats in the air. Yet an airship is seldom in an exactly neutral condition, *i.e.*, of such a weight that when at rest in the air it will neither rise nor fall. But an airship which when at rest would not float without rising or falling can, by the use of its engine power combined with its elevators (within limits), be caused when in motion to travel so that it neither rises nor falls. If it is "heavy," *i.e.*, if the condition and quantity of the gas it contains as compared with the outside atmosphere, are such as would not sustain it in the air at rest so that it would fall towards the ground, its propellors will, nevertheless, keep it travelling level if its nose is somewhat turned up and the elevators are used so as to counteract its tendency to rise under engine power. An airship travelling under these conditions is described as flying "heavy." If it loses more lift and becomes heavier, its nose may be raised to a slightly larger angle and thus level flight still secured. This consideration will become of great importance when the cause of the disaster to the R.101 is considered hereafter. On the other hand, it is also possible to fly an airship "light," *i.e.*, to secure by the use of engine power and elevator that an airship which is lighter than the air surrounding her will, none the less, progress level with the ground instead of mounting higher. When the airship is flown "light" her nose must be turned slightly downwards, and here again if she becomes still lighter, her nose can be turned down through a somewhat larger angle in order to maintain a horizontal flight-path.

Squadron Leader Booth's observation, therefore, above quoted, really indicates that the R.101 on the flight in question was found to be losing gas, and was thus getting "heavier"—a condition of things which would be appreciated in the control car, as it would be counteracted by movement of the elevator so as to raise the nose of the vessel slightly higher.

Observations on June Trials.

44. Colonel Richmond, when dealing with these June trials in his private diary, recorded that on the occasion of the Flight on June 27th the ship had taken a steep dive. Squadron Leader Booth, however, when giving evidence at the Inquiry dealt with this point and explained what happened. He said that the dive actually happened over the Aerodrome at Hendon when the R.101 was intentionally brought down to a low altitude. She was, in fact, brought steeply down to 500 feet from the ground (which was lower than was intended), and the height-coxswain then pulled her rapidly up on the other side of the Aerodrome. At that moment the bridle just abaft the passenger coach, at frame 8, broke, causing a jerk which was distinctly felt in the control car, a hundred feet further forward.*

* After the return of the R.101 to the shed, all these bridles were examined, and it was decided to replace these wire bridles by chains.

Captain Meager gave evidence that he was a watch-keeper on the R.A.F. Display Flight of June 28th, and that he was on duty from 4 to 6 p.m., when he noticed that the ship seemed heavy, and the height-coxswain had difficulty in keeping height. This heaviness he considered was due to a loss of gas, caused either by the chafing of the gasbags or by the gas valves "chattering." During the morning he had noticed considerable bumpiness over the land, but over the sea the ship flew very steadily on an even keel with very little movement of the elevator. Over the land while going to the Display the ship again experienced bumpiness, and he observed that the height-coxswain, a man called Oughton (who lost his life in the ultimate disaster), experienced difficulty in keeping the ship at her flying height. In consequence of this difficulty Captain Meager dropped half a ton of ballast from No. 8 frame about 5 p.m., and this made things easier. He reported, however, to Flight-Lieutenant Irwin, the Captain of the ship, that he considered the ship heavy, and as the ship was not far from Cardington he suggested landing immediately, but Irwin considered the weather too bumpy to make it advisable to land, and a landing was effected two hours later.

Wing Commander Cave-Browne-Cave, who was on the short flight which took place on June 26th, spoke of the dropping of the contents of two separate one-ton tanks of fuel-oil from about 1,000 feet as the ship came in to the mooring tower on that occasion. The oil was dropped in order to lighten the R.101. The necessity for dropping this fuel oil was largely brought about by atmospheric conditions. When the R.101 left Cardington at 4 p.m., on June 26th, it was a hot sunny afternoon and the gas in the gasbags was considerably super-heated (that is, the gas was at a very much higher temperature than the surrounding air) and thus gave an increased lift ; in the evening, when the ship landed at 9 p.m., the gas had cooled to approximately the same temperature as the surrounding air, thus causing a great loss of lifting power. It was in consequence of this loss of lift that the Captain considered it advisable to discharge two tons of oil from emergency tanks.

Some twelve hours later the Wing Commander went to the place where the oil had been dropped. Traces of it were found on the ground which was dry, but he formed the conclusion that if the ground had been wet it would have been very difficult to find any traces of the oil. This observation is of special interest in considering the probable course of events just before the R.101 crashed in France.

Investigation of Gas-leakage.

45. It is of particular importance to study the incidents of these three flights in June and to consider how far they afforded evidence that the ship was airworthy in various conditions of weather, since, after the Hendon Display was over, the R.101 was taken back (on June 29th) for the last time into her shed in order to have the extra bay inserted. She did not emerge again until October 1st, and after one more Trial Flight of 16 hours, which immediately followed, she started for India on the evening of October 4th.

Though there was little wind during the June Flights, the weather could not be described as ideal for flying. On each of the three days there was a hot sun with detached cumulus cloud, and these constitute conditions which produce a very bumpy atmosphere when flying over the land. Apart from the indications that she was losing gas at an undesirable rate, to which further reference is made in the following paragraph, the R.101's flying in June may fairly be regarded as confirming the confidence, as well as increasing the experience, of those who navigated her. She had now flown for over 102 hours, over land and sea, and though she had never had to face really severe conditions in actual flight, the belief that she was capable of doing so was confirmed by the way in which she withstood the fierce gale while moored to the mast in the previous November.

46. But the flights in June must also be considered as affording some experience of how the vessel would behave with her gasbags enlarged till they rubbed at various points against surface projections in her main structure. This tendency to chafe had already been observed when the vessel rolled at the mast before the gasbag wiring had been altered (*see* para. 35). When she was brought into the shed at the end of November, 1929, a most careful gasbag inspection was made. Each bag was taken out of the ship in turn and examined for holes in the fabric; every gasbag except one was found to be holed, and in some of them the number of holes was considerable. For example, bag No. 11 had 103 holes in the fabric; bag No. 5 had 57, while some other bags were in much better condition. The holes were repaired and, before the vessel came out again for further trials in June, points in projections which were thought to be likely to press against the bags were carefully padded. It was, of course, obvious that the enlargement of the gasbags, by reducing the clearance between them and the surrounding structure, increased the danger of chafing, and no less than 4,000 pads were manufactured for the purpose of protection. It must be remembered, however, that many of these holes would be microscopic in size, and that owing to the small pressure of the gas inside the gasbag, the presence of a certain number of small holes would not necessarily produce a serious loss of gas.

Chafing of Gasbag Fabric.

47. Nevertheless, immediately after the June flights were over, there can be no question that a serious view was taken for a time of the danger which might be caused by the creation of holes due to chafing of the gasbag fabric, and, in view of the amount of gas which the R.101 lost during the flights of June 27th and 28th, the question was raised whether this might be explained by imperfect functioning of the gas valves.

On July 1st, Flight-Lieutenant Irwin made a written report to Major Scott on the three flights which had just taken place, and a portion of this report is reproduced below :—

> " It was noticed during flight that the Outer Cover, E to F panel just for'd of Frame 13, was flapping considerably more than on previous trials. It should be worth while inflating * this panel.
>
> " The cover was also flapping all along between C and D and it is considered possible that gas valves may have been affected, as even allowing for the numerous holes which are now being found in gasbags where they have rubbed on protruding nuts of Main Longitudinals, the loss of gas would not have accounted for the heaviness of the ship during flight on Friday and Saturday.
>
> " A report on gasbags will be rendered later on. The non-padding of girders before inflation and flying has resulted in an abundance of holes in gasbags.
>
> H. CARMICHAEL IRWIN,
> Capt. R.101."

As regards the gas valves, it is stated in the Minutes of a Conference held in Wing Commander Colmore's room at Cardington, when Flight-Lieutenant Irwin's report was considered, that the tests on gas valves had not been completed before the ship left the shed for the previous flights. This presumably refers to the testing of gas valves after they had been attached to the gasbags, and it was decided that these tests should be completed in the shed before the R.101 undertook another flight. The gas valves had, of course, been most carefully tested before they were placed in position in the ship. This work had been carried out by the Inspector-in-Charge, Mr. McWade, and his staff. Mr. McWade in his evidence at the Inquiry told the Court that his instructions from the Design Department were to tilt each valve, under suitable conditions of pressure, to see that it did not open when placed at an angle of 3° from the vertical. But in fact, by increasing the tilt, he had ascertained and recorded at what angle the valve would begin to open. This limiting angle he found to be 5° or in some cases 4°. If, therefore, the valves retained this degree of sensitiveness, and the vessel at any time experienced weather which caused her to roll through a larger angle, the danger of gas beginning to escape is manifest.

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* *i.e.*, fixing a mattress inside it, and inflating the mattress with air.

48. As regards the loss of gas through holes worn in gasbags, Colonel Richmond also placed his own views on record. In the course of the Inquiry an "unregistered Minute" dated July 2nd and bearing his initials was found. It was addressed to Major Scott and ran as follows :—

> "In connection with the reported loss of lift of R.101 during flight I have been investigating the effect of holes in the gasbags. I find that, if it be assumed that the average height of the holes is equal to three quarters of the height of the ship, then, the rate of loss of lift is about 1 ton per square inch of opening in 12 hours. This calculation assumes quite a pessimistic coefficient of discharge such as would be applicable to a triangular hole. In my opinion, this result is somewhat startling and emphasises the great importance of guarding against holes in these present ships. Even if the holes are in the form of slits which have comparatively little effective area of discharge, it seems to me quite conceivable that we may have had leaks in both ships amounting to 4 or 5 square inches of area.
>
> "In order to enable me and my staff to determine what should be done to check holes in the present ships and also to guard against their occurrence in future ships, I should be glad if you could arrange to let me have full particulars of the positions, approximate sizes, etc., of the holes found by the crew, from time to time.
>
> 2.7.1930. V. C. R."

A copy of the above Minute was at the same time sent to Wing Commander Colmore, and another Minute from the latter's Department, also of July 2nd, records that Colonel Richmond had discussed this matter with Wing Commander Colmore and "naturally regards it as very serious." It was decided, therefore, that the Captain of the R.101 should carry out a very minute inspection of the bags immediately; and that when a hole was found the exact position should be recorded, and the necessary padding applied to any projection that was the cause of the trouble.

Report to Air Ministry on Gasbag Defects.

49. It will be appreciated that the Minutes above quoted passed between the Officers concerned at Cardington, and at the Inquiry the Court endeavoured to ascertain whether the serious view then taken of gasbag leakage by the Cardington Officers came before the notice of the Air Ministry in London. It was ascertained that on the following day Mr. McWade, the Inspector in Charge at Cardington, had written a letter addressed to the Secretary of the Air Ministry at Adastral House which he had specially marked "For the attention of the Director of Aeronautical Inspection," viz., Colonel Outram, whose office was at the Air Ministry. It will be observed that Mr. McWade was taking the unusual course of addressing the Head of his Department instead of merely minuting his observations to his immediate superior. Mr. McWade explained to the Court that his anxiety in part arose from the fact that it would be his duty at a later stage to hand over to the R.101 on behalf of the Air Ministry, a further "Permit to Fly."

Mr. McWade's letter was as follows :—

"Aeronautical Inspection Directorate,
At Royal Airship Works,
Cardington, Bedford.
3rd July, 1930.

The Secretary,
Air Ministry,
Adastral House,
Kingsway, W.C.2.

For the attention of D.A.I. (A.I.D.).
Thro : C.I.A. (A.I.D.).
Ref. 2/A.2/30/AID.
Subject :
Confidential.

H.M.A. R.101.

Airworthiness of the above 'ship.

" On the 26.6.30 I handed over the ' Permit to Fly " dated 20.6.30 —valid until 19.7.30 to D.A.D.

" Owing to the modifications which have recently been carried out on the Wiring System, the gasbags are now hard up against the main longitudinals and rubbing very hard on the nuts of the bolts positioning the stirrup into which the tie rods are screwed. Further, the gasbags foul very badly the heads of the taper pins at the joints of the main and intermediate struts at the inner ridge girder ends. This matter, in my opinion, has become very serious, as the points of fouling occur throughout the ship and amount to thousands.

" Padding has been resorted to by wrapping fabric over the parts mentioned above and this is the usual recognised method used in isolated cases. Padding to the extent now necessary is, in my opinion, very unsatisfactory, because the bags move when the 'ship is in flight and the padding becomes loose and the projection complained of is again exposed.

" Although the gasbags have recently been reconditioned and were in good order when placed in the ship a few weeks ago, there are now many holes in them.

" The next point is that where the fabric is wrapped round a joint it may be difficult to know what is happening underneath the wrapping (I have in mind the corrosion question). The fabric will become damp and in many cases wet when the ship is in flight; therefore, there will be alternate process of wetting and drying of the fabric which must be detrimental to the metal underneath.

" I am fully aware that to remedy the faults complained of is in the nature of a large undertaking and it may be necessary to remove the bags from the ship. Until this matter is seriously taken in hand and remedied I cannot recommend to you the extension of the present ' Permit to Fly ' or the issue of any further permit or certificate.

F. McWade,
Inspector in Charge, A.I.D.
at R.A.W. Cardington, Bedford."

3.7.30.
R.A.W.

50. Colonel Outram, on receiving Mr. McWade's letter at the Air Ministry next day, sent a Minute to Wing Commander Colmore stating that he would have to submit the document to Sir John Higgins, the Member of the Air Council under whom such questions would be dealt with, but that before doing so

he wished to have Wing Commander Colmore's comments. The reply from Wing Commander Colmore was as follows:—

"D.A.I.

"I feel sure you will agree that we cannot accept, as a matter of principle, that the gasbags in an airship should be clear of all girders. Also I expect you will agree that we can accept padding as being a satisfactory method of preventing holes forming in gasbags from this cause.

"As far as we can trace at present there have been remarkably few nips in the gasbags of R.101 and that the holes which have occurred are due to the bags fouling girders. We have little doubt that padding will be a permanent remedy and, if this is accepted, then it is certainly not a large undertaking to put the matter right. In fact, we hope to complete the necessary padding in R.101 by the end of the present week or, at any rate, some time next week.

"We do not think any objection can be taken to wrapping padding round obstructions of this nature.

"The above covers our views but I should be very glad to discuss the matter with you when you are next at Cardington.

R.A.W. R. B. B. Colmore,
8.7.30. D.A.D."

Colonel Outram explained to the Court at the Inquiry that, in view of Wing Commander Colmore's opinion, and after making other enquiries, he was convinced that the matter was not so serious as he had at first supposed, and that he, therefore, came to the conclusion that it was not necessary to submit Mr. McWade's report to Sir John Higgins. He stated that even if he had known of Colonel Richmond's Minute of July 2nd he would still have thought it unnecessary to do so. The result, therefore, was that neither the Secretary of State nor any member of the Air Council learned anything about it.

A fair inference from the facts is, that in view of the very special knowledge and experience possessed by the high officials at Cardington in every detail of airship construction, the remedy for what was no doubt regarded as a serious matter was left to their judgment, and it was considered that, notwithstanding the anxieties that had been expressed, adequate steps could and would be taken at Cardington to put the matter right. It has always to be remembered that the officers and experts specially acquainted with every detail of airship construction were concentrated at Cardington, just outside Bedford, and that the officials at the Air Ministry in London, who were technically their superiors, though accepting and discharging their proper responsibilities at Headquarters, were, almost without exception, men whose training and experience had been gained in the course of service with aeroplanes as distinguished from airships. When, therefore, questions arose at Cardington (such as the proper way of dealing with the escape of gas), which are peculiar to airships, there was a natural tendency at the Air Ministry to rely upon the advice and judgment of the airship experts who were congregated there. No doubt this situation sometimes resulted in the determining voice, in dealing with difficulties reported to the Air Ministry as arising out of the construction or flying of the R.101, being that of the very people who were engaged in designing or flying the ship. There was less opportunity for securing an outside opinion or taking effective instructions from Headquarters, than would be the case if the science of airships was more advanced or more widely studied. Thus, officials at the Air Ministry, whose special experience and technical knowledge were based on the construction and flying of aeroplanes, inevitably looked to Cardington, to a very large extent, to solve its own problems.

It is proper to add that Colonel Richmond, in a memorandum drawn up in the following September, expresses himself as satisfied that adequate padding proved a satisfactory cure. The incident was closed, so far as Mr. McWade was concerned, by a Minute from Colonel Outram of July 11th communicating the joint view of himself and Wing Commander Colmore. The Minute includes the following paragraph :—

> " Of course I fully realise the necessity of avoiding the contact of these damaging points to the gasbags. I have taken the matter up with D.A.D. '(i.e., Wing Commander Colmore),' who is in agreement, but as you yourself realise, it is impossible to alter the hull structure of the ship at this stage. The only expedient at the moment is to pad, and it is your duty to see that every point which may lead to damage is padded in a proper manner."

Programme for Insertion of New Bay.

51. The R.101, having been got back into her shed at dawn on June 29th (the day after her Display at Hendon), was now available for the insertion of an additional middle section which would increase her overall length from 732 feet to 777 feet, and which was calculated to enlarge her " useful lift " by some 9 tons. The girder work, all most carefully designed, had been ordered from Messrs. Boulton & Paul earlier in the year and was ready to be assembled in the ship when she was cut in two. The additional gasbag (the largest of the whole series), had been manufactured at Cardington, and it only remained to decide when the ship should be parted. The division was to take place at Frame 8 and there was to be inserted a new Frame called 8a between Frames 8 and 9. There was, however, one consideration which might have postponed the operation. The R.100, which had successfully performed an " endurance flight " of 53 hours early in the year, had undergone some modification in construction and had still to go through a further continuous flight of 24 hours before she attempted the journey to Canada. If she failed to perform this further flight satisfactorily, she might be unable to enter upon the Canadian voyage, and Sir John Higgins raised with the Secretary of State the question whether, in that event, the R.101 might not have to be commissioned to take her place and undertake the crossing of the Atlantic. If, therefore, the R.101 was to be available as a substitute, it was necessary to postpone the cutting of her open until the result of the R.100's further trial was known.

52. Sir John Higgins' Minute, sent to the Secretary of State on July 14th, was as follows :—

> " D.A.D., (*i.e.*, Colmore,) has now applied for authority to commence work on parting the airship to-morrow. Until, however, R.100 has completed her next trial flight and shown that the modifications to the cover, etc., are satisfactory, a possibility still remains that the R.101 may be required for the Canadian flight. In the circumstances I do not think R.101 should be put out of action for the present, even at the risk of delaying the Indian flight. I propose, therefore, if you agree, to hold up work on R.101 for a week in the hope that R.100's flight will be completed by then. In the meantime D.A.D. will press on with such work as is not dependent on opening up the airship."

53. Lord Thomson replied to Sir John Higgins' Minute on the same day, as follows :—

> " So long as R.101 is ready to go to India by the last week in September this further delay in getting her altered may pass.
>
> " I must insist on the programme for the Indian flight being adhered to, as I have made my plans accordingly."

Sir John Higgins informed Wing Commander Colmore of Lord Thomson's view, and on July 17th Wing Commander Colmore replied to Sir John Higgins in the following Minute :—

> " Every effort is continuing to be made to complete R.101 to enable the flight to India to take place at the end of September. Work on girders and parts is very well forward and a reliable estimate can be made of the time required to complete these parts and to assemble the frame.
>
> " It is in the parting of the ship and the insertion of the new bay, however, that delays may occur which cannot be foreseen, and, in our opinion, if we are to work to this programme it is absolutely essential that work on parting the ship should commence immediately.
>
> " In the event of further trouble with R.100 during her re-trial flight I am afraid the only alternatives would be either to abandon the Canadian flight until these troubles have been overcome or to carry out the flight with R.101 and postpone the Indian flight until November."

54. Sir John Higgins was thus faced with the difficulty that the Secretary of State was only prepared to authorise delay in opening up the R.101 and inserting the new bay, if this postponement would not prevent the Indian flight being undertaken at the date then contemplated, which was the end of September. On the other hand, Wing Commander Colmore was pointing out that the immediate cutting open of the R.101 might result in no ship being available to undertake the projected Canadian flight, and was suggesting that, as an alternative, the Indian flight might be postponed until November. Sir John Higgins felt it necessary to see Lord Thomson again on the subject, and what passed at the interview (on July 21st) may be gathered from Sir John Higgins' Minute to the Secretary of State made later on that day, and from Lord Thomson's reply.

55. These important documents run as follows :—

Sir John Higgins to Lord Thomson.

" S. of S.

" 1. I understand from our conversation this morning that you do not approve of the proposal that R.101 should be kept as a standby for the Canadian flight, and that if the modifications which have been made to R.100 do not prove satisfactory, the flight to Canada will have to be put off until satisfactory modifications are completed on this ship.

" 2. I propose, therefore, to issue instructions to D.A.D. to part R.101 immediately so as to give the best chance of its being ready according to the programme date which is being worked to.

" 3. Every endeavour is being, and will be, made to keep to this programme date but, as stated in my loose Minute of the 30th June, which I have inserted for reference at enclosure 5a, this date does not leave any margin for unforseen circumstances.

A.M.S.R."

21.7.30.

(The Minute of June 30th here referred to had stated that, according to the programme to which Colmore was working, the R.101 should be completed with the new bay by September 22nd. It continued " One trial flight will be necessary before the airship leaves for India, so the end of September is the earliest date on which the flight can commence. This leaves no margin for eventualities and assumes that the trial flight will be completely successful.")

Lord Thomson to Sir John Higgins.

" A.M.S.R.

" The first paragraph of your Minute states the position correctly.

" I note and approve course of action proposed in paragraph 2.

" As regards paragraph 3, I am sure everything possible will be done and am not unduly pessimistic.

T."

22.7.30

Decision to Instal Reversible Engines.

56. Accordingly, the insertion of the new bay was at once begun. The vessel was cut in two before the end of July and the work of enlargement, with a vast range of consequential adjustments, was carried forward at full pressure without intermission. But there was another circumstance which threatened to postpone the projected date of completion. The original plan of providing the R.101 with four engines which worked only ahead and a fifth which worked only astern (*see* para. 28) had been modified. Instead of this, all engines were to be capable of working forward ; as ultimately fitted, two of them would also work astern. There was delay in supplying these reversing engines and their airscrews, and by the end of August it was calculated that, with day and night work on these items, it might just be possible to complete the installation of the reversing engine by September 22nd. Early in September it was feared that, owing to delay in delivering the starting gear, it would be impossible to adhere to this date. In fact, reconstruction was complete by September 25th but, owing to weather, the R.101 was only able to leave her shed on October 1st.

Investigation of Airworthiness of R.101 as Modified.

57. Every effort, therefore, to save time in carrying out the alterations to the R.101 and in getting her out of the shed, was undoubtedly made ; but there is no reason to infer that the work was not properly done because of any pressure in its execution.

Another indication of the urgency with which matters were being carried through at the last stage is supplied by the way in which the two independent consultants, Professor Bairstow and Professor Pippard, had to act as compared with their more deliberate procedure with reference to the original designs in 1929.

This contrast must be explained further in detail. In 1929, before the R.101 left the shed for the first time, these two gentlemen, who are distinguished scientists and experts in airship construction, were employed to examine a complete set of calculations prepared by Colonel Richmond and his Department and called " Design Memoranda " Nos. 1 to 32, for the purpose of making a Report as to the airworthiness of the new ship. They drew up an elaborate Report, based on their examination both of these Design Memoranda and of diagrams and other data supplied by the Royal Airship Works. In this document (dated November 5th, 1929) they commented on any departure from the criteria of the report of the Airworthiness of Airships Panel, and they stated—

> " We do not see any such danger as would render the airship unairworthy for trial flights ; during these flights, experience will be gained on which the grant of a Certificate for overseas use can be decided."

The various trial flights were authorised by temporary " permits to fly " based on the views expressed in this document, and on the results of inspection from time to time by the Inspection Department of the Air Ministry.

58. After making their Report of November 5th, 1929, however, these two independent consultants had no further official connection with the R.101 until the summer of 1930. In June, 1930, they were invited by the Air Council to undertake an investigation of the airworthiness of the R.101 when modified by the insertion of the new bay. The Air Council stated that it would be guided by the terms of the consultants' Report in deciding whether the modified airship should be granted a " Certificate of Airworthiness," without which the Indian flight could not be sanctioned. Four more " Design Memoranda " were accordingly put before them, on which Professor Bairstow raised a number of queries in the course of September. These queries were dealt with by Colonel Richmond. Matters were now urgent, for a further temporary " Permit to Fly " was needed before the reconstructed R.101 could undertake its final trial on October 1st, and apart from this, a Certificate of Airworthiness would be necessary before she could start for India. Accordingly, on September 26th, Professor Bairstow's sanction to the issue

of a "permit to fly" was obtained by telephone; his full Report was to be furnished in time for the issue of the Certificate of Airworthiness. On October 1st, Professor Bairstow sent to to the Air Ministry the following letter, from which it will be observed that he and his colleague had not yet had time to prepare their final Report—

"The Secretary,
Air Ministry,
Adastral House,
Kingsway, W.C.2.

October 1st, 1930.

"Dear Sir,

Airworthiness of R.101. with additional bay.

"In accordance with instructions, we have examined the new information supplied to us by the Royal Airship Works, and have satisfied ourselves that R.101 as now existing with its additional bay complies with the specified requirements of the Airworthiness of Airships Panel.

"The difference between the conditions of loading of R.101 now submitted and those of the original design on which our previous report was based, surprised us by their magnitude; the differences are not primarily a consequence of the addition of the new bay.

"A good deal of general thinking and comparison on limited information has been required in reaching our conclusion and we have not had time since receiving essential information from the R.A.W., to prepare a sufficiently considered written report. We are proceeding to put our first draft into final form.

Yours faithfully,

L. BAIRSTOW.

"P.S.—The substance of this letter was agreed with Professor Pippard last evening."

Issue of Certificate of Airworthiness.

59. It is manifest that Professor Bairstow was working under severe limitation of time. Enough had been secured to justify the "Permit to Fly," and the final report was to be expected later. In fact, no further report from these two gentlemen was ever received, and at the Inquiry Professor Bairstow explained that he was actually engaged in drafting it when he heard of the disaster. The Certificate of Airworthiness issued by the Air Ministry was dated October 2nd, and was handed over to the ship just before the flight to India started, as soon as the Inspection Department of the Ministry was satisfied.

It is evident, therefore, that the Air Ministry's intention, as expressed in June, had been to get a final report from the two Professors before granting the Certificate of Airworthiness, and to be guided by the terms of this Report in deciding whether to grant it. But, owing to want of time, the actual course of events was that the Airworthiness Certificate was granted and handed over, and the flight to India begun, before this Report had been received or even completely written.

Professor Bairstow's Unfinished Report.

60. The draft of the Report, so far as it had gone when its authors heard of the disaster, was produced by Professor Bairstow at the Inquiry, and the following extracts are material :—

> " The most important considerations before us—although due in part to the addition of a new bay—arise chiefly from the difference between the fixed weights of R.101 as completed and flown and the weights assumed in design. This point is referred to in Design Memorandum No. 38 as follows :—
>
> > ' Owing largely to increase in the weight of power cars, passenger accommodation structure and bow and tail structure, the final fixed weight of the ship as completed considerably exceeded that used in design and its disposition was such as to produce, in the light condition of the ship, an excessive tail moment.'
>
> " A table prepared from the memoranda submitted to us shows in greater detail the variations of weight between ' R.101 designed ' and ' R.101 modified.' One of the effects of the heavier structure, etc., is a marked reduction in the differences between the ' heavy ' and ' extreme light ' cases of loading.
>
> " The considerable differences in weight between the designed and realised condition have corresponding consequences in the forces and moments which the airship has to resist. The bending moments for R.101 and its new bay are everywhere greater for corresponding states than for R.101 as designed. The same generalisation is not possible for shearing forces, there being a short section near the centre of the airship where the modifications have produced a reduction in the magnitude of the shearing force.
>
> " We have not been provided with calculations relating to R.101 as completed and before the addition of the new bay but sufficient information is available to show that much of the change found is not consequential on the added bay. We have in fact found our task one of difficulty owing to the lack of tables of forces and moments comparable with those for ' R.101 designed ' as given in Design Memorandum No. 3. Instead of some 200 pages of tables dealing with different states of loading we have Design Memorandum No. 35 and seven sheets of loadings and an additional note prepared at our request dealing with aerodynamic loadings in the vertical plane. We have necessarily had to change our procedure and decide the question of airworthiness on general considerations and not on specific calculations. It is our opinion that the newness of the venture would have justified complete recalculation of the stresses in R.101 when the magnitude of the changes in fixed weights had been realised. Such recalculation was at one time proposed."

61. It would not be fair or reasonable to deduce from the uncompleted draft of this Report that its authors were proposing to reach a pronouncement adverse to the airworthy qualities of the R.101 as reconstructed. On the contrary, though sounding a note of criticism and warning in connection with some of the calculations put before them, the general conclusion undoubtedly was that the R.101 was fit to fly. Indeed, as already stated, the temporary " Permit to Fly " under which she took her last trial flight on October 1st was issued with Professor Bairstow's approval. But the draft report does undoubtedly show that there was not sufficient time to spare for the re-examination of aerodynamic

calculations by the two independent referees to be anything like as complete as their earlier investigations. It is right to add that Professor Bairstow, after the disaster and in connection with the Inquiry, made, at the request of the Court, a very full and elaborate set of calculations from the data and dimensions of the reconstructed ship, and established that, from the theoretic point of view, her airworthy properties were adequate. Indeed, from some points of view, the lengthening of the ship had the effect of reducing rather than increasing the stresses imposed upon her.

62. It is convenient to close this part of the present Report at this point, and to postpone a description of the R.101's last trial flight to the Part which follows. For the circumstances of this last flight are so closely connected with the decision that the start for India should be made on October 4th that it is better to deal with the trial itself in that connection.

PART IV.—DECISION TO START INDIAN FLIGHT.

63. It is now necessary to put together the material which will show how the conception that the R.101 should undertake the flight to India came to be developed, and in what circumstances her actual date of departure (October 4th, 1930) came to be fixed.

The project of an Indian flight was really implicit in the experimental programme adopted in 1924 (para. 6 above) provided that the course of research and investigation then set on foot was found ultimately to justify it. Originally, as has been stated above (para. 8 (vi)), it was intended that both the R.100 and R.101 should be fitted with engines burning a fuel which could be safely carried and used in the tropics. But, when it was decided that the R.100 should have petrol-burning engines, the task of undertaking the flight to India necessarily fell upon the R.101. In 1926 work was begun in connection with the erection of mooring masts at Ismailia and Karachi and the building of a shed big enough to contain the R.101 at the latter terminus. The date at first contemplated for the Indian flight was unavoidably postponed because, as originally constructed, her useful lift was too small to allow of so prolonged and critical an undertaking. Reference had already been made to the communication of this change of time-table to the Government of India, and, when the R.101 was taken into her shed at the end of June, 1930, for the insertion of a new bay, official communications from the Air Council showed that it was contemplated that the Indian flight " should now take place in September next."

Proposal to start at end of September.

64. Wing Commander Colmore, who was the officer at Cardington responsible for carrying through the revised programme, drew up a Progress Report on the work then in hand, dated July 11th, in which he stated that it was impossible to give a firm estimate of the time required for joining up the new bay in the ship, but that he aimed at completing the ship by September 22nd. He added :—

> " every effort will be made to complete the ship as quickly as possible, but we have no allowance in our programme to cover unforeseen delays."

It is this Progress Report which is referred to in Sir John Higgins' Minute of July 14th (para. 52 above), and which led to Lord Thomson's comment quoted in para. 53 :—

> " I must insist on the programme for the Indian Flight being adhered to as I have made my plans accordingly."

The Secretary of State was here referring to the above programme that the reconstructed R.101 should be completed by

September 22nd and that the Indian flight should take place at the end of September. Indeed, in a Minute of July 2nd, Lord Thomson had already written—

> "I should like to be able to count definitely on starting for India during the week-end September 26–28th. I ought to be back by October 16th."

This general programme was so well understood that on August 13th, the Government of India telegraphed to inquire what would be the exact date of arrival of the R.101 at Karachi. Before a reply was sent, Wing Commander Colmore was consulted, and as a result, Mr. Reynolds, Lord Thomson's private secretary, put before the Secretary of State the following Memorandum dated August 26th :—

> "1. The date of the departure of R.101 for India now depends on five separate factors :—
>
> (i) the completion of the work on inserting the extra bay ;
>
> (ii) the completion and installation of a reversing Tornado engine to enable the airship to have five engines going ahead ;
>
> (iii) the completion of a reversible airscrew suitable for the engine ;
>
> (iv) suitable weather for getting the airship out of the shed when ready for flight ; and
>
> (v) the carrying out of a satisfactory trial flight of not less than 24 hours between being taken out of the shed and starting on the flight to India.
>
> 2. The position with regard to the above five factors is as follows :—
>
> (i) the work on the airship at R.A.W. should be completed by September 22nd ;
>
> (ii) the reversing engine should be delivered to R.A.W. by the 4th September but without the starting gear ;
>
> (iii) airscrews have been ordered to two different designs and are due for delivery between 16th and 28th September.
>
> 3. If the dates given in (ii) and (iii) are worked to, it will just be possible to have the reverse engine installed with airscrew by the 22nd September. Day and night work is going on on all these items.
>
> 4. There would therefore be six days available for items (iv) and (v), viz., getting the airship out of the shed and carrying out the trial flight. It is clear that this leaves no margin, but may just be possible."

It is plain, of course, that the programme of starting for India at the end of September could only be provisional, for at this time the work of reconstruction was not complete, and even if no further delay occurred in its execution there still remained the necessity for a further trial or trials and the consideration of what those trials showed.

Time Table influenced by Imperial Conference.

65. At a Conference with the Secretary of State which Wing Commander Colmore attended on August 29th, the latter stated that owing to delay in delivery of the starting gear for a reversing engine, he could not get the R.101 ready to leave the shed by September 22nd as he had hoped, and Lord Thomson is recorded as replying "that he could probably arrange for the Air business

of the Imperial Conference to be put off until about October 20th if necessary." Colmore was to do his utmost to start the flight on October 4th so as to arrive at Karachi about five days later, and the plan was to leave Karachi about October 13th or 14th and so get back to England about October 18th or 19th.

It is quite clear from the documents that the Secretary of State felt confident that he could thus count upon being back in this country in time to undertake his part in the Imperial Conference on October 20th.

It was therefore decided to send a reply to the Government of India stating that the present intention of the Air Council was, that the R.101's flight to India should start "at the end of September or during the first week of October."

"Permit to Fly" for Final Trial.

66. Preparations were now rapidly pushed forward. Early in September, a detailed, though still provisional, time-table for the double journey was drawn up and a list of probable passengers was settled. It was decided that when the R.101 came out of her shed she should undertake a trial flight under a temporary "Permit to Fly," but that she must have a final and official "Certificate of Airworthiness" before she started for India. The rather hurried circumstances in which this "Permit to Fly" was secured have been described in para. 58 above. The remaining work of reconstruction, including the fixing of a new outer cover between frames 3 and 12, proceeded so well that on September 11th, Wing Commander Colmore reported that he hoped, after all, to complete the ship by September 22nd, in which case she could be handled to the tower on the next favourable opportunity. But a few days later, in order to increase the engine power astern, it was decided to instal a second reversing Tornado engine which had just arrived from Messrs. Beardmore, although this would delay the completion of the airship to September 25th.

She was "gassed up" so as to become air-borne in the shed on September 26th, and her lift and trim were ascertained next day. It will be convenient here to set out in a table the comparison of these figures with those which were ascertained when the R.101 was first completed, and also when (before putting in the new bay) her gas bags were enlarged.

	As First Completed: 5th Oct., 1929.	After Minor Modifications: 26th June, 1930.	After New Bay: 27th Sept., 1930.
	Tons.	Tons.	Tons.
Gross Lift ..	148·6	152·0	167·2
Fixed Weights	113·6	111·3	117·9
Useful Lift ..	35·0	40·7	49·3

67. Though the R.101 was ready to leave her shed on September 27th, she had to wait for a spell of very calm weather such as would enable her to be brought out with safety and handled to the tower. The opportunity did not arise until the morning of October 1st, and she started her final trial flight at 4.30 p.m., on the same day.

This flight had been intended to have a duration of 24 hours (*see* for example para. 64 above). Indeed, at an earlier stage, Sir John Higgins had contemplated that before the R.101 got a Certificate of Airworthiness she would have to do 48 hours' endurance flight (*see* para. 40). It was a condition of the contract under which the R.100 was built that she should satisfy a corresponding test, and she in fact flew on one of her trials for 53 consecutive hours. In the case of the R.101, however, this final trial was ended after a lapse of 16 hours 51 minutes, and the circumstances in which it was abbreviated need to be considered.

Reason for reducing duration of Final Trial.

68. On the evening of September 30th (which was a Tuesday), the day before the R.101 came out of her shed, Wing Commander Colmore communicated with the Air Ministry, enquiring whether the Air Member for Supply and Research would agree to the duration of the impending trial flight being reduced to less than 24 hours if the ship behaved well, and if Major Scott was satisfied. The Air Member was no longer Sir John Higgins, for he had been succeeded in that position at the beginning of the month by Air Vice-Marshal Dowding. It is due to both these distinguished Officers to explain that their training and experience had been with aeroplanes, and they necessarily looked to the officials at Cardington, not only for advice, but for guidance on technical matters especially connected with Airships. Air Vice-Marshal Dowding told the Court that he enquired of Wing Commander Colmore what was the reason why the duration of the flight should be cut down, and that Colmore answered " So that we may have a chance, if all goes well, of starting on Friday evening. We shall thus have all Thursday to work on the ship, as well as Friday." The Friday, it will be observed, was October 3rd, and the circumstances in which it became necessary to postpone the start to Saturday will be explained later.

Air Vice-Marshal Dowding agreed to the request, and at 4.30 p.m., on October 1st, the *Eleventh and last trial flight* began. Air Vice-Marshal Dowding was on board.

Behaviour of R.101 on Final Trial.

69. At the Inquiry, no written report was forthcoming of the behaviour of the ship on this flight (except as to the working of the wireless installation). If any such report was ever made it must have been kept on the R.101, and has been destroyed with the ship. The absence of a report would be in marked contrast with

the course followed on some earlier occasions. Major Scott, Colonel Richmond, Wing Commander Colmore, Flight-Lieutenant Irwin (the Captain), and Lieutenant-Commander Atherstone (the 1st Officer), all took part in this trial flight, and were of course narrowly observing the behaviour of the reconstructed ship. But as they all perished in the disaster four days later, the only witnesses who could give evidence on the matter at the Inquiry were Air Vice-Marshal Dowding (who had never been in an airship before), Mr. Raisbeck (Chief Examiner of the Inspection Department at Cardington), who made a few notes, and half a dozen others, who were members of the crew, attending to particular branches of duty. Living airship Officers of experience, like Squadron Leader Booth and Captain Meager, did not happen to be on board during this trial flight and can say nothing at first hand of the ship's behaviour on this occasion. There are, however, two documents in existence which throw some light on this important matter: one is Colonel Richmond's diary, and the other a very detailed private journal kept by Lieutenant-Commander Atherstone.

Colonel Richmond's record runs as follows :—

> " *1st October* (*Wednesday*). R.101 brought out of shed at approximately 6.30 a.m.
>
> *Wednesday to Thursday*. Trial flight. Impossible to carry out full speed test owing to the early failure of the oil cooler in the forward starboard engine. Flying conditions were very perfect, and under these conditions, all other items in the ship behaved admirably."

The relevant portion of Lieut.-Commander Atherstone's journal is as follows :—

> " *Wednesday, 1st October*. This morning at 0630 hours R.101 was at last taken out of the shed in a very light N.Ely. wind and put on to the tower. . . . During the morning orders were given to have everything ready for flight by 1600 hours. At 1530 the passengers came on board and the ship slipped from the tower shortly after 1600 hours. The ship flew over London and then down the Thames and over Southend. The night was spent off the East coast and in the morning we came in just north of Yarmouth and straight back to Cardington. The trial was very successful except for a burst oil cooler in the starboard forward engine car which put that engine and the Beverly out of action for the rest of the flight. The ship appeared to be much better in the air than before and the cover was really good."

70. Notwithstanding the absence of any written report, the general conclusion which must have been drawn by the responsible officers on board at the termination of this final trial flight may be safely assumed. The vessel had been exposed to no very strenuous experience, for there was very little wind, and Colonel Richmond has recorded that " Flying conditions were very perfect." It was not possible to have any full speed trial owing to the breakdown of the oil cooler of one engine. This breakdown, however, was not in itself a serious matter, and was repaired after the ship returned to Cardington. The Officers were undoubtedly well satisfied with the performance of the ship.

Air Vice-Marshal Dowding told the Court that he had consulted his predecessor, Sir John Higgins, as to the attitude of mind of Wing Commander Colmore and the rest of the Cardington Staff, and that Sir John Higgins, speaking from a long experience, had said " that they were very enthusiastic over the airship but that he did not think that any advice that they would give would err on the side of rashness at any time ; in fact, when it came actually to making a decision their advice would rather be on the cautious side."

Longer trial to be preferred.

71. At the same time it cannot be doubted that if time had permitted, these officers would have preferred a longer test, if not a whole series of further flights. Squadron Leader Booth gave definite evidence on this point, based on conversations he had had with Flight-Lieutenant Irwin in Lieutenant-Commander Atherstone's presence. The following questions and answers appear to be important :—

Q.4076.—After the insertion of the new bay did you have a conversation with Flight-Lieut. Irwin and others with regard to the ship ?—Yes.

Q.4077.—As to what was to be done about trials and so on ?—He mentioned some time before the ship actually left the shed, in conversation with me and Lieut.-Commander Atherstone, that he hoped they would fly 36 or 48 hours at a reasonable cruising speed in bad weather in order to thoroughly test out the ship.

Q.4082.—Now we know that in fact she only did some 16 hours and 51 minutes flight. Do you know, as a result of anything that you have been told by Flight-Lieut. Irwin or anybody else on the ship, whether or not the officers were satisfied with that and satisfied with the behaviour of the ship ?—I think that after this flight they were satisfied generally with the way that she handled under those conditions.

Q.4083.—The weather as we know was almost ideal for flying ?—Yes.

Q.4084.—In your view would the insertion of the new bay make any difference to the handling of the ship in fair weather ?—No, I do not think it would make any difference at all.

Q.4085.—In fair weather ?—In fair weather.

Q.4094.—You told us a very important thing. You told us that Flight-Lieut. Irwin had expressed to you his hope that there would be a 36 or 48 hours trial, at a reasonable cruising speed in bad weather, in order thoroughly to test the ship ?—Yes.

Q.4095.—Then you told us that after the trial of some 16 hours in very calm weather, the officers (including Flight-Lieut. Irwin, I suppose) were satisfied with the way in which she handled in that calm weather ?—Yes.

Q.4096.—Have you any reason to think that, after finding that she handled well in calm weather for 16 hours, Flight-Lieut. Irwin changed his previous view that more elaborate trials in bad weather would be expedient ?—No, I have no reason to think that he changed his mind.

72. It is really quite beyond dispute that the reason why this final trial flight was shortened was because the intention to start on October 3rd or 4th left so little time for preparation after it was

over. Even though the trial were to disclose no defects to be remedied, there were many things to be done before the Indian journey could begin, and the Captain wanted every hour for a last look round. Indeed, this must be the reason why no report on the condition of the gasbags after the flight of October 1st–2nd appears to have been made. This is, however, a very different thing from supposing that so important a matter was not closely attended to. The situation was that, in view of the intention to start for India before the end of the week, the important matter was not to prepare elaborate documents, but to use the time in making a thorough examination of every part of the ship and repairing any defect that was found. Enthusiastic and confident as the officers of the R.101 were, they were the last people to leave anything to chance if it could be avoided. It is also to be remembered that when the ship was taken to her tower on October 1st she was handed over by the Building and Inspecting Staff at Cardington to the Captain and crew, so that after this date it is not the authorities at Cardington, but the officers of the R.101 who would ascertain the results of the final trial flight and arrange for any necessary repairs.

Importance of prolonged trial test.

73. But while there is no reason to suppose that the R.101 did not start for India until after any defects ascertained during her last trial had been remedied (and the officers in charge of her would certainly have refused to start if this had not been so), it is impossible to overlook the fact that the trials of the reconstructed ship were cut down to a degree that would never have been thought proper if it had not been for exigencies of time. Squadron Leader Booth, speaking with an obvious sense of responsibility and with the experience he had gained from being Captain of the R.100, placed the matter in its true light in the following impressive answers :—

Q.4098.—You will agree with me that the fact that the ship behaved well, as she seems to have done, in quite calm weather, would not seem to be quite the same thing as trying her out in bad weather ?—I agree.

Q.4099.—Is that your view ?—Yes.

Q.4100.—Do you regard a trial of 36 or 48 hours as useful from the practical point of view solely to discover consumption of fuel, or do you think that it is of value for the purpose of seeing how the ship behaves hour after hour under varying conditions ?—I think that it is of great value for training the crew, and finding out fuel consumption, and also finding out if any defects occur after long periods of flight. In R.100 we did a 50 hours' flight, and certain defects, and very important defects occurred after flying about 45 hours, which would have seriously hampered the ship if they had occurred over the middle of the Atlantic.

Q.4101.—In your view, if you had been responsible, do you think that the trial of the modified R.101, before she started to India, was adequate ?—I think that the officers concerned who had more experience of that ship than I have (and, of course, Major Scott, who had more experience of airships than anyone) were quite satisfied with

> the ship. They were confident in the ship and in their crew, but, at the same time, I feel that their decision to leave, or their agreement to leave, at that time was biased by the fact of the Imperial Conference coming off, and the psychological moment in airships when they could carry the Secretary of State to India, and bring him back to time. It biased their judgment in agreeing to fly. If that Imperial Conference had not been coming off, I feel confident that they would have insisted upon more trials, as was done in the case of R.100 before she left for Canada.

That this would be the view of an experienced and cautious airship officer who was planning trials without any regard to such considerations as are referred to by Squadron Leader Booth, is further made plain by another document which was produced at the Inquiry. It was a scheme of suggested trial flights drawn up at a much earlier stage by Flight-Lieutenant Irwin himself. After providing for flights by day and by night under good weather conditions, he had proposed a flight of 24 hours' duration under reasonably adverse weather conditions to be followed by "a flight of 48 hours' duration under adverse weather conditions to windward of base. Ship to be flown for at least 6 hours continuous full-speed through bumpy conditions and the rest of the flight at cruising speed. Ship to be berthed in shed as soon after landing to mast as possible, and a complete bow to stern inspection carried out." When it is remembered that the only trial of the R.101 after the new bay was inserted lasted for under 17 hours, and that under "perfect flying conditions," after which she started for India without ever returning to her shed for further inspection at all, it is impossible to avoid agreeing with the view of Squadron Leader Booth expressed in the final answer quoted in paragraph 71 above.

Postponement of start to October 4th.

74. It remains to describe how the decision was reached to start on Saturday, October 4th, instead of the previous day. On Thursday evening, October 2nd, Wing Commander Colmore came up to London and attended a conference with Lord Thomson. He reported that the trial flight was quite satisfactory except for the breakdown in the oil-cooler, and this was due to a defect of material which ought to be quickly remedied. Lord Thomson asked whether the start could not be made on Friday evening, to which Wing Commander Colmore replied that this would not leave time for the crew to have the necessary rest before undertaking so long a journey. The Secretary of State at once acquiesced and suggested starting on Saturday morning. Wing Commander Colmore pointed out that a morning start would bring them to Ismailia at the wrong time of day, since the estimated period for this first stage was 48 hours and it was important, for meteorological reasons, not to reach Ismailia before dusk. Wing Commander Colmore therefore suggested that the start might be made on the Saturday evening. Lord Thomson accepted this suggestion, but added an observation

which shows quite clearly that he was relying, as he was entitled to do, on the advice of his experts and had no desire to over-rule their better judgment. Air Vice-Marshal Dowding, who was present at the interview, told the Court that the Secretary of State's words were something to this effect : "You must not allow my natural impatience or anxiety to start to influence you in any way. You must use your considered judgment." An abbreviated note made at the time by Mr. Reynolds, Lord Thomson's Private Secretary, conveys the same idea in very few words—"*Colmore :* 'Leave Saturday 5 or 6 o'clock.' *Thomson :* 'No rush on my account.' "

Absence of full-power test.

75. Before the conference broke up, Air Vice-Marshal Dowding pointed out that the R.101 had never done full-power trials, and a conclusion was reached, according to Mr. Reynold's note, that the ship "ought to do full-power test near home," i.e., after leaving Cardington for India. The written instructions given to the ship before she left contained no such direction. It would seem obvious that there is a distinction between carrying out full-speed trials as a test to discover whether the vessel is efficient, and putting this extra strain on the ship when she is endeavouring to accomplish a flight of exceptional duration and difficulty. At any rate, when the ship started for India she did not waste fuel in full-power tests but continued on her way (as her wireless messages show) at normal cruising speed.

Confidence in carrying out time-table.

76. The actual hour of the start on the Saturday evening was left to be fixed at Cardington in consultation with Major Scott. Colonel Richmond's diary shows that at midday on Friday it was decided the ship should leave between 6 and 8 p.m. the following day. Air Vice-Marshal Dowding told the Court that just before the conference at the Air Ministry broke up Lord Thomson observed "Well that is all settled ; I can make certain of being back on the 20th." It is manifest that the Secretary of State was entirely confident, and that he derived this confidence from the views of the officers who were advising him. It was realised, however, that though the R.101 got safely out to India, circumstances might arise which would delay her immediate return, as the return journey would be more difficult to accomplish owing to weather conditions and fuel requirements, especially on the Karachi to Ismailia stage. Plans had in fact been tentatively made for the Secretary of State to return from Karachi, if need be, by aeroplane.

What is so impressive, on studying the details of these last hours before the R.101 started for India, is the high courage and genuine confidence of all concerned. For four years they had been preparing for this moment and, notwithstanding that the date of the Imperial Conference tended to condition the hour of their start, they believed themselves to be prepared for it. The last entry in Lieutenant-Commander Atherstone's private diary is as follows :—

> " *Friday 3rd October.* It was decided this morning that the flight to India would not commence until 1800 hours tomorrow as it would be too much of a rush to get everything ready by this evening. We really did need all yesterday and today to get everything on the top line. A reserve lubricating oil tank was put in today to hold 112 galls. lubricating oil and a spare oil cooler is also to be carried. One of the emergency ballast bags was found to be defective and had to be renewed and all the others carefully examined. Also the gasbags with low purities were purged through, and altogether the ship was given a proper look over. The weather conditions appear to be pretty good, with not much wind about. I think we should be able to get away with about 28 tons of fuel on board, which should give us nearly 100 per cent. reserve. Everybody is rather keyed up now, as we all feel that the future of airships very largely depends on what sort of a show we put up. There are very many unknown factors, and I feel that that thing called " Luck " will figure rather conspicuously in our flight. Let's hope for good luck and do our best."

PART V.—THE FINAL JOURNEY.

77. The R.101 started on her flight for India on Saturday evening, October 4th, 1930. She was slipped from the mooring-tower at Cardington at 6.36 p.m., G.M.T. (7.36 summer time: the clock was put back that night). It was, of course, already dark. There was as yet no rain, but the wind was blowing in gusts and its force was rising. The barometer had been dropping during the day.

There had been organised at Cardington a Meteorological Department, in charge of an able scientist, the late Mr. Giblett, who perished in the disaster. The Department was under the general direction of Dr. G. C. Simpson, F.R.S., Director of the Meteorological Office of the Air Ministry, who greatly assisted the Court by his evidence at the Inquiry. In Appendix V of this Report will be found a paper contributed by my Assessor, Colonel Moore-Brabazon, dealing more in detail with the meteorological questions involved in the investigation. Here it will be sufficient to say that a chart prepared by the Meteorological Department at Cardington showed that at 1 p.m., on October 4th there was a centre of low pressure south of Iceland and of high pressure in Northern Spain. A corresponding chart five hours later showed that the centre of the depression was moving eastwards, and that the barometric gradient was getting steeper, i.e., there was an increase in wind velocity, and still higher wind was to be expected.

The weather conditions, therefore, at the time when the R.101 started were far from ideal, and evidence was given at the Inquiry that Major Scott came off the ship an hour before she was due to leave and said that he was going to get all the passengers on board early, as he wished if possible to get away before the original starting time, as the barometer was falling.

Fuel, Ballast, and Numbers on Board.

78. The ship carried about 25 tons of fuel oil. Ten tons of this would be in tanks from which the contents could be jettisoned in an emergency. Under favourable conditions, two-thirds of the total quantity carried, or even less, might have been sufficient to reach Ismailia. Even if circumstances were adverse, the fuel provision was fully adequate—a fact which should be remembered when considering whether the Captain, when finding himself in difficulties before the crash, would seek to lighten his ship by dropping oil.

In preparing to start, the R.101 took on board $9\frac{1}{4}$ tons of water ballast, but 4 tons of this were got rid of before, or at the moment of, leaving, to compensate for the weight of passengers, crew, etc., and to help in the initial rise. It is worth noting that the dropping of so much water ballast at the start meant that if during flight more water ballast had to be dropped forward of the control car, this could only be done by sending a man forward to perform the operation (*see* para. 88 below).

So far as can be ascertained, the lift and load of the R.101 when she started approximated to those prevailing when her trial flight began on October 1st, the greater weight of oil being compensated for by a smaller quantity of water ballast and by other adjustments.

There were 54 people on board, six of them passengers, while another six were officials from the Cardington Airship Works. The Officers and crew of the ship, therefore, amounted to 42. A list of those on board, indicating which of them escaped from the disaster with their lives, is given in Appendix II.

Available Sources of information.

79. The materials available for a description of the experiences of the R.101 after leaving Cardington down to the moment of the disaster are of three kinds: (*a*) wireless messages sent from the ship and received at Cardington or other receiving stations; (*b*) the statements of the six survivors; and (*c*) observations from the ground of various people, mostly in France, who watched the vessel as she passed. The Court is most grateful to the French Authorities for assisting to make these witnesses available. Most of them were private citizens, living in Beauvais or its vicinity, who had no special experience of airships or aeroplanes, and no means of judging accurately on such a night how high the vessel was from the ground, since they did not know anything of her actual dimensions. One witness, however, was the resident in charge of the Poix Aerodrome north-west of Beauvais (M. Maillet), who was accustomed to make observations of aeroplanes, and another witness (M. Rabouille), who worked in a button factory in the daytime, but happened to be out rabbit-snaring that night very close to the place where the R.101 fell, gave a remarkably clear account of her movements just before she struck the ground. Putting together the material drawn from the three sources named above, it is possible, notwithstanding the loss of all the officers responsible for her navigation, to present some account of the last journey of the R.101 as follows.

From Start to the Coast of France.

80. The R.101 got away from the tower in trim, i.e., with her nose and tail in the same horizontal line. Squadron Leader Booth, who saw her off, estimated that she was at the time approximately half a ton light, so that apart from the use of elevator combined with engine-power she would have risen steadily until reaching her pressure height. There had been a little difficulty in getting the new starting-engine of one of the forward power-cars to function, and this had somewhat delayed the departure, but, as far as is known, once the start was made all the engines worked as they should for some time. After circling Bedford the vessel set her course for London, by which time

rain had begun to fall. She mounted gradually to her pressure height (about 1,000 feet) and thereafter rose further to 1,500 feet, which would mean that she spilled about 3 tons of gas. Mr. Leech, who had been in the ship on several of her trials, noted that she was pitching and rolling more than before, and recalled speaking to Squadron-Leader Rope about it. This was when the vessel was over Hitchin. Squadron-Leader Rope had noticed the movement but did not appear worried about it.

A wireless message sent off from the ship at 8.21 p.m., runs—

> "Over London. All well. Moderate rain. Base of low clouds 1,500 feet. Wind 240 degrees"—(i.e., about West-South-west). "25 m.p.h. Course now set for Paris. Intend to proceed *via* Paris, Tours, Toulouse and Narbonne."

An hour later the R.101 was requesting the Meteorological Office at Cardington to wireless a forecast of the weather to be expected from Paris to Marseilles "with special reference to wind and cloud" and at 9.47 the following message shows that she was just reaching the Channel:—

> "At 2135 G.M.T. crossing coast in vicinity of Hastings. It is raining hard and there is a strong South-westerly wind. Cloud base is at 1,500 feet. After a good get-away from the Mooring Tower at 1830 hours ship circled Bedford before setting course. Course was set for London at 1854. Engines running well at cruising speed giving 54·2 knots. Reached London at 2000 hours and then set course for Paris. Gradually increasing height so as to avoid high land. Ship is behaving well generally and we have already begun to recover water ballast."†

The crossing of the channel took two hours, for at 11.36 p.m. the vessel in her next wireless message reported:—

> "Crossing French coast at Pointe de St. Quentin. Wind 245 true 35 m.p.h."

The Point of St. Quentin is at the mouth of the Somme and its distance from Hastings is nearly 60 miles. The vessel was on a proper route from London to Paris, and it was a route well known to Squadron Leader Johnston, who had often navigated aeroplanes between the two capitals. It will be noted that, according to the two telegrams last quoted, the wind velocity was increasing. But it must be borne in mind that, to those in an airship, the force and direction of the wind can only be ascertained by observation of drift over the ground, since an airship (apart from gusts or lulls), has no sensation of movement

† This reference to recovering water ballast has a special interest. The R.101 was fitted, on the top of its envelope, with catchment arrangements by which, when rain fell, water could be captured to increase ballast and so compensate for loss of weight arising from consumption of fuel. There is no reason to suppose that any considerable addition to the ballast was thus obtained, but the incident is significant because it shows that at the time the R.101 did not consider herself too heavy.

with the moving air, but only of passage through the wind-stream, whatever it is. In fact, the wind observations reported by wireless from the R.101 do not appear to have been quite accurate, for, unless the wind which she encountered from time to time was stronger than she reported, her engines working at cruising speed (even allowing for the temporary breakdown of one engine referred to in the next paragraph), would have carried her a good deal further in the time.

81. In the meantime there had been trouble with the engine in the after car. Two of the survivors, Mr. Binks and Mr. Bell, were the Engineers in charge of this engine and their evidence has enabled the facts to be accurately ascertained. Before reaching London the main oil pressure connected with this engine failed, and it required the attention, not only of the two engineers who were in charge of the after car, but of Mr. Gent (the Chief Engineer) and Mr. Leech (Foreman Engineer from Cardington). The engine was not got working again until about 11 o'clock, shortly before the ship crossed the French coast. This incident partly accounts for the length of time occupied in crossing the Channel. But it has no further significance, for the evidence of survivors and other indications make it certain that the engines of the ship were working satisfactorily till orders were given just before the crash.

Height across the Channel.

82. Evidence was given at the Inquiry as to the height at which the R.101 was flying when crossing the Channel. Mr. Leech, who was assisting to get rid of the oil-pressure trouble in the after-engine, mentioned that when going over the Channel he estimated that the R.101 was flying at a height of 700 or 800 feet, and that he came to this conclusion because of the distinctness with which he saw the white caps of the waves, and from previous flying experience over the sea. Mr. Cook, who was an engineer in charge of the port mid-ship engine, testified that when the R.101 was flying over the Channel he looked out of his engine-car several times, and could distinctly see the waves of the sea being lashed up. He considered that the R.101 was extremely low over the water, and he noticed that she several times got lower and then climbed again. Mr. Disley, the electrician, had occasion to go and speak to the wireless operator in the wireless cabin adjoining the control room, where he remained for about ten minutes. This happened at about 10 p.m., and while he was in the wireless cabin he heard a conversation between Lieut.-Commander Atherstone, the first officer, and the Height-Coxswain who was at the elevator wheel. Lieut.-Commander Atherstone took over the elevator wheel from the Height-Coxswain, the altimeter at that moment reading 900 feet, and himself pulled the ship up to 1,000 feet. On handing back the wheel to the coxswain he remarked "Do not let her go below 1,000 feet." Mr. Disley then left the wireless cabin. He explained that at this time Squadron

Leader Johnston was dropping calcium flares into the sea for the purpose of ascertaining the drift of the ship. It may be, therefore, that the vessel had been allowed to come down to about 1,000 feet in order to permit of the drift of the R.101 being thus ascertained without intervening cloud. Squadron Leader Booth, when asked for his observations with regard to the incident of Lieut.-Commander Atherstone taking over the elevator wheel, said that he thought it tended to show that the Height-Coxswain was perhaps rather careless in maintaining the flying height of 1,000 feet over the Channel, and that he might have let the ship sink below that height several times until at last Lieut.-Commander Atherstone took the wheel himself (as he was a very experienced man on the elevators from his previous training), just to show the Height-Coxswain how he wanted the ship flown. He did not think that Lieut.-Commander Atherstone would have taken the wheel from the man and operated it himself until he became strongly impressed with the importance of bringing the ship up to 1,000 feet.

11 p.m. to 2 a.m. Watch.

83. At 11 p.m. the watch on the R.101 was changed, and men who came on duty at this hour remained on watch until 2 o'clock next morning. It is clearly established that the disaster occurred between 2.5 and 2.10 a.m., and it is therefore of extreme importance to ascertain whether anything occurred during the preceding watch of three hours which indicated impending trouble or put the Officers of the ship specially on their guard. Nothing whatever in the evidence or documents which were before the Court lends any support to such a conclusion. On the contrary, there are the strongest reasons for believing that nothing abnormal occurred until after the watch was changed at 2 a.m., or, at all events, that any earlier incident was of a sort which would escape observation.

A wireless message was received at Cardington from the R.101 at 0018 a.m., giving the ship's midnight position. The message was as follows :—

To Cardington from R.101.

"2400 GMT. 15 miles S.W. of Abbeville. Average speed 33 knots. Wind 243 degrees (*i.e.*, W.S.W.), 35 miles per hour. Altimeter height 1,500 feet. Air temperature 51° Fahrenheit. Weather—intermittent rain. Cloud nimbus at 500 feet.

"After an excellent supper our distinguished passengers smoked a final cigar. and having sighted the French coast have now gone to bed to rest after the excitement of their leave-taking. All essential services are functioning satisfactorily. The crew have settled down to watch-keeping routine."

This was the latest message as to the position of the ship and the course of her voyage sent by the R.101 to Cardington. But the ship continued at intervals to send out calls for the purpose of checking her position by Directional Wireless, or for testing the strength of her signals. Her last wireless signal addressed to Cardington was sent at 1.28 a.m. As regards Directional Wireless, she had made use of the Croydon Station while crossing the Channel, and after reaching France got corresponding help from the station at Le Bourget, just north of Paris. Not only so, but at a quarter-to-two her signals enabled a cross-bearing to be worked out by lines of intersection from Valenciennes (80 miles to the North-east), and Le Bourget (40 miles to the South). The resulting position†—one kilometre north of the landing-ground at Beauvais—was sent to the ship by Le Bourget at 1.51 a.m., and its receipt was acknowledged by the R.101 at 1.52 a.m. This is the last message or signal of any kind that the ship ever sent off.

84. While the Captain of the R.101 would not be likely to use his wireless communication to report unimportant or temporary difficulties (no report was made of the trouble with the after engine) it seems impossible to suppose that any serious mishap could have occurred until after the watch was changed at 2 a.m., and this inference is greatly strengthened by the fact that the watch *was* changed in the ordinary course. For if the Captain had been conscious at that moment of any serious trouble he would have certainly not allowed the men who were going off duty to turn in, but would have ordered them to stand by. The evidence of the survivors, and in particular of the surviving engineers, is conclusive on this point, for had any such order been given the men going on duty would have heard of it.

Two other pieces of evidence relating to the period before 2 a.m. remain to be recounted. Mr. Leech told the Court that about 1 a.m. Flight Lieutenant Irwin came into the smoke-room and spoke to him and the Chief Engineer, Mr. Gent. The Captain made no remark about the behaviour of the ship except that the after-engine was continuing to run satisfactorily, and when the Captain left the smoke-room Mr. Gent turned in and Mr. Leech again went round all the engine-cars. He found that all engines were running well and came back to the smoke-room where he was sitting alone when the disaster occurred. His evidence as to the movement of the ship in the last few minutes, which will be recounted in the following paragraphs, is of the greatest importance.

The other piece of evidence which falls within the period before 2 a.m. is the observation of M. Maillet at the Poix aerodrome. Poix is half-way between Abbeville and Beauvais, and the R.101

† There is reason to think that this position was only approximate, for the signals did not enable a " definite cut " to be obtained. The probability is that the R.101 was several kilometres more to the North at 1.45. But the significance of the fact that she was in full wireless communication remains.

passed this point at about one o'clock. M. Maillet told the Court that the airship passed to the West of the aerodrome; he saw white lights in a line, but it was too dark or cloudy to see the outline of her shape. This witness gave an estimate of her distance from the aerodrome and of her height in the sky, but, since it was too far off for him to see her red side-light, and since so enormous an object might well appear to be nearer than she really was, it would be dangerous to rely on this. Mr. Maillet said that he had an impression that she was struggling very hard against the wind.

The last incidents of the Flight.

85. The ship reached Beauvais at about 2 a.m. and passed somewhat to the East of the town. A number of Beauvais citizens gave evidence at the Inquiry and recounted what they observed. In most cases they had been woken out of their sleep by the noise from the approaching engines and went out-of-doors to see the sight. Estimates of the height of the vessel in the air, made in such circumstances, are necessarily unreliable, but there is no doubt that it was the impression of these witnesses that the R.101 was labouring heavily in very gusty weather. There was a storm of rain and wind at the time. A curious feature of the testimony of more than one of the Beauvais witnesses is that the row of lights along the side of the ship became temporarily obscured; no amount of rolling would explain this and it seems probable that the explanation is to be found in an intervening cloud.

86. For the events which happened on the R.101 after 2 a.m. the Court has to rely on the evidence of six witnesses who survived —four of them engineers responsible for working the after-engine (Binks and Bell), the starboard midship engine (Savory), and the port midship engine (Cook). One of the remaining witnesses was the electrician (Disley), and the other a foreman engineer on the staff at Cardington (Leech). There is also a significant statement on one point taken from a rigger named Church before he died from his injuries.

These witnesses give a remarkably clear and consistent account of what occurred. Before summarising the evidence of each of them more in detail, it is desirable to state the general effect of their testimony, which the Court unhesitatingly accepts.

At a few minutes after two the vessel got into a long and rather steep dive—sufficiently steep to throw the engineers attending to the engines off their balance, and to cause furniture in the smoke-room to slide down to the forward bulkhead. This first dive may have lasted for half-a-minute, and would bring the ship many hundreds of feet nearer the earth. At length the ship was brought out of this first dive (doubtless by the height-coxswain putting his elevator hard up), and she returned for a very short time to an approximately even keel. But this was immediately followed by a second dive of shorter duration which brought her, nose first, to the ground, when she immediately burst into flames. It is clearly established that, before she crashed, orders were given from the control car by engine-room telegraph to reduce the speed of the engines, if not to stop them. Orders to this effect would take some seconds to transmit, since each engine car has a separate telegraph, but the significant thing is that the bells were heard ringing and, (in at any rate one case), the orders were received and acted upon before the vessel passed into her second dive. At about the same time that the bells were heard ringing, Chief Coxswain Hunt passed aft from the control car to the quarters where Mr. Disley the electrician, and the crew, were sleeping, and warned them, saying " We're down, lads." The inference, therefore, that those responsible at that moment for navigating the vessel realised that she was bound to come to earth, and were making preparations for it, is overwhelming. The blow with which the nose of the ship struck the ground seems to have been less severe than might have been expected. One witness described it as a " crunch." After first striking the earth, the wrecked ship moved forward about another 60 feet before finally coming to rest.

Evidence of Survivors.

87. It is now necessary to set out the most material portions of this evidence in more detail.

Dealing first with the after-engine car, Binks was due to relieve Bell at 2 o'clock. He proceeded from the crew's quarters along the keel, passing through Frames 8, 8a, 9, and 10, into Frame 11—approximately 140 or 150 feet. (If, therefore, the ship had already taken up a steep angle, he must have observed it.) He descended into his engine-car, and the time, according to him, was then 3 minutes past 2 o'clock. (Bell thinks it was 2.5.) At any rate, Bell, who was waiting to be relieved, drew his attention to the fact that he was late: it was owing to this circumstance that Bell's life was saved. Bell was still standing in the position where the engineer on duty has control. Just after Binks arrived, the ship put her nose down and started the first dive which would be " not much more than possibly 30 seconds." (Binks and Bell agree as to this.) She then returned to a more even keel for a few seconds (" not more than 10 " according to Binks; " not more than 5 " according to Bell), and then got into another dive, the length of which Binks estimates at 10 seconds, and Bell at 20. Just as the ship was passing into her second dive the telegraph rang to " slow." Bell immediately obeyed the order, and it had been carried out before the car hit the ground. The crash was followed immediately by explosion and fire, but Binks stated that his car did not strike the ground heavily, but bumped along the ground so that the bottom caved in.

As regards the port midship engine, Cook relieved Blake at 2 o'clock. Blake, on handing over, reported that everything was all right. About 5 minutes after Cook entered the car, and after Blake had left it, the ship took up a " slight diving attitude." He could not estimate the length of that dive because, as the ship took up a diving attitude, his engine telegraph rang for the engine speed to be reduced to " slow." He carried out that order, and as he did so the ship took a steep diving attitude. The second dive, in his opinion, was quite considerably steeper than the first. After he had slowed his engine, he looked out of the doorway of the engine car, as he inferred that something serious was happening by reason that he had received an order for " slow " after his engines had been running at cruising speed for such a long period. As he looked out, the main body of the ship struck the ground. He succeeded in stopping his engines and a second crash came, followed by an explosion. Between the first and second striking of the ground was a matter of seconds, and he thought that an explosion took place simultaneously with the second bump.

Savory, who was in the starboard midship car, states that he took over this engine from his mate Hastings at 2 o'clock. He does not seem to have observed the first dive followed by a straightening out, and he speaks only of the final plunge. He says that the ship gave a dip which was just sharp enough to throw him against the starting engine. He was standing with his back to the starting engine looking aft. After that, all he recollects is, that he heard " rumbling and crashing and things breaking," but he does not know whether that was due to his car hitting the ground. His engines were still running at cruising speed, for he had noticed no signal on his engine telegraph. It should be appreciated that the noise in the engine car is so great as to drown the sound of the telegraph bell : any change of orders on the indicator must be observed with the eye. Savory also stated that he heard no explosion at all. The only thing he seems to have remembered was that a vivid flash entered the open door of his engine car, which scorched his face, and practically blinded and dazed him.

Disley, the electrician, was asleep in his bunk near the switchboard, which was in his charge. He was lying with his head in the direction in which the ship was proceeding, and was actually awakened by the first of the two dives. While still in his bunk he felt the ship starting to come out of this dive, and his own impression was that she not only got for a short time on an even keel, but actually became nose up. At that moment the Chief Coxswain, Mr. G. W. Hunt, came to where he was lying and passed on in the direction of the crew's space, saying " We're down, lads." The moment after Hunt had passed, a number of things happened at once. He heard the telegraph bells ringing, and the ship took up a final dive. The switchboard was close to his left hand ; he started to get out of his bunk and to cut off the electric current. There were two field switches ; he remembers " tripping " one of them. He did this because he knew that in any aircraft crash there might be a chance of fire. But, unfortunately, the pulling out of one switch would not cut off all the current of the ship, as there were two generators running and he had no time to "trip" the second field switch. Disley stated that when the ship hit the ground the lights went out. This seems to show that down to that moment the circuit in the forepart of the ship was still unbroken—a very probable cause of fire when the crash came. The impact, he believes, was not sufficiently severe to throw him down. As, however, he and the other survivors a moment later were all struggling for their lives out of a burning mass of wreckage, and all sustained injuries as well as having to pass through a horrible experience, recollection of such details must be uncertain.

88. Leech was alone in the smoke-room, which was in the interior of the vessel, amidships. The ship, he says, took up a steep angle, the effect of which was to upset a siphon and some glasses which were on a table, and throw them on to the floor. The motion caused him to slide along a settee up to and against the forward bulkhead. He at first estimated that this dive lasted for 45 seconds, but on reconsideration thought it might be only 15 or 20 seconds before the ship began to straighten out again. He then picked up the siphon and glasses from the floor and replaced them on the table, which had also slid down against the bulkhead. Just after doing this, he felt the nose of the ship go down again, and he heard the engine-room telegraphs ring. He himself thought that the angle of the second dive was slightly less that that of the first. A few seconds later, the vessel struck the ground. There was no very violent jar; the striking was more of a "crunch." At the moment of impact the lights in the smoke-room went out, and within a second there was a flash of flame. The effect of the impact was that the ceiling of the room shut down on the top of the settee, and this prevented him from rising more than 4 feet. He ultimately got out of the room and escaped into the open by tearing away the partition with his hands.

Finally, there is the statement of a rigger named Church, who died three days after the crash. The condition of this man when his statement was taken was such that it was very difficult to obtain any information from him. He was probably the rigger on watch in the forward part of the ship, and his account ran as follows :—"I would consider the flight rather bumpy, but not exceptionally so. The second watch had just come on and I was walking back when the ship took up a steep diving attitude. At this moment I received an order to release an emergency forward water ballast (½ ton) but before I could get to it the crash came." The water ballast referred to was in the nose of the ship. Unlike most of the emergency ballast, it could not be released from the control car, but had to be jettisoned locally.

The Origin of the Fire.

89. The only direct evidence as to the part of the ship in which the fire started is the statement of Rabouille, the rabbit-catcher, who was approximately 250 metres away from where the ship

fell. He heard three explosions, and at that moment the ship lit up, the flames seeming to come from the fore part of the vessel. This conclusion is indirectly confirmed by several considerations. No one (except Church) escaped alive who was in the fore part of the vessel. The indications on the ground show that the ship must have struck with the underside of her bow: the marks on the earth indicate that the propellor of the starboard forward engine was still revolving and this engine car was twisted completely round by the impact. A careful diagram was prepared and put before the Court based on the marks on the ground and the condition of the wreckage which established that the angle of final descent was between 15 and 25 degrees.

Though the R.101 had been specially fitted with heavy-oil engines in order to reduce the risk of fire, she was carrying petrol for use with her starting engines in four of the engine cars. In the event of a crash this was an undoubted source of danger. But if a spark caused by the broken electric circuit reached a mixture of hydrogen-gas and air it would instantly set the mixture on fire, though the force of the immediate explosion would vary with the proportions of the mixture. This seems, therefore, to be the most probable cause of the fire. It started immediately the ship came to rest on the ground and spread with immense rapidity. The flames must have swept almost instantaneously along her length. They died down, however, before completely consuming the after end, and fabric still remained on the underside of the port elevator. This last fact is of very great importance in determining the final manœuvres of the vessel.

Condition of the Ship after the Crash.

90. The R.101 came to rest with her forepart in a wood of small trees and her afterpart in a meadow. It is not to be expected that those who escaped from this burning mass of wreckage could make close examination of the condition of the ship at the time, but after getting away Disley and Cook did notice two facts of importance. Disley remembered that though the cover was burning on some parts of the ship, there appeared to be no cover left on top of the ship at all; it seemed to be a skeleton aft of frame 10 and 11. Cook, who had escaped from the port midship-engine car, on getting away from it, walked a few yards through the wood and looked back toward the tail of the ship. The only part of the ship on which he saw any fabric left was on the under-side of the elevator, which was upright. He saw the position of the elevator quite clearly in the light of the flames. The height-coxswain, therefore, had put up the elevator in an effort to raise the nose of the ship. The number of turns of wire on the drum of the elevator wheel in the control car, and on the auxiliary drum, definitely confirms this conclusion.

Immediately after the disaster, a Committee of Investigation, of which Air Commodore Holt was Chairman, went over to France to hold an Inquiry. The Committee consisted of Major J. C. P. Cooper (Inspector of Accidents); Professor Bairstow; Squadron

Leader Booth ; Messrs. T. S. D. Collins, A. E. Gerrish and E. F. Randle (Technical Staff Royal Airship Works) ; Mr. F. M. McWade (Inspector of the Aeronautical Inspection Department) ; and Messieurs P. Jougland and H. Bournat (French Aviation Department). The Committee finished their investigations on October 10th, and later made a report. In the course of their Report and when dealing with the controls the Committee stated :—

> " In the final closed-circuit of cable operating the elevators a fracture had occurred on the side which would be pulled to raise the elevators, and this fracture was close to one spliced end of the short length of cable inside the tensioning spring. The spring itself was extended to several times its normal length but was not broken. This cable was jammed under the pulley wheel on the horizontal girder but this was obviously due to recoil following fracture of the cable.
>
> On the evidence available we have been unable to arrive at a definite conclusion as to the cause of the fracture of this particular cable, and we consider that the broken pieces which, together with the principal parts of the auxiliary control mechanism have been preserved, should be the subject of laboratory examination."

91. Major Cooper had all the parts of this control gear brought back to the Royal Aircraft Establishment at Farnborough, and kept in close touch with the laboratory examination which was subsequently carried out there. In his opinion the further examination established beyond doubt that the control cable broke after, and not before, it became heated.

The Court had further tests of this cable made at the Engineering Laboratory at Cambridge. The two broken ends each had been exposed to intense heat for a distance of about half an inch, and the presumption that this heat had been applied before the cable parted was therefore strong. Mr. W. E. Woodward, who conducted the further experiments, came to the conclusion that the cable certainly did not break before the conflagration. The Court unhesitatingly accepts this conclusion. The break could not have been the cause of the accident as it only happened either during or after the fire.

The Committee of Investigation formulated the following conclusions based on the evidence afforded by the wreckage :—

(*a*) That no part of the main structure of the airship broke in the air.

(*b*) That impact with the ground occurred when the airship was inclined nose-downwards at an angle of between 15 and 25 degrees from the horizontal.

(*c*) That the elevator control wheel was set for full " Up elevator," while the rudder was practically straight at the time of the crash.

(*d*) That a violent explosion occurred immediately or very shortly after the ship struck.

The possible causes of the accident are dealt with in the following section of the Report.

PART VI.—DISCUSSION OF CAUSE OF DISASTER.

92. In discussing the cause of the accident, one starts with a series of definitely ascertained facts. It is then possible to exclude, by a process of reasoning which appears conclusive, certain suggested explanations which need to be examined before they can be rejected. In the result, the analysis indicates, with some degree of confidence, the general nature of the true cause, though precise detail can never be attained, since no one who was in the control-car has survived.

The established facts.

93. The following facts may be regarded as definitely established :—

(*a*) When the watch was changed at 2 a.m., there was no cause for immediate alarm known to those in charge of the navigation of the ship. The vessel must have been at least 1,000 feet above the ground. The ground itself at this point is two to three hundred feet above sea level.

(*b*) At 2 a.m. the elevator wheel would be handed over to another height-coxswain. (The difficulty of the new hand at once getting the "feel" of the ship is dealt with below, para. 97.)

(*c*) The weather was exceedingly bad. A strong wind was blowing from the S.W.; at that elevation its velocity might attain to 40 or 50 miles per hour. Moreover, the wind was not steady but was blowing in fierce gusts which would cause the nose of the vessel to move through a considerable angle above and below her horizontal line of flight. The height-coxswain would seek to limit or counteract this movement by use of the elevator.

(*d*) The ship in her trials had lost gas at an abnormal rate (*see* paras. 47 to 50 above), certainly by the wearing of holes in the gasbags, and perhaps through her valves when she rolled.

(*e*) On the Indian journey she had rolled more than ever before (*see* para. 80), and had failed to keep height as the officer of the watch intended at an earlier period (*see* para. 82).

(*f*) If she was becoming increasingly heavy, this could be counteracted by suitable use of the elevator, but in very bumpy weather it would be more difficult to detect the rate and extent of the change.

(*g*) All her engines had been running satisfactorily at cruising speed for a considerable time right down to 2 a.m. This ought to give a speed through the air of a little over 50 knots. The course of the vessel was not directly in the teeth of the wind, and her speed over the ground might be expected to be 15 to 20 miles per hour.

(*h*) In these circumstances, at about five minutes past two, her nose dropped and she continued in this position for about 30 seconds, descending rapidly during that period of time. Her pitch downwards was sufficiently severe to wake up a man who was asleep in his bunk (para. 87), and to cause things to slide to the lower end of the smoke-room (para. 88).

(*i*) The height-coxswain, by putting his elevator up, succeeded at length in bringing the ship again to about an even keel, but she remained in this position only for a few seconds.

(*j*) At about the time when it appeared that she was not further responding to up-elevator so as to recover height, the officer of the watch gave orders through the engine-room telegraph to reduce speed.

(*k*) About this moment the vessel got into a second steep dive, which lasted for only a few seconds before she struck the earth. The impact was not severe.

(*l*) The slowing down of the engines combined with the warning given by Chief Cowswain Hunt to Disley and the crew, is only consistent with the view having been taken that the vessel could not recover.

(*m*) Apart from reducing speed, the only other action that could be instantly taken to lighten the impact would be to drop such ballast as could be released from the control car. Releasing ballast in the nose of the ship which could not be automatically controlled was a further and slower operation, and yet orders were given to Church to do this.

(*n*) The fire did not break out till after the ship struck the ground.

Accident not due to structural weakness.

94. First among the explanations of the accident which may be definitely rejected is any idea that the vessel, from internal weakness, broke up in the air. This had happened with some previous airships—with the "Shenandoah" for example, and the R.38 (*see* para. 3). But in the present instance such an explanation is entirely inadmissible. The elaborate care with which the ship had been designed and constructed is set out in Part II of this Report. All the evidence of her behaviour at the critical moment goes to show that she came down intact. Rabouille, who watched her fall, was quite clear that she did not break up at all before she struck the ground. The preliminary Committee of Investigation came to the same conclusion (*see* para. 91). When the remains of the ship lying on the ground were examined, it was found that in spite of the blow she had received she had only crumpled up to a small extent, with a reduction in total length of 88 feet. This was chiefly due to the buckling of the base members of the triangular transverse frames which

encircled the vessel. The conclusion, therefore, is that the R.101, so far as her metal structure was concerned, was abundantly strong, and that her designers had provided adequately for withstanding the aerodynamic forces which she might encounter in flight.

No failure of control gear.

95. Next, the explanation may be set aside that there was any failure in the control gear. If the break in the wire controlling the elevators had occurred in mid air, very serious results might have followed therefrom. But this is quite inconsistent with the position in which the elevator was found after the crash, and (as already stated in para. 91 above), it is conclusively established that the break in this control wire occurred in the course of, or in consequence of, the subsequent fire, and not, therefore, before the accident.

Extent to which weather conditions were a contributory cause.

96. Next, the weather conditions have to be considered as a possible explanation of what occurred.

It will be seen from examining the detailed forecasts set out in Appendix V that the R.101 started from Cardington after receiving weather reports that she might expect to meet at 2,000 feet wind of the speed of 20 to 30 miles per hour in Northern France, and the period in respect of which this forecast was made ran from 5 p.m. on October 4th, to 5 a.m. on October 5th. These forecasts seriously underestimated the wind she actually met with, and indeed after she had started she received a further forecast from the Meteorological Office at Cardington indicating that at 2,000 feet she might expect to meet in Northern France wind of 40 to 50 miles per hour. Consequently the wind conditions she actually had to face were much more severe than had been anticipated when she started.

Squadron Leader Booth expressed the view to the Court that at the time of the accident "the weather, from an airship point of view, over land was extraordinarily bad, or extremely bad." "During the war," he added, "and since the war, ships have flown in worse weather as regards the strength of the wind, but on practically every occasion it has been bad weather over the sea, where you do not get turbulent effects or violent gustiness such as may be experienced over land." This view may be accepted, and it amounts to saying that the weather conditions constituted a predisposing cause in the presence of which it would be much more difficult to surmount a sudden crisis otherwise occasioned. But the evidence as a whole does not justify the conclusion that the accident was simply due to the weather. (If it were otherwise, such a conclusion would be extremely damaging to any argument in favour of airship travel, for, bad though the weather was, it was not worse than must occasionally be experienced in the course of a long journey.) Dr. G. C. Simpson gave to the Court an elaborate and most instructive account of the circumstances in which very sudden and severe vertical currents are sometimes met with in the air. But the result of his evidence was to establish that the meteorological conditions in the neighbourhood of Beauvais at the time were not such as to permit of vertical currents of very high velocity being present. The wind was blowing with pronounced gusts, and this would aggravate a characteristic of the ship which had been noted on some of her trial flights, viz., her tendency when on a horizontal path alternately to drop and raise her nose through a considerable angle. The height-coxswain, of course, would attempt to control this variation in pitch by the use of the elevator. Squadron Leader Booth, dealing with this sort of movement, told the Court "Normally you should keep within 250 to 300 feet on either side of your flying height; that is under normal bumpy conditions. That might be extended possibly to 400 or 500 feet under bad conditions. I think that is an absolute maximum." Dr. Eckener, the distinguished President of the Zeppelin Company, who was good enough to come over to this country to assist the Court with his views, said that under gusty conditions he had experienced an angle of pitch up to 18° or 19°.

On this part of the case, therefore, the Court reaches the conclusion that the accident could not be explained solely by reference to abnormal weather conditions. Some other cause, combined with these admittedly bad conditions of weather, must be sought. The right view seems to be that the weather was a predisposing cause in the sense that if the weather conditions had been good the ship would have had a much better chance of escaping disaster. In particular, it must not be assumed that the path of the gusts moving over undulating country, with the Beauvais ridge only five miles away to the south, would be uniformly horizontal.

Competence of officers and crew.

97. Next, it is necessary to review the probabilities of an error in navigation causing the accident. One of the consequences of the R.101 starting for India without first having gone through a more complete set of trials is, as Squadron Leader Booth pointed out, that the officers and crew had had less training in flying the ship than might have been desirable. Moreover, the opportunity of practical experience in other airships was necessarily limited. Yet Major Scott had probably had more practical experience than anyone in the service. Wing Commander Colmore, Squadron Leader Johnston and Flying Officer Steff had all, like Scott, flown with the R.100 to Canada and back. During the war, Flight Lieutenant Irwin had been Captain of all types of non-rigid airships. In 1921 he was given command of the R.36; in 1924 he was selected to be Captain of the R.33. Squadron Leader Booth,

who had served under him as First Officer, expressed to the Court the highest opinion of his capacity, saying that he was exceptionally good in handling a ship in the air and was distinguished by thoroughness and carefulness in the carrying out of his work. The other officers also had records of much distinction and the Court would entirely reject, as an explanation of the disaster, any failure in skill on the part of any of them. It seems clear that the vessel passed in a few moments from a condition which appeared to be safe into a condition of extreme insecurity, but there is no reason to doubt that the officers in charge dealt with the crisis to the best of their ability.

The actual movements of the elevator would be under the control of one or other of the height-coxswains. Three (in addition to Chief Coxswain Hunt) were carried on the Indian voyage and it is impossible to determine which of them took over the wheel at 2 a.m. Nor is it material to enquire. They were all trained men and the coxswain on duty would be under the immediate observation and control of the officer of the watch. There is, therefore, equally little ground for suspecting any deficiency on the coxswain's part.

Evidence was given to the Court that at a change of watch, when the new hand comes on duty, it is difficult, especially in bumpy weather, for him at once to get the " feel " of the ship. Dr. Eckener stated that it was his own experience when in a Zeppelin that after a change of watch the coxswain had to " feel his way " into the prevailing flying condition of the ship and that until he did so, increased motion was noticeable. He took the view that if the vessel, shortly after a new coxswain had taken over, was exposed to a strong gust above her nose at a time when she happened to be pitched downwards it would be very difficult for the man to judge the extent of the elevator action which would be needed to counteract the dive.

The conclusion, therefore, is that there is no reason to attribute the accident to any failure in the competence of officers or crew, but that in view of the recent change of watch and of the prevailing weather it may well have been impossible to bring the ship rapidly back to a horizontal position if her nose was forced down in the way suggested.

Longitudinal movement of gasbags.

98. A suggestion put forward from various quarters to the effect that the R.101 might develop instability owing to longitudinal movements of the gasbags has received most careful attention.

Owing to the fact that the novel gasbag wiring of the R.101 provided bulkheads of a " slack " variety, longitudinal surging of the gasbags to a limited extent is a possibility.

It would appear, however, from drawings and information supplied from Cardington, that, under extreme conditions, the longitudinal movement of the centre of gravity of a gasbag could hardly exceed 3 feet, and even if a considerable number of the gasbags were sufficiently deflated to enable them to participate in this movement, the reduction in fore-and-aft stability would be relatively insignificant. The depth of the centre of gravity of the ship below its centre of buoyancy was 29 feet, and the pendulum action consequent on this depth would limit the range of instability to 3 or 4 degrees on either side of the horizontal, even in the case where the ship was merely ballooning with engines stopped.

Officers who had flown in both the R.100 and the R.101 formed the opinion that the latter ship was comparatively sluggish in answering to her elevator controls, and this may quite possibly be due to a certain measure of instability occasioned by longitudinal gasbag movement. This movement, however, is so limited in extent that by itself it is quite insufficient to account for a serious loss of control, even in the tempestuous conditions which prevailed at the time of the accident.

Hypothesis of loss of gas.

99. The experts (both theoretical and practical), who gave evidence to the Court believe that the explanation of the disaster must be associated with a substantial loss of gas. In this connection certain subsidiary questions arise : (1) was the loss of gas general throughout the length of the ship, or was it chiefly concentrated in the fore part ? (2) was the loss of gas a gradual process in consequence of which the ship became steadily heavier, or is it to be explained by a sudden catastrophe which would empty the contents of one or more of the forward gasbags immediately before the final dive : or again (3) is the explanation a gradual loss of gas spread over a considerable interval, culminating in a further and catastrophic loss ?

On the subject of the possibility of a gradual loss of gas, extremely important evidence was given to the Court by Professor Bairstow. (*See Appendix VI.*) In the interval which occurred between the two periods when the Court sat, he worked out calculations which he subsequently explained to show that if the ship steadily lost gas, her increasing heaviness would nevertheless not call for more than a very slight adjustment of the elevator until she approached a critical condition. As she put her nose further up to counteract this increasing heaviness, her speed forward through the air would drop owing to increased "drag." A critical condition, beyond which steady flight ceases to be possible, would be reached if she ever became 13½ tons generally heavy, and earlier if the heaviness was due to deflation in the forward part of the ship. Yet Professor Bairstow's calculations went to show that a very considerable loss of gas might take place before any large movement of the elevator would be required, and that in certain circumstances the loss of the last 2 or 3 tons of dynamic lift would produce an exceedingly rapid change in the available pitching moment.

The importance of this evidence is of course that it suggests the possibility of some such gradual deterioration having gone on through the wearing of holes in the gasbags or through gas escaping through the valves when the ship was rolling, without the full extent of the loss being promptly appreciated in the control car. On the other hand, the practical experts were disposed to think that, in any event, there was superimposed upon any slow change of condition such as these calculations seem to make possible, a more definite and sudden further loss of gas from a forward gasbag or gasbags within a very short time of the disaster.

The chief difficulty in the way of supposing a prolonged and substantial leakage of gas is that such a condition of affairs would make itself known to the officer of the watch by the increasing angle of pitch needed to regain height. If serious leakage were suspected, one would expect that men going off duty would be told to stand by. The fact that no survivor knows anything of the men whose watch was ended being kept on duty militates against the hypothesis of prolonged leakage, at any rate if it were so pronounced as to be observed.

Dr. Eckener's conclusions.

100. After Professor Bairstow had explained the result of his calculations, Dr. Eckener gave evidence. His view was to the following effect:—

> "The extremely interesting and clear statements given yesterday by Professor Bairstow based on the experiments made in the wind tunnel clearly show that by assuming certain losses of gas it would be impossible to prevent an airship of the R.101 type from stranding in a trimmed and loaded condition, as was the case with the R.101 immediately prior to stranding (unless there be, for instance, sufficient time to retrim the ballast). Professor Bairstow, in my opinion, has dealt in a most convincing manner with all factors determining the pitching moment. I particularly agree with him that the elevator is rendered ineffective when the ship comes into certain out-of-horizontal positions, and also that a heaviness of 13 to 15 tons is the maximum which can be carried dynamically."

Dr. Eckener then went on to contrast the pitching moment of the Graf Zeppelin with that worked out for the R.101 by Professor Bairstow, pointing out that the larger figure in the latter case was due to the greater effectiveness of the elevator. He then proceeded to discuss what must have been the course of events to produce the disaster and said:—

> "In forming my opinion I commence with the fact that the ship made a sudden very steep dive, and that in spite of the probable dropping of ballast she could no longer be

kept on a level keel, although she had been able up to that moment to hold her altitude. It lies very near at hand to connect the sudden occurrence of head-heaviness with the particularly steep dive, because the steep dive itself can hardly be explained by the sudden loss of gas, because the effect of a rent in one of the fore gasbags would not show itself so suddenly. The whole happening no doubt was as follows : At 2 o'clock the new watch came on to take over control of the elevator. He (the coxswain) would have to feel his way into the condition of the ship. This is an old experience. The weather was bumpy and the ship probably not only heavy, three to four tons, but a little heavy by the nose owing to the loss of gas in one of the forward gasbags—in the same gasbag which later sustained a large rent. It is very difficult at once to feel the head-heaviness of a ship, when the ship is heavy as a whole and at the same time head-heavy. It may now have happened that in a slight gust of wind the ship made a movement downward which the new coxswain of the elevator did not immediately and correctly counteract, because he could not be quite clear about the condition of the ship. The movement became steep because the ship now received a current of air from above on her nose, thus accentuating the effect of the head-heaviness. The gas between the gasbags and the outer cover escaped to the tail of the ship, thus increasing the pitching moment still further. Owing to this unusual violent movement of the ship the already damaged gasbag sustained a larger rent from which the gas now quickly escaped. Thus it took some time (perhaps fully 30 seconds) to bring the ship back on a level keel. This would be done by putting up the elevator and by dropping fuel ; otherwise it would not have been possible, in my opinion. This oil would fall under the ship, owing to the fact that the vessel, owing to her reduced speed in the strong wind, was making very slight way over the ground, which I estimate as 4 to 5 miles per hour. The ship having righted, through the throwing out of ballast, was unable to maintain her horizontal position, by reason of the fact that the gas continued to escape quickly and because the ship had no longer the pitching moment upwards. The people in the control-car would know that they were going down, and they therefore stopped the engines, and thus, with the second dive, the stranding occurred."

Squadron Leader Booth agrees.

101. Before Dr. Eckener had given evidence, Squadron Leader Booth had given a written statement of his opinion as to the cause of the accident. He agreed generally with Dr. Eckener's view.

He considered that the ship was flying more or less normally at 1,500 feet just prior to the accident. At any rate, at 2 a.m. he thought that everything on the ship must have been normal because, otherwise, the watch would not have been changed. His view was that the ship might have been 4 tons heavy at that time. He arrived at this figure by taking into consideration the expenditure of fuel, the amount of gas expended, and the rain that had been encountered. Before he heard Dr. Eckener's evidence he thought that some accident had happened to the ship when flying at 1,500 feet, but having heard that evidence he was inclined to think that Dr. Eckener's suggestion that the steep dive which the ship took after 2 a.m., when the watch was changed, may itself have led to damage to a gasbag. Those on the ship, by using full elevator, would pull the ship out of the dive, but if gas continued to escape and the ship continued to get heavy forward, she might have got into a second dive in spite of the fact that ballast had during these incidents been dropped. After that, the officer in charge in the control-car would slow his engines to reduce the force of the impact. Squadron Leader Booth thought that in an emergency of this kind it would take the officer of the watch some seconds to realise what was happening. He had been in the ship flying over France for three hours, during which time undoubtedly the ship had been pitching up and down 5, 6, and possibly 10 degrees, so that during the first 10 degrees of the dive he may have considered that it was merely a normal dive occasioned by the weather conditions. Until the officer realised that he had to take action, the ship would be getting into a more unmanageable position, and thus time would be wasted. He did not think that it could be assumed that the moment the ship started putting her nose down in the first dive, action would be taken to correct it. Speaking of the position of a man in the control-car he said that, normally speaking, when coming out of a steep dive in which considerable height had been lost, the ship would be pulled out of the dive by the use of a large angle of elevator, and that angle of elevator would be kept on so that the ship would get an equally steep climb in order to regain height. The height-coxswain would see from his instruments that he was a long way below his correct height, and would pull the ship up sharply and keep her at that angle in order to return to, and possibly to exceed, his flying height. If the height-coxswain then saw, in spite of his excessive use of the elevator, that the ship appeared to be coming only slowly out of the dive and did not appear to be continuing her upward path, notwithstanding the dropping of ballast, he would immediately know that his position was hopeless, because he had 15 or 20 degrees of up-elevator and yet the ship would not be recovering. All that he could do then would be to report to the officer of the watch, who probably would have noticed the position for himself. If the ballast had gone and the elevator was hard up, and yet the ship was still horizontal, they must have realised that there was nothing more they could do except to send a man forward as a last chance to release the ballast in the nose. After that, if the nose again fell, those in the control-car could only slow down the engines and attempt to decrease the force of the impact. They might possibly turn the head of the ship to the wind if they had time, but he did not think in this particular case that there would be time to do so.

Captain Meager and Squadron Leader Wann also agree.

102. Captain Meager was in agreement with Dr. Eckener's view as to the cause of the accident, but thought that the rent in the gasbag was caused by the first dive. He could think of no way of explaining the course of events spoken of by the witnesses without assuming some substantial loss of gas.

Squadron Leader Wann said that, having examined many theories, the only one that he could really get to fit the facts of the accident was a large gasbag failure forward in the ship, though he could not judge whether the failure took place immediately prior to the dive, or whether it was during the first dive.

Considerations pointing to a definite conclusion.

103. Having examined alternative explanations in detail, and excluded, for the reasons given, all but the theory of a substantial loss of gas, the Court would in any case be led to adopt this last named explanation as the inference to be deduced from rejecting other conceivable causes. But when this conclusion is confirmed by the unanimous opinion of the experts, both British and Foreign, who, after giving close attention to the evidence assisted the Court with their views, the conclusion suggested by the absence of any other explanation is confirmed and ratified by the judgment of practical men, and acquires a positive validity. For reasons which will be developed in the following paragraphs, the Court has reached the conclusion, that whatever the predisposing circumstances may have been, the immediate cause of the disaster was leakage culminating in a substantial loss of gas from one or more of the bags in the fore part of the ship. It will, of course, always be impossible to re-establish every detail, but in the light of the evidence of survivors and experts this general deduction may be regarded as solidly founded.

The definite conclusions at which the Court arrives, and the course of reasoning which leads to their adoption, are set out in paragraph 105 below.

Was there want of manœuvring space?

104. Before explaining the theory of the accident which the Court adopts, it is convenient to mention one more possible, though not probable, alternative which has been considered and rejected. It is clearly established that, whatever may have been the cause of the first long dive, the vessel lost much height before she was brought into a horizontal position. Is it possible

to assume that the reason why she did not rise again was that she had no more room to manœuvre, and that the navigating officer knew or feared that if her nose was forced up too quickly her tail would strike the ground? To prevent this, the elevators would have to be eased off, or even put down. On this assumption, another downward gust hitting her bow at that moment, when her angular velocity had been checked, might have started a second and final dive.

The circumstances which justifies the rejection of this conjecture is the fact that the cable on the drums showed that the elevators were hard up at the instant when the ship struck the ground, and there could hardly have been time to get them into this position a second time if they had been eased off or even put down a few seconds previously. The elevators must have been put hard up before the end of the first dive, and the probability is that they remained in this position to the end. If this state of affairs is accepted as established, the fact that this elevator action did not succeed in bringing the ship's nose up, proves almost conclusively that it was not want of manœuvring space, but a serious loss of buoyancy, which explains the ultimate disaster.

CONCLUSION AS TO CAUSE.

105. The conclusion reached as to the cause of the disaster is as follows:—

The Three Phases.

The clearest way in which to explain the theory of the accident which the Court adopts, is to regard the final movements of the R.101 as consisting of three phases. In the *first phase* she drops her nose and descends, at a noticeably steep angle, for half a minute or thereabouts before, by use of up-elevator, she is brought back to an approximately horizontal position. The *second phase* then begins and continues for a short time during which, in spite of her utmost efforts, she does not succeed in getting her nose appreciably up but continues horizontal until she suddenly passes into a *third phase*, when she dives again and strikes the ground almost at once at an angle of at least 15 degrees.

In seeking the explanation of these successive movements, it is best first to direct attention to the second phase. Notwithstanding that the vessel had lost much height during the first phase, if she had been in a normal condition there seems no reason why she should not have pointed her nose up again and regained altitude. From the fact that she failed to do so, it may be argued most conclusively that she was by then crippled beyond recovery, and the inference is that, though momentarily on an even keel, she was descending rapidly to earth. The action of Chief Coxswain Hunt in leaving the control room to warn the crew indicates that, in spite of his great experience, his assistance there was no longer of any use and that those in charge knew there was nothing they could do which would prevent the ship from stranding. And the explanation of this would be provided if she had lost sufficient gas in the fore part of the ship. All that remained was to minimise the impact, and accordingly orders were given to stop the engines and release ballast. If this was the course of events the ship would proceed to put her nose down again, enter upon her second dive and crash.

Now, working back to the first phase, the question is what was the course of events which brought the ship down from say, 1,200 feet, into this first long dive ? Inasmuch as the reasoning above set out suggests, and, indeed, practically requires, that at the end of the first dive the vessel had lost a quantity of gas forward, it is natural to assume that this loss of gas had begun before the first phase was entered upon, though it became greater as the vessel descended. If the fore part of the cover had become torn and wind entered the envelope, serious damage to gasbags would be most likely to occur with startling suddenness.

The reconstruction of the first phase would therefore be somewhat as follows :—Assume that the vessel had become somewhat heavy and was being buffeted in the wind so that her nose was sometimes above and sometimes below the line of horizontal flight. If she had been raised by a buffet, the elevator would be put down by the coxswain who had just come on duty to check and counteract this movement. The coxswain, not yet having got the " feel " of the ship thoroughly, might put his elevator rather more down than was necessary, or keep it down longer than was exactly right. The vessel's nose would drop. If when her nose is inclined downwards she gets a strong buffet of wind above her nose it will push her nose further down. If she was already heavy from loss of gas—especially if a rent had occurred in a gasbag which involved progressively rapid deflation—the descent is emphasised. The ship is now on her downward track in the first phase. The coxswain will begin to put his elevator up, and in order to get the ship out of her first dive has to put it up harder. None the less, she does not come out of her first dive as rapidly as she should because she is losing more gas all the time. The slowness of her recovery would give significant warning of the crisis.

This gives the explanation of the course of events which is most consistent with the evidence, and at certain points is the only explanation which readily presents itself in accordance with the facts. At other points it is no doubt possible to assume certain variations in the data. For example, the final dive might have been assisted by another buffet of wind, and the exact relation between the angle of the elevator and the amount of gas lost can never be ascertained by any process of reconstruction.

How the vessel began to lose gas can never be definitely ascertained. The weather was exceptionally bad ; the gasbags were hard up against padded projections, some of which may have begun to wear the fabric ; the bumpiness of the wind and the pitching of the ship would intensify the strain ; and earlier flights had indicated the possibility of leakage through chafing, or, if the vessel rolled through an unusually large angle, through intermittent opening of the gas valves. But it seems very probable that the more serious and sudden loss of gas which followed was connected with a specific misfortune such as the ripping of the fore part of the envelope. Something of this sort had happened on a previous occasion (*see* para. 41), and no amount of care could secure that it would never happen again.* If a rip had begun in the fore part of the envelope it would tend to develop into a larger tear which would both check the speed of the R.101 through the air and expose the gasbags to additional strain. This seems the most probable explanation of a further loss of gas in increasing quantity and suddenness. But whatever the precise circumstances may have been, the explanation that the disaster was caused by a substantial loss of gas in very bumpy weather holds the field. This is the unanimous view of all the three members of the Court of Inquiry.

Subsequent calculations by the National Physical Laboratory.

106. After the public sittings of the Court of Inquiry were closed, the National Physical Laboratory was asked to make a series of calculations for the purpose of ascertaining what would be the theoretic movement of the R.101 on various assumptions as to loss of gas, angle of elevator, increasing pressure due to buffets of wind, and so forth. These calculations were assisted by experiments made with a model, some 4 feet long, which precisely reproduced the external form of the R.101, and by measuring the effect upon this model of currents of air of ascertained velocity when the model was put in various positions in a wind-tunnel. The use of models for the working out of theoretical calculations cannot be regarded as taking the place of full-scale experiments or as reproducing in due proportion all the factors in actual operation. Nevertheless, if it could have been said that, on the assumptions which the Court was prepared to make, the track followed by the R.101 immediately before she crashed could not have been such as it in fact was, this would have given ground for mistrusting the conclusions at which the Court was

* In fact a reference in Colonel Richmond's Diary dated 24th September, 1930 (seven days before the R.101 came out of her shed for the last time), shows that defects had occurred in a few places on the outer cover where rubber solution had been used. These defects were analysed and it was discovered that rubber solution when used in conjunction with dope had a tendering or weakening effect on the strength of the cover, so much so that it was possible for a man to punch a hole in the fabric with his finger. All these points of possible weakness were, therefore, strengthened by means of reinforcing strips, and the Aircraft Inspection Department pronounced themselves as satisfied with this remedy.

prepared to arrive. These calculations are of great complexity for they involve, in each case, assumptions on a large number of points, and these assumptions may be varied in many ways. The Court is greatly indebted to the officials of the National Physical Laboratory* for the investigation which they have carried through, and understands that the full results are likely to be published hereafter, as a contribution to aeronautical science, by the Aeronautical Research Committee. If the factors are not suitably chosen, it appears that the R.101 would be more likely to come to the ground tail first, which it is quite certain she did not do. But by varying the assumptions these calculations indicate that she might follow a course through the air in her last moments which closely approximates to what actually occurred.

In Appendix VI to this Report will be found diagrams, worked out by the scientists at the National Physical Laboratory, showing what would be the motion of the R.101 under conditions there assumed. On inspection of one of these diagrams, it will be apparent that the plotted course of the ship most closely agrees with the actual sequence of events. It must be clearly understood that each diagram furnished by the National Physical Laboratory has been worked out in accordance with certain assumptions. The National Physical Laboratory is in no respect responsible for the assumptions made; its diagrams merely represent what, according to theoretical calculations, would be the track of the airship if a given set of assumptions were fulfilled. But the significant thing is that on the assumptions indicated above it is demonstrated by the calculation that the R.101 would, in fact, go through a series of movements which closely approximate to those which are proved actually to have occurred.

The conclusion as to the cause of the accident which is above set out is, therefore, not merely the conclusion recommended to the Court by the body of expert evidence which was presented before it, and the conclusion which by its own course of reasoning the Court is prepared to affirm, but it is a conclusion which is shown by the calculations of the National Physical Laboratory to be consistent with the facts and to correspond to assumptions which may reasonably be made.

107. Before bringing this Report to a close my colleagues and I desire to add certain general observations.

It is clear that if those responsible had been entirely free to choose the time and the weather in which the R.101 should start for the first flight ever undertaken by any airship to India, and if the only considerations governing their choice were considerations of meteorology and of preparation for the voyage, the R.101 would not have started when she did. She was undertaking a novel task in weather conditons worse than any to which she

* Dr. R. Jones, Mr. D. H. Williams, Mr. A. R. Collar, and Mr. A. H. Bell were specially associated with these calculations.

had ever been exposed in flight, and with the prospect of more unfavourable weather after she started. She had never gone through trials which proved by their length and conditions that she was well able to cope with a continuance of unfavourable circumstances. The programme of trials drawn up by her Captain had never been carried through, and the intended length of her last trial was avowedly cut down in order to provide a little more time for preparation before the date which was contemplated for her to start for India. No adequate speed trials had ever been carried through, and indeed this fact was so clearly realised that an official of the Air Ministry urged that she should conduct such speed trials on her voyage to India.

It is impossible to avoid the conclusion that the R.101 would not have started for India on the evening of October 4th if it had not been that reasons of public policy were considered as making it highly desirable for her to do so if she could.

108. But this is not to say that the authorities, political and technical, who were responsible for, or acquiesced in, this decision, would ever have done so if they had considered that the risk that was being taken was unjustified. The Secretary of State expressly stated that he relied on his experts, and it must never be forgotten that he was entitled to do so. Granted that it must always have been difficult for the distinguished officers at Cardington who sailed in the R.101 to resist the strongly expressed urging of the Secretary of State that a start should be made in time for him to be a passenger and to return for the Imperial Conference, we do not for a moment believe that Colmore or Scott would have accepted, without the strongest protest, the carrying out of a course which would in their judgment expose the whole enterprise to ruin, and risk the lives of men under their orders as well as those of distinguished passengers, to say nothing of threatening to make havoc of future airship policy. Wing-Commander Colmore's conversation with the Secretary of State, of which Mr. Reynold's notes are convincing evidence, proves this. The real situation can only be reconstructed by resolutely excluding from the mind the sombre impression produced after the event by the disaster.

109. We think the atmosphere in which the decision to start was taken must be regarded as made up of several elements.

There was the knowledge possessed by all concerned that the carrying out of this first flight to India was in any case an experiment involving a first experience of conditions which could never be defined and allowed for by theoretic calculations, but must be faced sooner or later by resolute men who believed wholeheartedly in the policy to which it would give expression.

There was the influence exerted upon them by a long period, continually extended by intervening difficulties and disappointments, during which they had been waiting for the day when the flight could be undertaken—a period much greater than had been first anticipated or calculated.

There was the knowledge that further developments in Airship policy which might involve expenditure of more public money, the building of more mooring towers, and the construction of a yet bigger airship, the design of which had been already authorised, could not be proceeded with until the existing outlay was seen to be justified by results.

There was the stimulus arising from the fact that the R.100, notwithstanding considerable gas-leakage and a very alarming experience when over the St. Lawrence River, had made its journey to Canada and back without serious mishap.

There was the fact, which never should be overlooked by those who now criticise, that more careful calculations had been made with regard to every part of the R.101 than of any previous airship.

And there was the personality of the Secretary of State, whose enthusiastic backing of this part of British Air policy must have been from first to last a most comforting support to the Cardington experts, and whose resolution to travel himself in the ship, provided it started at a date which made this possible, gave the *cachet* of Government support in the most striking way to the enterprise which completely filled the minds and hopes of the Officers who perished.

110. Airship travel is still in its experimental stage. It is for others to determine whether the experiment should be further pursued. Our task has been limited to ascertaining, as far as is possible, the course and cause of a specific event.

That event brought to a close, in a few moments of tragedy, an enterprise upon which years of concentrated effort had been directed by the pioneers who perished. The circumstances of their death can only add to the admiration evoked by their skill, courage, and devotion.

(*Signed*) JOHN SIMON.
,, J. T. C. MOORE-BRABAZON.
,, C. E. INGLIS.

L. F. C. Darby. } *Registrars.*
A. H. Wann. }

APPENDIX I.

LIST OF WITNESSES.

Professor Leonard Bairstow.
A. V. Bell.
J. H. Binks.
Squadron Leader R. S. Booth.
H. Brunnett.
Wing Commander Cave-Browne-Cave.
A. J. Cook.
Major J. P. C. Cooper.
T. S. D. Collins.
M. Dean.
A. Disley.
Air Vice Marshal H. C. T. Dowding.
J. W. W. Dyer.
Dr. Hugo Eckener.
A. E. Gerrish.
Flight Serjeant T. E. Greenstreet.
Sir John Higgins.
P. H. Jougland.
H. S. Lack.
H. J. Leech.
L. E. Lechat.
F. McWade.
L. A. Maillet.
G. F. Meager.
Flight Lieutenant R. J. Montgomery Moore.
F. W. Musson.
Sir Walter F. Nicholson.
Squadron Leader S. Nixon.
Lt.-Colonel H. W. L. Outram.
J. E. Patron.
L. A. Petit.
A. E. Rabouille.
M. F. Radel.
G. R. Raisbeck.
L. G. S. Reynolds.
V. Savory.
Dr. G. E. Simpson.
H. Turminel.
J. Walkinshaw.
Squadron Leader A. H. Wann.
C. T. Weight.
E. W. Woodward.

APPENDIX II.

LIST OF THOSE ON BOARD ON INDIAN FLIGHT.

(*The names of survivors are in italics.*)

PASSENGERS (6).

Brig.-General The Rt. Hon. Lord Thomson, P.C., C.B.E., D.S.O. (His Majesty's Secretary of State for Air).
Sir W. Sefton Brancker, K.C.B., A.F.C. (Director of Civil Aviation).
Major P. Bishop, O.B.E. (Chief Inspector, A.I.D.).
Squadron Leader W. Palstra (Representing Australian Government).
Squadron Leader O'Neill (Deputy Director of Civil Aviation, India, Representing Indian Government).
Mr. James Buck (Valet to Secretary of State for Air).

OFFICIALS FROM THE ROYAL AIRSHIP WORKS (6).

Wing Commander R. B. B. Colmore, O.B.E. (Director of Airship Development).
Major G. H. Scott, C.B.E., A.F.C. (Assistant Director (Flying) Officer in Charge of Flight).
Lt.-Colonel V. C. Richmond, O.B.E. (Assistant Director (Technical)).
Squadron Leader F. M. Rope (Assistant to Assistant Director (Technical)).
Mr. A. Bushfield (Aeronautical Inspection Directorate).
Mr. H. J. Leech (Foreman Engineer).

R.101 OFFICERS (5).

Flight Lieutenant H. Carmichael Irwin, A.F.C. (Captain).
Squadron Leader E. L. Johnston, O.B.E., A.F.C. (Navigator).
Lieut. Commander N. G. Atherstone, A.F.C. (1st Officer).
Flying Officer M. H. Steff (2nd Officer).
Mr. M. A. Giblett, M.Sc. (Meteorological Officer).

R.101 CREW (37).

Chief Coxswain	G. W. Hunt.
Asst. Coxswain	Flight-Sgt. W. A. Potter.
,, ,, ...	L. F. Oughton.
,, ,, ...	C. H. Mason.
Rigger	E. G. Rudd.
,, ...	M. G. Rampton.
,, ...	H. E. Ford.
,, ...	C. E. Taylor.
,, ...	A. W. J. Norcott.
,, ...	A. J. Richardson.
,, ...	P. A. Foster.
,, ...	W. G. Radcliffe.*
,, ...	S. Church.†
1st Engineer	W. R. Gent.
Charge-hand Engineer	G. W. Short.
,, ,, ...	S. E. Scott.
,, ,, ...	T. Key.
Engineer	R. Blake.
,, ...	C. A. Burton.
,, ...	C. J. Fergusson.
,, ...	A. C. Hasting.
,, ...	W. H. King.
,, ...	M. F. Littlekit.
,, ...	W. Moule.
,, ...	A. H. Watkins.
,, ...	*A. V. Bell.*
,, ...	*J. H. Binks.*
,, ...	*A. J. Cook.*
,, ...	*V. Savory.*
Chief Wireless Operator	S. T. Keeley.
Wireless Operator	G. H. Atkins.
,, ,, ...	F. Elliott.
,, ,, ...	*A. Disley.*
Chief Steward	A. H. Savidge.
Steward	F. Hodnett.
,, ...	E. A. Graham.
Galley Boy	J. W. Megginson.

Total on board, 54.

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* Too seriously injured to make any statement; died at Beauvais, 6.10.30.

† Fatally injured, but made statement in Beauvais Hospital before he died, 8.10.30.

APPENDIX III.

GAS VALVES OF R.101.

The general nature of the design is illustrated by Fig. 6 (*a*).

A metal seating A is fixed to a light casting in the form of a wheel with four spokes. This casting, which forms the mouth of the discharge orifice, is connected to the bag by a fabric petticoat, and its weight is supported by the gasbag wiring.

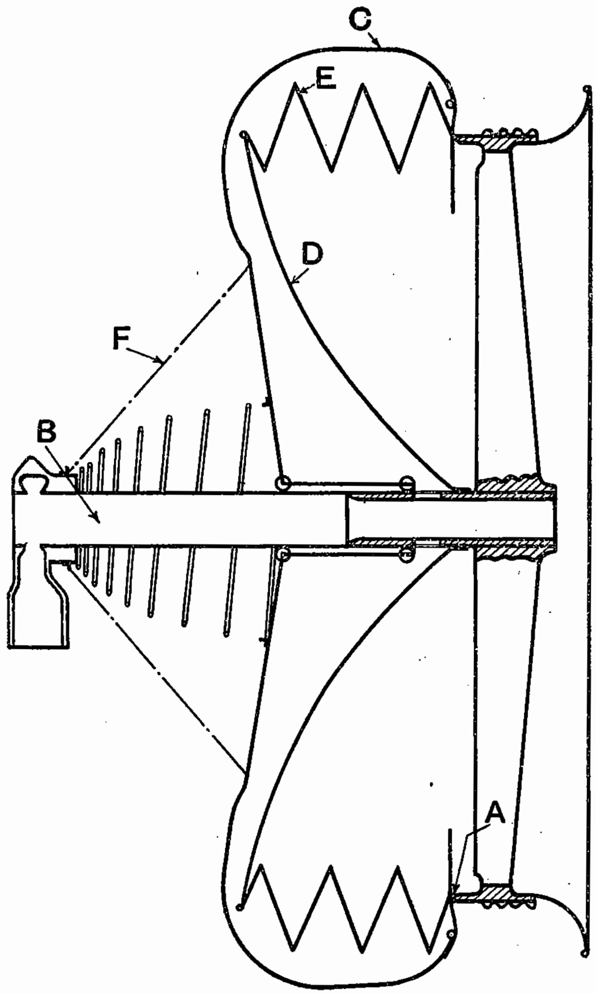


Fig. 6 (*a*).

From the hub of the casting projects a tubular spindle B. Travelling on this spindle is the moving part of the valve C, which consists of a spun metal casing carrying a flexible fabric annulus which constitutes the face of the valve. Fitted to the spindle B is a fixed conical metal diaphragm D, connected to the fabric annulus by a gas-tight fabric bellows E.

When the space outside the bellows is at atmospheric pressure, the gas pressure inside exerts a closing force on the flexible annular valve face, since the effective diameter of the bellows is somewhat greater than that of the valve seating A.

The valve is opened by the introduction of a small gas pressure to the space between the movable casing C and the fixed diaphragm D, this operating chamber being connected to the gas supply through the hollow spindle B and the fabric cone F.

If no gas is flowing into the operating chamber, atmospheric pressure is maintained by a direct leak and the valve remains closed. If the gasbag becomes over full, gas spills round the siphon pipe, shown in Fig. 6 (b) and so up into the operating chamber. The pressure developed in this chamber, in spite of the small leak previously mentioned, causes the valve to open deliberately to its full extent of about 10 inches, and to remain fully open so long as the gas continues to spill over through the siphon pipe.

With this method of control, the valve is very sensitive, and an increase of gas pressure, amounting to only 2 millimetres of water, is sufficient to cause the valve to move wide open.

It will be seen in Fig. 6 (*b*) that two cross-connections exist in the siphon pipe marked H and J.

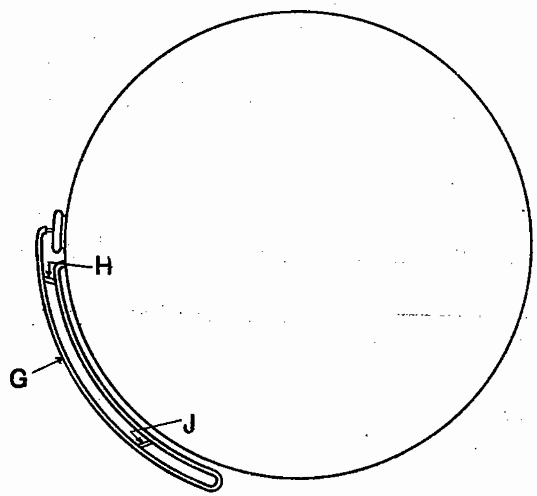


FIG. 6 (*b*).

If connection H is opened, gas will enter the operating chamber and open the valve, even if the bag is considerably deflated, and this method of opening the relief valves avoids the necessity of providing separate manœuvring valves.

The cross-connection J is a fabric pipe, which is normally tied off. It was only intended to be used in the event of the pilot anticipating a sudden rise of height, which might render it advisable for the valves to come into operation when the free surface of the gas is level with J.

APPENDIX IV.

FLIGHTS CARRIED OUT BY R.101.

No. of Flight.	Date.	Itinerary, etc.	Duration of Flight. Hrs.	Mins.
	12.10.29	Ship brought out of shed.		
1	14.10.29	Round London	5	38
2	18.10.29	Midlands	9	38
	21.10.29	Ship in shed		
	1.11.29	Ship brought out of shed.		
3	1.11.29	Norfolk	7	15
4	2/3.11.29	Isle of Wight	14	2
5	8.11.29	Local	3	4
6	14.11.29	Local	3	9
7	17/18.11.29 (Endurance Flight).	England, Scotland and Ireland ..	30	41
	30.11.29	Ship in shed.		
	23. 6.30	Ship brought out of shed.		
8	26. 6.30	Refit Flight	4	35
9	27. 6.30	Rehearsal for R.A.F. Display ..	12	33
10	28. 6.30	R.A.F. Display Flight	12	21
	29. 6.30	Ship in shed. New bay inserted.		
	1.10.30	Ship brought out of shed.		
11	1/2.10.30	First Trial Flight with extra bay	16	51
12	4/5.10.30	Cardington—Beauvais	7	24
		Total Flying Time	127	11

APPENDIX V.

METEOROLOGICAL CONSIDERATIONS.

(*Note prepared by* COLONEL MOORE-BRABAZON.)

1. When the 1924 airship programme was drawn up it was realised by those in charge of Airship Development in this country, that if the airship was to be successfully used as a means of Imperial Air Communication, it was essential that definite knowledge as to the air conditions on the airship route which was to be adopted should be acquired.

In order to ascertain the air conditions which an airship might meet, especially between this country and Ismailia, and Ismailia and Karachi, an entirely new department of the meteorological service was set up. The new division of the Meteorological Office was created for the purpose of directing its attention especially to meteorological problems connected with airships. This division was established in January, 1925, and was known as the Airships Meteorology Division. The new division was put in charge of Mr. M. A. Giblett, who was one of the most able of the scientific staff of the Meteorological Office. He unfortunately lost his life in the disaster which befell the R.101. The personnel of this division at first consisted of four people, but as the work developed the personnel grew and at the time of the disaster the staff of the Airships Meteorology Division numbered seventeen.

The work of the division consisted of investigating the general conditions upon a route and in giving specific information to ships in flight. Much work was done by this division in the investigation of the change of temperature of the air at various heights ; of the structure of the wind as it affected an airship, and of the vertical motion of the atmosphere.

While this work was going on, information was being collected in order that the frequency of types of weather that might be met with on the Indian and other air routes should be ascertained. This work was more completely developed on the Indian route, as it was intended at first that both airships—the R.101 and the R.100—would be tried out on this route, but this plan was ultimately revised and the R.101 was the only airship which attempted a voyage to India.

A large amount of meteorological information was available for the region along and round the England to India route, but it was scattered in the publications of various meteorological services and had never been co-ordinated and discussed. Further, for the whole of the part of the route that lay between Egypt and India, no weather chart had ever been prepared. The Airships Meteorology Division therefore proceeded to collect data from every possible source for the years 1924 and 1925. All information of importance to airships was extracted from the reports of many of the air stations, and maps were prepared showing the simultaneous conditions at all the selected stations for a particular hour each day. From these charts it was possible to obtain an idea of the kind of weather which might be expected, where the regions of bad weather generally occurred, the size of such regions, and what would be the best routes to take in order to avoid them. With this information it was possible to estimate how much fuel it would be necessary to carry in any particular month in order that the airship should cover the space between her point of departure and her next proposed stopping place while meeting the air conditions which the data collected showed it was probable she would encounter.

In addition to the work of investigation referred to above, it was necessary to create an organisation for the purpose of conveying information to an airship when in flight, and also to give an airship a forecast of the weather she might expect when about to make a flight.

Some idea of the amount of information available and used in the preparation of these forecasts, which were issued every six hours, is shown by the fact that reports might be received from as many as 130 stations extending from Spitsbergen and Greenland in the North to Tunis in the South, and from the Azores in the West to Karachi in the East. From a chart showing the existing weather conditions obtained from the 130 reports, the weather conditions for the route from England to India might be clearly set out. This information was obtained at 1 a.m., 7 a.m., 1 p.m., and 7 p.m. In addition to these main charts, other charts were prepared at intermediate hours during the daytime, viz., at 5 a.m., 10 a.m., and at 4 p.m. The result was that during the normal day at Cardington seven charts showing the existing weather conditions over a very large area were available for the use of those proposing to start on a voyage in the air or actually engaged on one.

With regard to the giving of meteorological information to the R.101 on her last voyage, an elaborate programme had been drawn up arranging for the forecasting centres at Cardington, Malta, Ismailia, and Karachi, to take part in the work. Areas had been marked out and limited to each of these forecasting stations, so that when the ship was in the first area she received all her information from Cardington; when in the second area she received it from Malta; when in the third area she received it from Ismailia, and when in the fourth area she received it from Karachi. Detailed directions had been given to each of these four centres as to the information which was to be sent to the R.101, and the meteorologist on board the ship, if he wished for information, could always obtain it from one or other of these centres.

Having given this general survey of the condition and work done by the Airships Meteorology Division, it is now necessary to consider the actual information given to the R.101 on her last flight.

2. The following reports were provided for the R.101 from the Meteorological Office at Cardington during the course of the 4th October, before the ship took her departure. The first was sent at 9.9 a.m. (Greenwich mean time), and was in the following terms :—

To :—The Captain, R.101. Sent 0909 G.M.T. 4.10.30.
From :—Meteorological Office,
Royal Airship Works,
Cardington.

GENERAL INFERENCE from Observations at 0700 G.M.T. Saturday 4.10.30.

A shallow depression centred off Tynemouth is moving North East, while another depression over the Eastern Atlantic is moving in Eastward. The occluded front of the first-named depression is passing Eastward over France. Weather will improve temporarily winds being West or South West.

FORECASTS.

Cardington Base.—Period 7 a.m. to 7 p.m. G.M.T. Saturday.

Surface wind.—{ *Direction*—Westerly backing later. *Speed* (*m.p.h.*)—10 to 20 m.p. h.
Weather.—Cloudy with brighter intervals.
Cloud.—10 tenths breaking later.
Visibility.—Improving to 6 miles.
Surface temperature.—Rising to about 60° F.

Cardington to South of France.—Period 5 p.m. Saturday to 5 a.m. Sunday.

Upper wind at 2,000 *feet.*—{ *Direction*—260 to 240°. *Speed* (*m.p.h.*)—20 to 30 m.p.h.
Weather.—Fair to cloudy.
Cloud.—Variable 1,000 to 1,500 feet above sea level at times.
Upper air temperatures————

FURTHER OUTLOOK.

Cardington Base.—Period 7 p.m. Saturday to 7 a.m. Sunday. South Westerly winds and unsettled weather.

France.—For 12 hours more. South Westerly winds and unsettled weather.

At 9.30 on the morning of October 4th, a conference was held in the Forecast Room at the Meteorological Office at Cardington. There were present at that conference, Major Scott, Flight-Lieut. Irwin and Mr. Giblett. The weather charts were discussed, and it was noted that a shallow depression centred near Tynemouth was moving North-East and the occluded front associated with it was moving Eastward over France. Behind the front it was thought that winds would be West or South-West, and that the weather would improve for a time with a probability of broken cloud in the evening.

At 11.15 a.m., a second report was furnished to the Captain of the R.101, in the following terms :—

To :—Captain R.101.
From :—Meteorological Office, Royal Airship Works, Cardington.
Sent :—11.15 G.M.T. 4.10.30.

Inference Cardington to Ismailia.

Anticyclone over the Balkans. Depression Eastern Atlantic spreading East. Occluded front running from shallow low centred near Tynemouth to South of France moving East. Winds to-night over France are likely to be from W. or S.W. of moderate strength over Northern France, light over Southern France. Weather mainly cloudy.

In Western Mediterranean light variable or S.W. winds are probable to-morrow with fair weather.

Central Mediterranean light easterly or variable winds weather fair.

Eastern Mediterranean wind Nly or NEly Athens to Crete lighter towards Egypt. Weather mainly fair perhaps local thunderstorms.

At 3.3 p.m. on the 4th October, a further report was sent to the R.101 at the Cardington tower. That report consisted of a general inference from observations made at 1 p.m. on that day. The report was in the following terms :—

The occluded front over France this morning has now passed eastward while a trough of low pressure off western Ireland is spreading in quickly. Rain will spread in from the west probably reaching Cardington to-night.

FORECASTS.

Cardington Base.—Period 1 p.m. Saturday to 1 a.m. Sunday.

Surface wind.—*Direction*—SWly.
Speed (m.p.h.)—10 to 15 m.p.h. freshening later.

Weather.—Fair at first. Rain later.

Cloud.—7 tenths increasing to 10 tenths. Mainly high at first, falling to 1,000 feet.

Visibility.—2 to 6 miles.

Surface temperature.—Falling to about 55°.

To South of France.—Period 5 p.m. Saturday to 5 a.m. Sunday.

Upper wind at 2,000 *feet.*—*Direction*—270° to 240°.
Speed (m.p.h.)—20 to 30 m.p.h. in Northern France, lighter in Southern France.

Weather.—Cloudy. Local rain in Northern France.

Cloud.—8 to 10 tenths 1,000 to 1,500 ft. at times above sea level.

3. On the basis of these reports no great increase in wind velocity was to be expected over the South of England and Northern France during the evening and night of the 4th October.

The R.101 having started at 6.34 p.m., at 8.8 p.m. the following report was wirelessed to her from the Meteorological Office at Cardington.

To :—R.101.
From :—Meteor Airships Bedford. Sent 2008 G.M.T.

1800 G.M.T. Situation trough low pressure Western Coasts British Isles moving East Ridge high pressure Southern France Forecast next 12 hours flight SE England, Channel, Northern France wind at 2000 ft. from about 240 degrees 40 to 50 m.p.h. Much low cloud with rain. Central France upper wind about 250 degrees 30 to 40 m.p.h. Cloudy local rain. Southern France wind westerly to variable mainly light, variable amount of cloud, local morning mist and fog.

The previous forecasts had shown that wind of a velocity of 20–30 m.p.h. might be expected. In this forecast the weather conditions had deteriorated so quickly that the Meteorological Department at Cardington forecasted a wind of 40–50 m.p.h.—a velocity which no British airship had met with over land before.

A further forecast (in reply to a request by the R.101) was sent by Cardington at 9.38 p.m., but this forecast dealt with anticipated weather conditions beyond Paris and is therefore not particularly relevant.

4. The evidence as to the wind met by the R.101 while on her last voyage is, that when she left Cardington the wind velocity recorded by the anenometer 150 ft. above the ground level was 16 m.p.h. with gusts of 22 m.p.h. At Croydon the anenometer, which there is at a height of 105 ft., recorded a velocity of 16 m.p.h. with gusts up to 27 m.p.h. There is no anenometer at the actual position where she crossed the English coast near Hastings, but the wind velocity would probably be similar to that recorded at the meteorological station at Lympne, which is some miles away to the east of the point at which the R.101 crossed the English coast. This anenometer at a height of 75 ft. recorded a wind velocity of 19 m.p.h. with gusts up to 29 m.p.h. The anenometer used by the French Meteorological Office in North-East France differs from those used in England, in that they do not give the actual velocity at each moment but only show the total wind movement. At Beauvais for the period from midnight to 2 a.m. the anenometer at Beauvais, which is 53 ft. above the ground, indicated a velocity of approximately 30 m.p.h. The wind records at the three Wind Recording Stations in England referred to above, show that the wind increased in velocity during the night. The R.101, however, appears to have kept ahead of the strongest winds. It must, however, be remembered that the velocity of the wind which the ship would encounter would be greater than the velocity of the wind on the ground.

This fact must be brought out clearly, that never, with or without the extra bay, had the R.101 ever experienced weather approaching in violence anything met with during this journey.

The vessel thus started with a promise of winds over the next 12 hours of 20 to 30 m.p.h. at 2,000 feet; yet an hour and a half after leaving she is informed that she is to meet winds of 40 to 50 m.p.h., as she actually did—an increase of roughly 100 per cent. The meteorological service which supplied this information was second to none in skill and personnel, but the circumstances were such that, in the present state of the science it was not possible to predict the strength of the wind with accuracy for 12 hours in advance. Had it been possible to do so, and had such information been available two hours earlier, it is doubtful whether the decision to start would ever have been taken.

5. The result of the investigation into the actual wind conditions the ship experienced from the time she left Cardington up to the time of the disaster is of much interest.

The investigation was undertaken by the Meteorological Office of the Air Ministry, as it was found impossible to reconcile the reports received from the R.101 of the upper wind with the actual course she is known to have travelled (her cruising speed being taken as 54·2 knots with five engines running).

It is theoretically possible to calculate the wind direction and velocity at all heights from the pressure distribution shown on a weather chart, and the table below gives the figures for different stages of the R.101's last flight at varying heights (columns 2, 3, and 4). Column 5 gives the actual wind observed near the ground.

1.	2. 500 Metres. Calculated Wind.		3. 300 Metres. Calculated Wind.		4. 150 Metres. Calculated Wind.		5. Ground. Observed Wind.	
	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.	Velocity.	Direction.
	m.p.h.		m.p.h.		m.p.h.		m.p.h.	
Bedford to London	38	228°	36	223°	23	219°	18	202°
London to Hastings	38	233°	36	229°	31	221°	18	225°
Hastings to French Coast	45	226°	42	221°	37	216°	30	214°
French Coast to Beauvais ..	46	219°	43	214°	38	207°	30	202°

It will be remembered that the R.101 reported her flying height as 1,500 ft. (approximately 500 metres) and she would therefore encounter winds shown in column 2, which, though of the order forecasted in the message sent to the ship at 8.8 p.m., were of much greater velocity than had been predicted earlier in the day.

Weather charts for the period 6 p.m. (G.M.T.) October 3, to 7 a.m. (G.M.T.) October 5 are, to be found at the end of this Appendix.

6. It has been suggested that the rain which fell between the time at which the ship left Cardington and crashed at Beauvais may have been one of the causes which led to the disaster.

The evidence as to the rain encountered on the final flight is that it was fine at Cardington until shortly after the ship left, but rain then began to fall at Cardington, and this band of rain moved across the country in a South-Easterly direction reaching the S.E. coast at about 9 p.m. It reached St. Inglevert at about

10 p.m. and Beauvais at about 11 p.m. In England this rain band took about an hour to pass over each station, after which the rain ceased for a short time, and there occurred a number of moderate to heavy showers. The R.101 appears to have travelled slightly more slowly than the rain band, with the result that it caught her up before she reached London, and she would therefore experience rain on her journey to the Channel. As she crossed the south coast near Hastings she sent a message that it was raining hard. It may be that the main band of rain had by this time passed ahead of her, and that the hard rain to which those on board the R.101 were referring was one of the heavy showers that occurred after the main rain band had passed.

In the report which came from the R.101 when she was crossing the French coast at 11.36 p.m., no mention was made of rain, but in the message sent at midnight (when she gave her position as 15 miles South-West of Abbeville) "intermittent rain" was reported. This message tends to show that the main rain band had passed over the R.101 and kept ahead of her. The report made by the French observer at Abbeville was :—

Period G.M.T.	
22 h. to 22.20	à 22.20 début d'une pluie continue faible puis moderée a faible.
0 to 1 h.	Pluie continue faible à moderée.

while the observer at Beauvais made the following observation regarding the rain :—

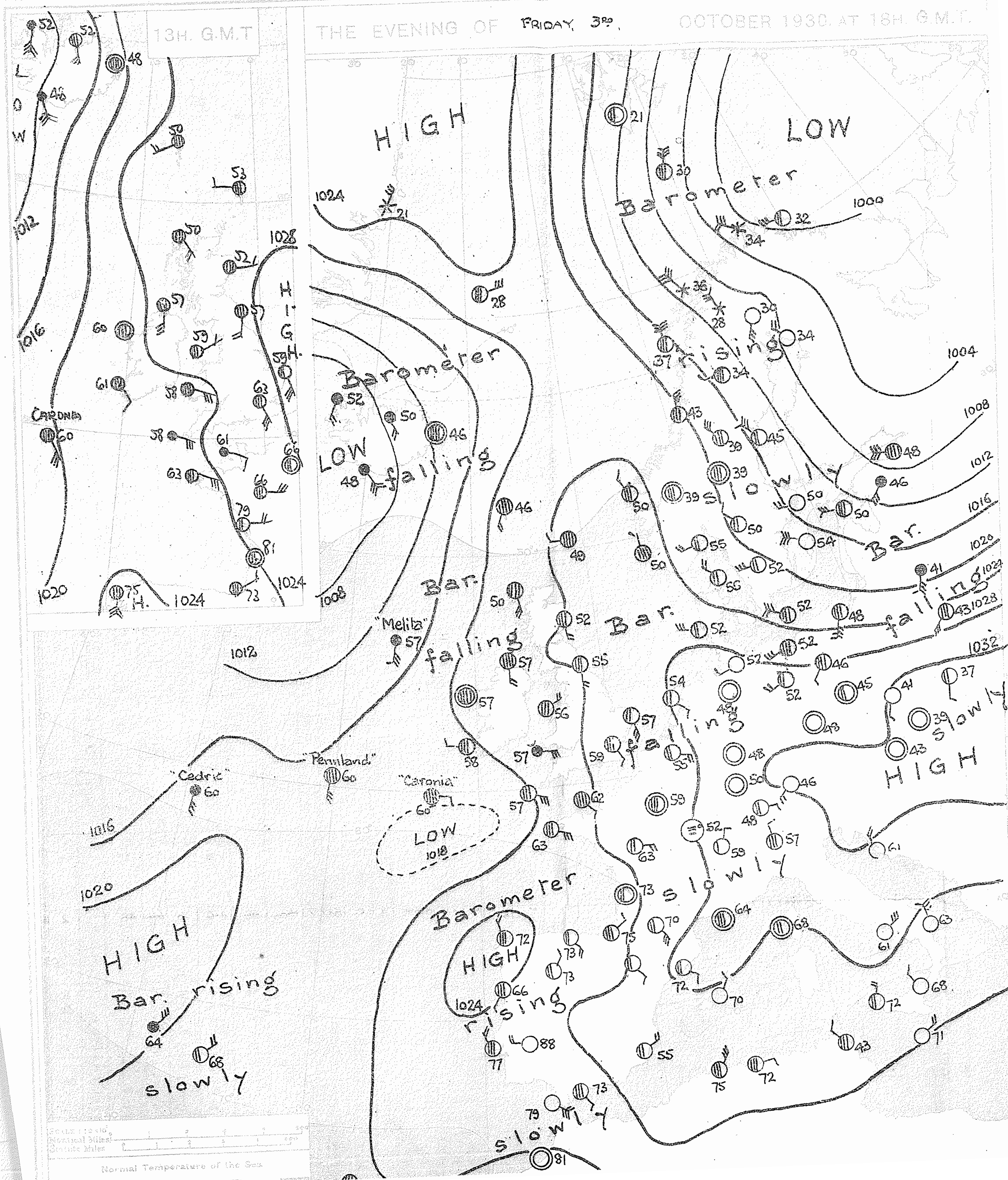
Period G.M.T.	
22 h. to 22 h.	les Fracto Cumulus se transforment en Fracto Nimbus donnant une pluie faible à partir de 22 h. 55 min.
0 to 1	La pluie continue à tomber : faible à moderée.

Both these observers went off duty at 1 a.m. on Sunday morning.

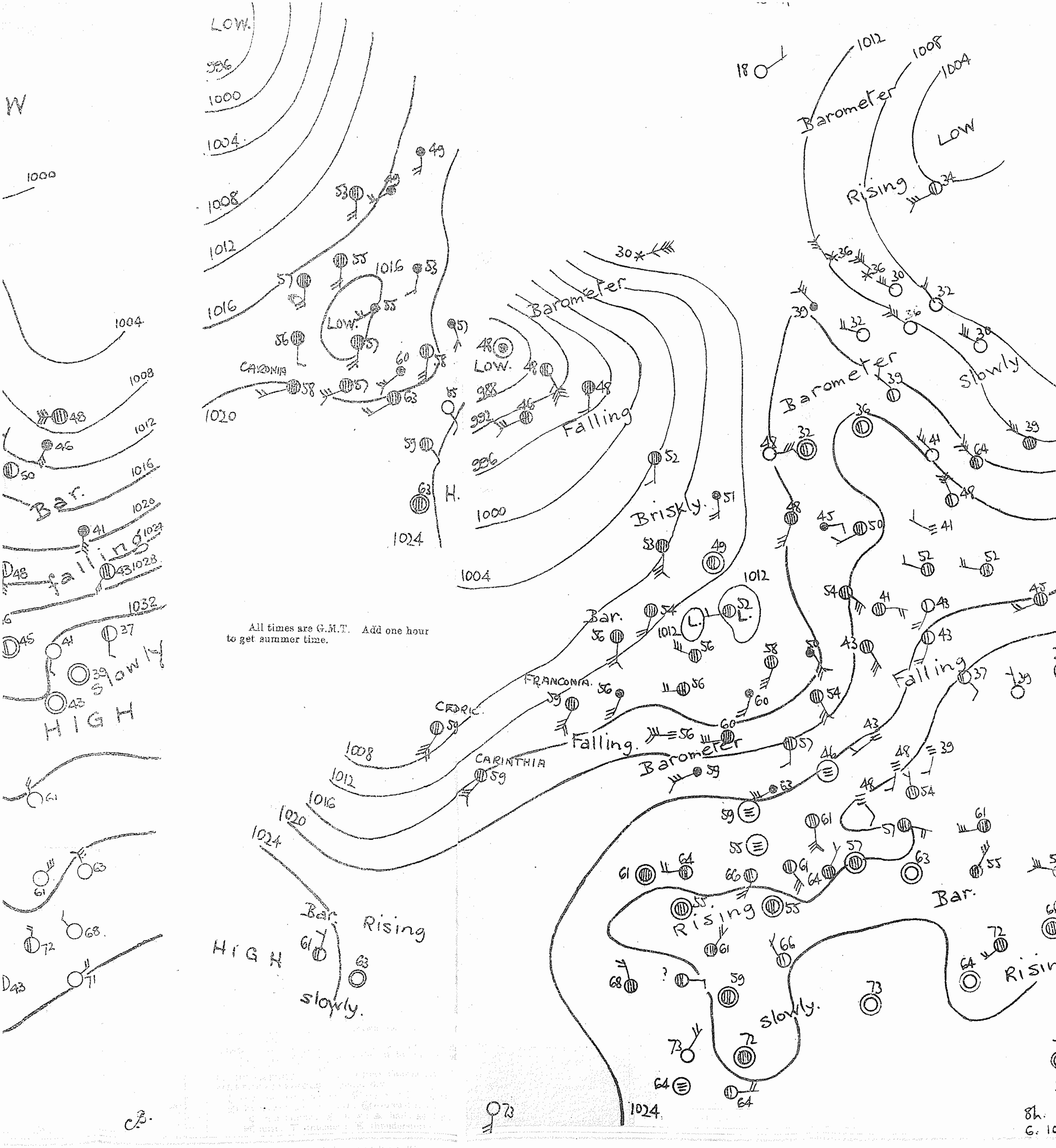
From the above information it would appear that the R.101 encountered rain on this voyage, but the probabilities are that the continuous rain had ceased by the time that she had got to the south coast of England, and that from that time on she was meeting with intermittent rain only. This conclusion is borne out by the fact that members of the general public at Beauvais were of opinion that from the time the airship reached Beauvais up to some little time after the crash, only very light rain fell in that district. Heavy rain had fallen a little earlier.

7. During the investigation a suggestion was made that the disaster might have been caused by the ship meeting with a vertical current of air due to thunderstorms. Enquiries were made and a representative from the Air Ministry was specially sent over to enquire into this point, but no evidence was

M.O. FORM 2371.



13H. G.M.T.
THE EVENING OF FRIDAY 3rd OCTOBER 1930, AT 18H. G.M.T.
HIGH
LOW
Barometer rising slowly
Barometer falling
Bar. falling
Bar. falling
Bar. falling slowly
Bar. falling slowly
HIGH
Barometer rising slowly
HIGH
Bar. rising slowly
LOW 1018
"Melita"
"Pennland"
"Cedric"
"Caronia"
CARONIA
1000
1004
1008
1012
1016
1020
1024
1028
1032
Normal Temperature of the Sea


LOW
Low.
LOW.
HIGH
H.
Barometer Rising
Barometer Falling Briskly.
Barometer slowly
Bar. falling slowly
Bar. Falling.
Bar. Rising slowly.
Bar. Rising
CAR0NIA
FRANCONIA.
CEDRIC.
CARINTHIA
1000
1004
1008
1012
1016
1020
1024
1028
1032
996
992
988
All times are G.M.T. Add one hour to get summer time.

STATIONS.	Height above Mean Sea Level. Feet.	OBSERVATIONS at 18h. G.M.T. 3rd October: Barom. at M.S.L. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt. 0–10	OBSERVATIONS at 7h. G.M.T. 4th October: Barom. at M.S.L. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F.	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt 0–10	Temp. Max. Day. °F.	Temp. Min. Night °F.	Rainfall. Day. mm.	Rainfall. Night mm.
ITALY & MEDITERRANEAN.																											
Turin	906												1029·2		—	0	fb	55									
Padua	102												1027·9	-49	—	0	c/f	55									
Leghorn ...	46												1027·9		NE	1	bc	61									
Rome	168												1029·2	0	NE	2	c/clr	57									
Taranto	126	1027·5	+14	N	4	b	63	7	–	–	0	0	1028·6	+12	WNW	4	b	59	8	-	-		0			–	–
Messina	116	1025·4	+8	NNW	1	b	68	8	–	–	0		1028·7	+14	-	0	c	66	6	4000	Sr	9+	9+			–	–
Cagliari	248												1030·6	+49	NNW	3	b	61									
Gibraltar ...	53																										
Rabat	210												1017·4	+6	-	0	of	64	1	2500	Sr	10	10				-
Oran	174																										
Mahon	141	1027·4	+10	NE	1	b	70	6	–	–	0	Tr														–	
Bizerta	30	1025·4	+4	ENE	4	bc	73	7	2500	2	2-3	2-3	1028·3	+14	-	0	b	64	8		-	0	0			–	–
Malta	231	1024·1	+8	E'N	2	b	71	8	1500	S	Tr	Tr	1027·0	+14	ENE	2	b	71	8	2500	Sc	1	1	75	68	–	-
Benghasi ...	—												1021·9	+52	N	2	c	75	?	?	?	?	9+				–
Athens (1) ...	351												1027·0		NE	4	z	61	8								
Candia†(2) ...	88	1021·8		NE	2	c	68						1023·5	+12	NW	3	bc	68						79	63	–	
Limassol†(2) ...	26																										
Cairo† (Helwan) (2)	379	1017·0	0	N	3	b	79						1019·0	+12	N	?	bc	72								–	
Matruh†(2) ...	33												1020·0	+12	-	0	bc	72								–	

(1) Observations at 19h. and 6h. G.M.T. (2) Observations at 18h. and 6h. G.M.T. ** Figures refer to New International Code, 1929. (*See* British Section).

WIRELESS REPORTS FROM THE ATLANTIC AND NORTH SEA.

Date and Hour.	Ship.	Lat. °N.	Long. °W.	Direc. of Ship.	Speed of Ship.	Bar. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather. Present.	Weather. Past.	Temp. Air. °F.	Temp. Dif. betw. Sea & Air Temp.	Visibility.	Cloud. Form Low.	Cloud. Form Med.	Cloud. Form High	Cloud. Amount. Low. 0–10	Cloud. Amount. Total 0–10	Swell. Code No.	Swell. Direc.
3rd 12h	Melita	56°12'	18°30'	E	*	1018	-30	S	3	1f	f	56	4	4	St	-	-	10	10	3	SE
3rd 18h	"	56°6'	15°42'	E	*	1014	-30	S'W	4	df	f	57	4	3	St	-	-	10	10	3	SE
3rd 12h	Pennland	50°42'	22°18'	E	*	1017	0	S'E	1	1f	0	59	3	7	St		1		9+	4	E
3rd 18h	"	50°36'	20°0'	E	*	1017	0	S'W	3	0	0	60	3	6	St		–		10	2	E
3rd 12h	Cedric	48°30'	31°18'	NE	6	1019	-10	SSW	2	0	0	57	4	7	4	2	–	4-6	10	8	E
3rd 18h	"	48°54'	28°48'	NE	6	1017	-20	SSW	3	d	0	60	4	6	4	–	–	10	10	8	E
4th 0h	"	49°24'	26°30'	NE	6	1013	-40	SW	4	0	p	59	5	6	5	–	–	10	10	8	E
4th 6h	"	49°54'	24°6'	NE	6	1007	-60	SW	5	od	p	59	0	6	8	-	-	10	10	4	E
3rd 12h	Coronia	49°36'	15°24'	E	6	1020	+2	SE'S	3	0	0	60	4	5	S	–	–	10	10	3	SE
3rd 18h	"	49°42'	12°42'	E	6	1019	0	E	1	o/r	0	60	4	8	S	–	–	10	10	1	NE
3rd 24h	"	49°42'	10°0'	E	6	1020	0	WSW	2	0	f-z	58	4	7	S	–	–	10	10	1	NE
3rd 12h	Corinthic	46°15'	23°48'	E	*	1014	+16	E'N	3	bc	0	63	4	8	Cu		1		4-6	9	-
4th. 6h.	"Carinthia"	47°36'	18°30'	E	·	1018	0	SSW	4	c	f-z	59	5	6	St.Cu	·	A.St.	·	9	1	SW
4th 6h	"Laurentic"	55°30'	5°0'	N	4	1014	-	N	1	oz	f-z	53	6	5	5	-	-	10	10	-	-
4th 0h.	"Franconia"	49°12'	28°12'	E	6	1014	-10	N'E	4	0	0	57	0	6	5	-	-	10	10	1	E
" 6h.	"	51°12'	18°54'	E	*	1014	-12	SW'S	5	bc	0	59	0	7	Sc	-	-	5	5	3	SW.
4th 6h.	"Armadale Castle"	49°6'	4°30'	SW	*	*	0	WSW	2	f	f-3.	*	e.	*	*	*	*	*	*	1	W

†† Barometric change in 3 hours is given in tenths of millibars.

SPEED OF SHIP.

0... 0	5...13–15 knots
1...1–3 knots	6...16–18 "
2...4–6 "	7...19–21 "
3...7–9 "	8...22–24 "
4...10–12 "	9... >24 "

DIFFERENCE BETWEEN SEA & AIR TEMPERATURE

°F

0	... >9	Air temperature same as or higher than sea temperature.
1	... 6–9	
2	... 3–6	
3	... 1–3	
4	... 0–1	
5	... 0–1	Air temperature lower than sea temperature.
6	... 1–3	
7	... 3–6	
8	... 6–9	
9	... >9	

STATE OF SWELL.

Ships using New International Code (1929) report swell in following code:—

0...None.
1...Short or average length } Low.
2...Long
3...Short } Moderate height.
4...Average length
5...Long
6...Short } Heavy.
7...Average length
8...Long
9...Confused.

CLOUD AMOUNT.

Figures indicate number of tenths of sky covered by low cloud. An entry 4–6 means that cloud amount may be 4, 5 or 6: similarly for other grouped entries, "tr" signifies a small amount of cloud covering less than $\frac{1}{10}$ of the sky. "9+" signifies an overcast sky with a few small openings.

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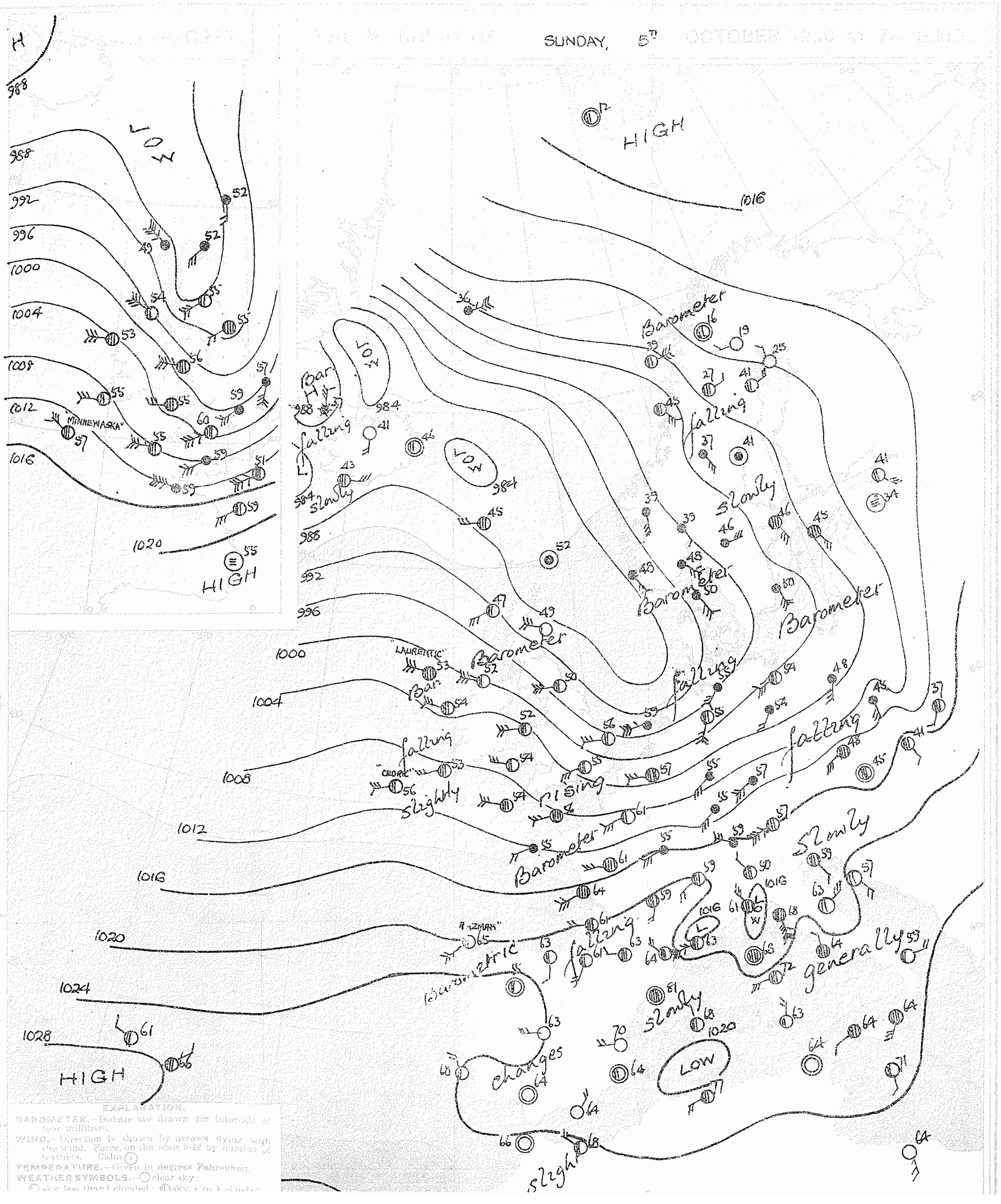
AIR MINISTRY.

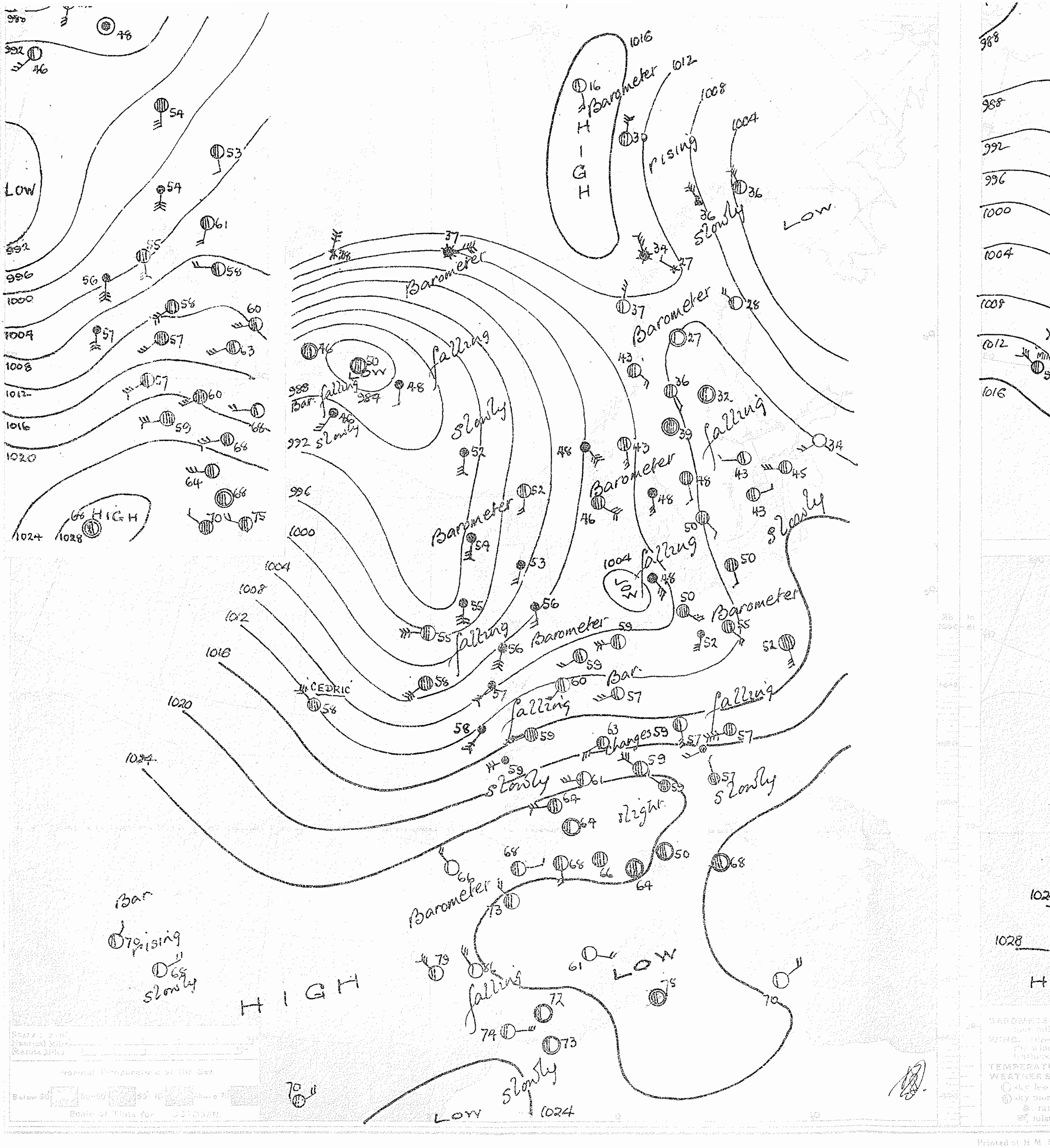
DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON:

INTERNATIONAL SECTION. No. 25153 4th October, 1930.

	STATIONS.	Height above Mean Sea Level. Feet.	OBSERVATIONS at 18h. G.M.T. 3rd October — Barom. at M.S.L. mb.	Change in 3 hours ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt. 0–10	OBSERVATIONS at 7h. G.M.T. 4th October — Barom. at M.S.L. mb.	Change in 3 hours ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F.	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt 0–10	Sea.	Temp. at 13h. 3rd	Rainfall. Day. mm.	Rainfall. Night mm.
ICELAND, &c.	Julianehaab (¹)	213							•	•	•	•	•							•	•	•	•	•	•	•	•	•
	Isafjord	13	1004·8	-40	S	3	ro	52	•	•	StCu	•	10	987·1	-47	–	0	oRR	48	•	•	Nb	•	10	•	52	•	•
	Reykjavik	92	1005·0	-40	SSW	3	c/r	50	6	1500	St	9	10	991·4	0	SW	4	c/r	45	6	1500	CuNb	9	9	•	50	0·6	1
	Vestmanna	433	1005·8	-53	SE	5	rr	48	•	•	St	•	10	995·0	-7	WSW	4	cjp	46	•	•	CuNb	•	7	•	48	•	•
	Seydisfjord	28	1022·3	-27	–	0	o	46	•	•	Nb	•	10	993·0	-47	S	1	o/r	48	•	•	Nb	•	10	•	48	•	•
	Thorshavn	34	1021·4	-12	SSW	2	z	46	6	220	6	10	10	1003·8	-34	S	1	o	52	7	450	Nb	10	10	•	50	–	1
	Spitsbergen	37	1013·5	+2	–	0	bc	21	6	2500	6	4-6	4-6	1014·7	+2	ENE	1	b	18	9	7200	–	0	1	•	28	Tr.	–
	Bear Island	182	1005·5	+15	NE'N	6	c	30	9	1500	6	4	8													20	–	
	Jan Mayn	76	1023·1	-12	ENE	3	c	28	8	2500	2	2-3	10	1013·0		ENE	8	ss	30	4							–	
NORWAY.	Vardö	46	999·9	-8	W	3	bc	32	9	–	–	0	2-3												•	.	0·3	
	Ingöy	25	1000·7	+2	NW	5	is	34	6	2500	8	2-3	7-8	1004·9	+16	W	4	bc/AHR	34	9	1500	StCu	2-3	4-6	3	32	1	2
	Röst	34	1016·6	+6	NW	6	c/pr	37	6	4000	9	7-8	9	1015·9	-6	NW	4	c/pr	39	7	4000	Nb	4-6	9	4	39	0·6	0·2
	Kinn	26	1024·6	-4	NW	1	c	50	8	2500	6	9+	9+	1016·4	-38	E	4	o	48	8	4000	St	10	10	4	52	–	2
	Utsire	188	1025·4	-8	N	1	c	50	8	2500	8	10	10	1016·0	-30	SSW	3	o	48	9	4000	St	10	10	2	52	0·3	-
SWEDEN.	Haparanda	30	1006·4	0	NW	2	b	34		•	–	0	0	1009·0		NW	2	b	32	9	•				•		0·1	
	Härnösand	67	1014·3	+22	NW	4	bc	45	9	1500	S	2-3	2-3	1016·7	0	NW	1	bo	39	9	-	•	0	4·6	1		–	-
	Stockholm	144	1015·8	+14	W	2	b	50	6	•	–	0	0	1019·8	+6	NW	3	b	41	6	•		0	0	•	55	0·1	-
	Wisby	36	1017·2	+6	WNW	6	b	54	9	•	–	0	1	1020·6	+14	NNW	5	bc	48	9	•	Cu	tr	4-6	•		–	-
	Karlstad	172	1019·8	+2	NW	1	bc	50	•	•	4	2-3	2-3												•		–	
	Särna	1430	1019·8		–	0	c/pr	39	9	•	6		9	1020·2	?	-	0	bc	36	9	•	-	0	2·3	•		/	-
DENMARK & HOLLAND.	The Scaw	10	1032·0	0	NW	2	bc	55	8	4000		2-3	2-3	1019·0	-6	WSW	1	c	50	7	4000	Cu	1	7-8	1	57	–	-
	Blaavands Huk	49	1027·1	-14	WNW	3	bc	52	8	4000	S	4-6	4-6	1019·6	-26	SE	3	cjp	54	8	2500	Nb	7-8	7-8	2	54	–	-
	Copenhagen	16	1025·0	-2	W	3	o	52	7	2500	S	10	10	1021·6	-16	WSW	2	om	50	3	1500	St	10	10	1	54	Tr	-
	Bornholm	253	1023·6	0	WNW	5	c	52	8	2500	9	7-8	7-8	1021·9	-2	WNW	1	c	52	8	2500	StCu	9	9	1	54	0·2	-
	Helder	19	1028·0	-6	SE	1	bc	54	6	5700	4	4-6	4-6	1015·9	-26	SSE	4	oir	50	4	1500	?	10	10	1	59	–	2
	Flushing	26	1026·7	-6	SE	2	bc	59	5	4000	7	2-3	2-3	1015·8	-20	S	3	o°	55	6	2500	St	10	10	1	59	–	1
																									Temp. Max. Day.	Temp. Min. Night		
SWITZERLAND, GERMANY, ESTONIA, Etc.	Geneva	1329	1029·8	0	NE	1	b	59	7		S	1	1	1028·4	-4	SE	1	o	48	7	2500	St	10	10	61	46	–	•
	Lugano	906	1030·2	-10	N	1	c	57	7	–	–	0	10	1029·1	-12	N	1	c	54	7	7200	-	0	9+	59	52	–	0·2
	§Säntis	8202	762·1	0	WSW	7	c	36	6	•	St	7	10	753·2	-13	WSW	8	bc	39	8	•	St	3	4	41	36	–	–
	Munich	1726	1032·0	-2	WSW	2	z	46	4	–	–	0	0	1028·8	-12	SW	1	oF	39	1	4150	St	10	10	55	37	–	-
	§Fichtelberg	3979	1012·4	-4	S	2	b	36	7	–	–	0	Tr.	907·7	-4	WSW	5	c	43	8	2500	St	4-6	7-8	43	36	–	-
	Berlin	138	1030·0	-6	WSW	2	bc	52	6	–	–	0	2-3	1024·3	-16	SW	2	bcm	43	4	-	-	0	4-6	57	?	–	?
	Hamburg	85	1028·7	-6	WSW	1	b	52	7	–	–	0	Tr.	1020·6	-24	ESE	2	c	41	4	5700	-	0	9+	59	39	–	-
	Stettin	49	1028·1	-6	WSW	3	c	52	7	4000	S	7-8	9	1022·7	-14	SW	2	b	43	7	-	-	0	1	57	39	–	-
	Breslau	410	1030·9	-4	–	0	bc	45	9	–	–	0	2-3												55		–	
	Dorpat	246	1008·8	-6	WSW	4	ir₀	46	6	1500	6	10	10	1011·5	+14	NNW	4	o	39	8	1500	St	10	10	•	•	1	0·4
	Danzig	72	1023·4	-18	SSW	5	c/pr	48	7	1500	6	4-6	7-8	1021·7	-2	WSW	1	bc	50	8	2500	Cu	tr	2-3	54	45	Tr	-
POLAND.	Warsaw	364												1024·0		W	2	f	45	4								
	Lemberg	1043	1032·3	-15	SW	1	bc	37	6	–	–	0	5	1028·0		SW	3	o	41	5					46		–	
	Pinsk	469	1027·4	-5	WSW	3	c	43	6	-	–	0	8												48		–	
	Vilna	466	1018·5	-20	SW	4	rr	41	5	1500	Nb	10	10												46		Tr	
FINLAND & RUSSIA.	Helsingfors	38																										
	Kuopio	275																										
	Archangel‡	23							•	•	•	•	•							•	•	•	•	•	•	•		
	Moscow‡	512							•	•	•	•	•							•	•	•	•	•	•	•		
	Sverdlovsk‡	922			•				•	•	•	•	•							•	•	•	•	•	•	•		
S.E. EUROPE.	Prague	833	1030·8	-6	–	0	m	48	4	–	–	0	0	1028·0	-16	SSE	1	bcm	37	4	-	-	0	2·3	59	41	–	-
	Kosice	657	1033·5	-8	–	0	b	39	8	–	–	0	0	1031·5	+4	-	0	bc	36	6	-	-	0	4-6	54	27	–	-
	Sofia (²)	1821																										
	Belgrade	453												1032·0		-	0	b	39	7								
	Zagreb	533																										
FRANCE & BELGIUM.	Brussels	328	1027·1	-10	ESE	2	bc	55	7	–	–	0	2-3	1017·2	-30	SSE	4	c	54	7	1500	Nb	4-6	10	64	48	–	2
	Calais	396	1026·1	-10	–	0	z	54	5	–	–	0	7-8														1	
	Le Havre	321	1024·9	-8	ESE	3	z	61	5	–	–	0	9+	1018·5	-4	SW	5	c	61	7	800	Nb	4-6	9+	•	•	–	2
	Brest	—	1020·9	-6	ESE	3	c	63	6	2500	9	4-6	9+	1021·6	?	WSW	4	oDDf	59	3	2500	St	10	10	•	•	3	0·5
	Rochefort	28												1025·0	+8	-	0	cf	59	3	4000	StCu	2·3	10	•	•		-
	Tours	361	1025·3	-4	E	2	m	63	4	–	–	0	4-6	1022·6	-4	WSW	3	ciR	63	6	1500	Nb	7-8	10	70	57	–	6
	Paris	527	1026·9	-6	ESE	1	z	61	5	–	–	0	4-6	1020·5	-16	S	1	c	57	5	1500	Nb	4-6	10	68	55	–	2
	Strasbourg	495	1030·6	0	–	0	z	50	5	–	–	0	0	1024·7	-14	W'S	1	of	43	3	4150	St	10	10	61	39	–	-
	Dijon	725	1028·1	-6	–	0	m	52	4	800	S	2-3	10	1024·2	-16	-	0	cf	64	2	450	St	4-6	9+	57	41	–	-
	Toulouse	535	1025·5	+4	SE	3	bc	70	7	–	–	0	4-6	1026·5	+10	SSE	3	c	61	6	800	St	9	9+	59		–	-
	Bayonne (Socoa)	—	1023·0	0	NE	1	c	75	6	–	–	0	7-8	1027·1	?	SW	2	c	66	4	2500	St	1	10	•	•	–	-
	Perpignan	98	1028·2	+8	ENE	1	o	66	6	2500	S	10	10	1027·7	+6	NE	1	o	64	5	450	St	10	10	•	•	–	tr
	Marignane	18	1028·5	+8	–	0	c	64	7	–	–	0	10	1028·2	+0	-	0	c	57	7	-	-	0	7-8	•	•	–	-
	Ajaccio	5	1027·4	+2	–	0	bc	68	7	2500	S	2-3	4-6	1028·2	+4	-	0	b	63	7	-	-	0	0	•	•	–	-
SPAIN, PORTUGAL, Etc.	Corunna	82	1025·4	+6	NNW	2	c	72	7	2500	7	2-3	7-8	1027·0		-	0	o	61	5					•	•	–	
	Madrid	2183												1029·0		NNE	2	o	61	9								
	Lisbon	312	1023·2	0	NNW	2	c	77	7	–	–	0	10	1026·0	0	NW	2	c	68						81		–	
	Azores (³) (Horta)	213	1020·3	+2	NNE	3	pr	64	7	2500	8	9	9	1025·4	+8	NNW	1	bc	61	9	4000	Cu	1	2·3	*	*	2	tr
	[illegible]	72	[illegible]	+8	NE	[illegible]	[illegible]	[illegible]	8	2500	7	2-3	4-6	[illegible]	+6		0	b	63	7	2500	Cu	1	1	*	*	–	-

SUNDAY, 5th


H
988
LOW
992
996
1000
1004
1008
1012
1016
1020
HIGH
"MINNEWASKA"
HIGH
1016
Bar
H
LOW
984
falling
slowly
LOW
984
988
992
996
1000
1004
1008
1012
1016
1020
1024
1028
HIGH
Barometer
falling
slowly
Barometer
falling
Barometer
"LAURENTIC"
Barometer
Bar
falling
"GEORGIC"
slightly
rising
Barometer
falling
slowly
generally
falling
Barometric
changes
slowly
1020
LOW
slight
EXPLANATION.
BAROMETER.—Isobars are drawn for intervals of four millibars.
WIND.—Direction is shown by arrows flying with the wind. Force, on the scale 0-12 by number of feathers. Calm
TEMPERATURE.—Given in degrees Fahrenheit.
WEATHER SYMBOLS.—clear sky;


LOW
HIGH
Barometer rising slowly
LOW
Barometer falling slowly
Bar. falling slowly
Barometer falling
Barometer falling slowly
LOW
Barometer falling
Barometer falling slowly
Bar. falling
changes
slowly
slight
CEDRIC
Bar rising slowly
HIGH
Barometer falling
LOW
LOW slowly
1004
1008
1012
1016
1020
1024
1028

STATIONS.		Height above Mean Sea Level. Feet.	OBSERVATIONS at 18 h. G.M.T. 4th October											OBSERVATIONS at 7 h. G.M.T. 5th October											Temp.		Rainfall.	
			Barom. at M.S.L. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F.	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt. 0–10	Barom. at M.S.L. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F.	Visibility 0–9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0–10	Cloud. Total Amt 0–10	Max. Day. °F.	Min. Night °F.	Day. mm.	Night mm.
ITALY & MEDITERRANEAN.	Turin	906												1019.9	-27	–	0	r	54									
	Padua	102												1017.2	?	N	1	u	57									
	Leghorn ...	46												1016.5	-10			c	68	6	5700	8	10	10	*	*		2
	Rome	168												1021.0	-14	N	1	c	64	*	*	5	7-8	9+		52		-
	Taranto	126												1022.6	0	E	2	c		7	-	-	00	7-8				-
	Messina	116												1022.4	-4			c	64	7	4000	7	4-6		*	*		-
	Cagliari... ...	248												1022.0	0	NNE	2	bc	63	6	*	4	4-6	4-6		55		-
	Gibraltar ...	53	1024.7	-4	E	3	bc	74	7	1500	5	2-3	4-6														-	
	Rabat	210	1022.9	+2	-	0	bc	77	3	-	-	0	2-3												*	*	-	
	Oran	174	1022.1	-6	-	0	bc		7	-	-	0	4-6												*	*	-	
	Mahon	141												1021.3	+35	NNW	1	bc	68	7	5700		4-6	4-6	*	*		-
	Bizerta	30	1026.1	0	E	3	bc	72	7	-	-	0	4-6												*	*		
	Malta	231	1026.0	+2	-	0	b	69	8	-	-	0	0	1022.2	-4	S	1	bc	71	8	-	-	0	4-6	74	64	-	-
	Benghasi ...	—	1026.1	0	E	3	b	72	7	-	-	0	1	1023.0		E	1	c	79	6					*	*	-	
	Athens (1) ...	351																										
	Candia†(2) ...	88	1024.0		NW	4	bc	64	*	*	*	*	*	1022.2	+3	NW	2	bc	66	*	*	*	*	*	75	61		
	Limassol†(2) ...	26	*	*	*	*	*	*	*	*	*	*	*							*	*	*	*	*	*	*		
	Cairo† (Helwan) (2)	379							*	*	*	*	*							*	*	*	*	*	*	*		
	Matruh†(2) ...	33	*	*	*	*	*	*	*	*	*	*	*							*	*	*	*	*	*	*		

(1) Observations at 19 h. and 6 h. G.M.T. (2) Observations at 18 h. and 6 h. G.M.T. ** Figures refer to New International Code, 1929. (*See* British Section).

WIRELESS REPORTS FROM THE ATLANTIC AND NORTH SEA.

Date and Hour.	Ship.	Lat. °N.	Long. °W.	Direc. of Ship.	Speed of Ship.	Bar. mb.	Change in 3 hours. ††	Wind. Direc.	Wind. Force.	Weather. Present.	Weather. Past.	Temp. Air. °F.	Dif. betw. Sea & Air Temp.	Visibility.	Cloud. ** Form Low.	Cloud. ** Form Med.	Cloud. ** Form High	Cloud. Amount. Low. 0–10	Cloud. Amount. Total 0–10	Swell. Code No.	Swell. Direc.
4th 12h.	CEDRIC	50°18'	21°18'	NE	6	1005	+2	NW	6	c/r	p	60	3	5	5	3	.	7-8	10	4	E
" 18h.	"	50°12'	18°30'	NE	6	1013	+50	NW	5	o	p	58	3	5	5	-	.	7-8	10	4	E
5th 0h.	"	50°48'	15°54'	NE	6	1011	-20	NNW	3	bc	b	56	5	7	5	-	2	2-3	4-6	5	W
" 6h.	"	51°06'	13°18'	NE	6	1010	-10	WSW	4	bc	p	56	0	7	4	-	-	4-6	4-6	5	W
5th 0h.	TRANSYLVANIA	55°30'	8°30'	W	*	998	+27	WNW	6	c	bc	55	4	7	8	-	9		7-8	5	W
" 6h.	"	55°30'	11°06'	W	*	?	+12	W	6	o	o	52	5	7	6	-	-	10	10	5	W
4th 12h.	CORINTHIC	48°00'	16°36'	E	*	1018	0	SW	4	o	o	60	5	6	9	-	-	10	10	1	SW
" "	DUNBAR CASTLE	46°36'	7°00'	SW	*	1024	0	W'S	5	bc	bc	64	4	7	8	-	4		2-3	1	SW
" "	FRANCONIA	51°18'	11°12'	E	6	1011	-24	SSW	5	d	d	58	4	7	5	-	-	10	10	3	SW
5th 0h.	MINNEWASKA	50°12'	11°54'	E	*	1014	0	NW	4	c/r	p	57	5	8	4	-	-	7-8	7-8	2	W
" 6h.	LAURENTIC	56°06'	11°36'	W	6	1002	+2	W'N	6	o	r	53	6	7	6	-	-	10	10	3	W
" "	RAZMAK	44°18'	8°42'	SW	*	1022	0	SW	5	c	bc	65		7	8	-	-	4-6	4-6	1	SW
5th 01h.	DIEPPE	50°18'	E0°30'	*	*	*	*	WSW	6	r	*	60	5	7	*	*	*	*	*	5	SW
4th 12h.	ST. JULIEN	50°00'	2°24'	*	*	*	*	WSW	6	d/r	*	58	4	7	*	*	*	*	*	4	W

†† Barometric change in 3 hours is given in tenths of millibars.

SPEED OF SHIP.

0... 0	5...13–15 knots
1...1–3 knots	6...16–18 „
2...4–6 „	7...19–21 „
3...7–9 „	8...22–24 „
4...10–12 „	9... >24 „

DIFFERENCE BETWEEN SEA & AIR TEMPERATURE °F

0	... >9	Air temperature same as or higher than sea temperature.
1	... 6–9	
2	... 3–6	
3	... 1–3	
4	... 0–1	
5	... 0–1	Air temperature lower than sea temperature.
6	... 1–3	
7	... 3–6	
8	... 6–9	
9	... >9	

STATE OF SWELL.

Ships using New International Code (1929) report swell in following code:—

0...None.
1...Short or average length } Low.
2...Long
3...Short } Moderate height.
4...Average length
5...Long
6...Short } Heavy.
7...Average length
8...Long
9...Confused.

CLOUD AMOUNT.

Figures indicate number of tenths of sky covered by low cloud. An entry 4–6 means that cloud amount may be 4, 5 or 6: similarly for other grouped entries, "tr" signifies a small amount of cloud covering less than $\frac{1}{10}$ of the sky. "9+" signifies an overcast sky with a few small openings.

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AIR MINISTRY.

DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON:

INTERNATIONAL SECTION. No. 25154 5th October 1930.

	STATIONS.	Height above Mean Sea Level. Feet.	OBSERVATIONS at 18h. G.M.T. 4th October: Barom. at M.S.L. mb.	Change in 3 hours.††	Wind. Direc.	Wind. Force	Weather.	Temp. °F	Visibility 0-9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0-10	Cloud. Total Amt. 0-10	OBSERVATIONS at 7h. G.M.T. 5th October: Barom. at M.S.L. mb.	Change in 3 hours.††	Wind. Direc.	Wind. Force.	Weather.	Temp. °F.	Visibility 0-9	Cloud. Low. Height Feet.	Cloud. Low. ** Form.	Cloud. Low. Amt. 0-10	Cloud. Total Amt 0-10	Sea.	Temp. at 13h. 4th.	Rainfall. Day. mm.	Rainfall. Night mm.
ICELAND, &c.	Julianehaab (1) ...	213							•	•	•	•	•							•	•	•	•	•	•	•	•	•
	Isafjord ...	13	987.2	+7	-	0	c	46	•	•	Nb.	•	8	989.5	-7	N	4	RRS	37	•	•	St.	•	10	•	46	•	•
	Reykjavik ...	92	988.2	-13	SW	1	bc/r	46		1500	Cu.Nb	3	4	985.8	0	SSE	1	b-	37	8	1500	St.	2	2	•	48	0.5	-
	Vestmanna ...	433	991.1	-13	SW	3	c/pr	46	•	•	Cu.	•	5	984.7	-7	E	3	c/pr₀	43	•	•	Cu.Nb.	•	8	•	46	•	•
	Seydisfjord ...	28	985.5	-20	S	1	od/q	48	•	•	Nb.	•	10	985.4	+7	-	0	bc	46	•	•	St.Cu.	•	6	•	54	•	•
	Thorshavn ...	34	990.2	-18	S	4	rr	52	6	800	6	10	10	987.5	+2	W	3	c	45	7	800	6	9	9	•	48	3	3
	Spitsbergen ...	37	1017.4	+2	S	2	bc	16	9	4000	5	2-3	2-3	1016.2	-8	-	0	bc	12	8	2500	5	2-3	2-3	•	18	Tr.	•
	Bear Island ...	182	1012.3	+5	NE	5	c	30	9	5700	St.Cu.	9	9													30	-	
	Jan Mayn ...	76	1006.1	-10	ENE	7	rs	37	7	450		10	10	[illegible]		ENE	7	RR	36	4						32	/	
NORWAY.	Vardö ...	46	1003.7	+6	NNE	4	c	36	9	-	-	0	9+												•	32	-	
	Ingöy ...	25	1008.2	+26	N	5	c/pr	36	8	2500	8	4-6	9													34	2	
	Röst ...	34	1011.9	-12	NNE	3	bc	37	9	4000	4	4-6	4-6	1003.1	-20	ENE	6	bc	39	9	5700	/	2-3	4-6	3	39	Tr.	-
	Kinn ...	26	1005.7	-26	SE	6	r/o	48	7	1500	6	10	10													48	/	
	Utsire ...	188	1004.7	-16	SSE	5	c/s	46	8	2500	8	10	10	989.0	-36	ESE	4	r/o	48	8	2500	6	4-6	10	2	50	/	8
SWEDEN.	Haparanda ...	30	1009.2	+2	NW	2	b	38		•	-	0	0	1008.4	0	N	1	b	35	9	•	-	0	0	•	41	-	-
	Härnösand ...	67	1012.4	-14	-	0	bc	32	9	4500	/	2-3	2-3	1003.5	-26	-	0	rr	41	6	450	6	10	10	0	46	-	3
	Stockholm ...	144	1014.0	-20	WSW	1	bc	43	5	•	-	0	2-3	1002.0	-26	SE	3	c	46	6	•	5	4-6	10	•	40	-	•
	Wisby ...	36	1014.9	-14	E	1	c	45	9	•	-	0	7-8		-30	E	5	o	50	9	•	6	10	10	•	48	-	•
	Karlstad ...	172	1010.7	-26	S	1	o	48	•	•	5	10	10	997.7	-32	E	3	d₀d₀	46	•	•	6	10	10	•	52	-	/
	Särna ...	1430	1010.6		-	0	c	39	9	•			10								•				•	46	-	
DENMARK & HOLLAND.	The Scaw ...	10												994.3	-26	SE	5	d	50	5	2500	6	10	10		54		4
	Blaavands Huk ...	49	1006.4	-34	SE	3	r/o	48	6	2500	6	10	10													50	2	
	Copenhagen ...	16												996.0	-44	WSW	2	f	52	3						52		2
	Bornholm ...	253	1013.8	-44	S	1	o	50	7	2500	6	10	10													54	•	
	Helder ...	19	1008.3	0	W	5	c	59	6	1500		9+	9+	994.7	+6	W	7	PR	59	6	800	6	2-3			59	/.	
	Flushing ...	26																								61		
SWITZERLAND, GERMANY, ESTONIA, Etc.																									Temp. Max. Day.	Temp. Min. Night		
	Geneva ...	1329	1024.7	+4	NW	1	c/r	59	8	2500	6	10	10	1020.0	-4	SW	2	c/p	59	9	4000	9	10	10	66	55	2	0.1
	Lugano ...	906	1023.2	-16	N	1	c	57	7	7200			10	1017.9	-14			c	50	7				7-8	63	46	-	
	§Säntis ...	8202	755.7	-13	WSW	7	orr	37	0	•	St.	10	10								•				41		4	
	Munich ...	1726	1018.7	-10	W	8	c/pr	57	5	1500	6	4-6	10	1013.2	-6	WSW	8	c/pr	57	8	2500	6	4-6	10	68	54	4	3
	§Fichtelberg ...	3979	999.7	-12	WSW	6	r/o	41	5	220	6	10	10												48		Tr.	
	Berlin ...	138	1011.9	-28	SSE	2	o	55	5	2500	5	10	10	1002.0	-18	SW	2	r/o	54	4	1500	6	10	10	57	52	Tr.	3
	Hamburg ...	85	1008.3	-32	SE	3	l	50	5	1500	6	10	10	995.9	-46	SSW	4	dr	55	6	800	6	10	10	52	52	7	17
	Stettin ...	49	1013.4	-26	SSE	1	c	52	7	4000	5	7-8	10	1000.4	-14	SW	3	c	54	5	2500	6	7-8	9+	59	48	-	/
	Breslau ...	410	1015.3	-32	S	3	c	52	5	4000		10	10												63		-	
	Dorpat ...	246	1012.8	0	W	2	b	34	7		-	0	0	1009.6	-4					5	1500				•	•	-	-
	Danzig ...	72																										
POLAND.	Warsaw ...	364																										
	Lemberg ...	1042																										
	Pinsk ...	469																										
	Vilna ...	466																										
FINLAND & RUSSIA.	Helsingfors ...	38												1009.0		NE	3	o	34	7								
	Kuopio ...	275																										
	Archangel‡ ...	23							•	•	•	•	•							•	•	•	•	•	•	•		
	Moscow‡ ...	512							•	•	•	•	•							•	•	•	•	•	•	•		
	Sverdlovsk‡ ...	922							•	•	•	•	•							•	•	•	•	•	•	•		
S.E. EUROPE.	Prague ...	833												1007.0		WSW	5	p/r₀	59	8								
	Kosice ...	657												1016.7	-12	SSE	1	c	41	8	4000	5	4-6	9		36		/
	Sofia (2) ...	1821																										
	Belgrade ...	453																										
	Zagreb ...	533																										
FRANCE & BELGIUM.	Brussels ...	328	1013.2	0	WS	3	c	59	7	4000	7	9+	9+	1002.3	+14	W	4	o/r	57	7	450	6	10	10	63	55	0.4	2
	Calais ...	396	1013.4	0	WSW	7	c	57	6	450	9	7-8	9	1009.6	+8	WSW	7	c	57	6	800	9	7-8	9	•	•	0.5	14
	Le Havre ...	321	1016.7	-4	WSW	6	u	59	7	1500	6	10	10	1007.4	-2	W	8	c/p	66	6	•	6	4-6	9+	•	•	0.2	4
	Brest ...	—												1012.2	-12	W	2	r₀d₀	55	4	450		10	10	•	•		3
	Rochefort ...	28	1024.7	0	W	4		64	6	1500	2		7-8	1017.1	-20	WSW	5	c	64	6	1500	9	7-8	10	•	•	0.2	0.2
	Tours ...	361	1021.1	0	W	3	bc	61	7	2500	2	2-3	4-6	1013.9	-10	W	3	c	61	6	800	6	7-8	10		57		Tr.
	Paris ...	527												1009.7	-14	WSW	4	c	61	6	1500	6	7-8	10		57		2
	Strasbourg ...	495	1019.3	-4	S	3	c	59	7	1500	2	7-8	7-8												59			
	Dijon ...	725	1021.1	0	NW	4	c	59	7	1500	6	4-6	7-8	1016.1	-18	WSW	4	r/o	55	6	1500	6	7-8	10	61	55	7	0.6
	Toulouse ...	535	1024.9	+4			c	66			7		10	1021.8	0	W	1	bc	63	6	800	5	2-3	4-6	77	63	0.3	-
	Bayonne (Socoa)	—	1025.7	-2	S	2	bz	64	6	-	-	0	4-6	1022.1	-10	SSW	2	bc	61	7	-	-	0	2-3	•	•	/	-
	Perpignan ...	98	1024.3	-4	-	0	z	64	7	1500	6		10	1020.7		WNW	2	c	64	7	2500	2	4-6	7-8	•	•	0.3	0.3
	Marignane ...	18	1023.7	0	-	0	c	50	7	2500	5	9	10	1019.3	-2	WSW	8	z	63	6	-	-	0	9+	•	•	-	-
	Ajaccio ...	5	1024.8		-	0		68	7				10	1018.9	-4	-	0	c	68	7	2500	9	7-8	10	•	•		Tr.
SPAIN, PORTUGAL, Etc.	Corunna ...	82	1027.4	-4	NW	2	b	66	6	2500	/	/	/												•	•	-	
	Madrid ...	2183												1023.8	0	W	3	b	63	8	-	-	0	0		61		-
	Lisbon ...	312	1026.0	0	NW	4	c	79						1024.0	0	NNW	2	bc	68									
	Azores (5) (Horta)	218	1026.8	+6	NNE	1	bc	70	9	4000	8	2-3	4-6	1027.9	+2	WNW	1	bc	61	9	2500	/	Tr	2-3			-	-
	,, (P. Delgada)	72	1026.0	+2	NE	2	bc	68	8	2500	2	4-6	4-6	1027.3	-4	NEE	5	c	66	6	2500	4	7-8	7-8			-	-

APPENDIX VI.

EXPERIMENTS AND CALCULATIONS CARRIED OUT AT THE NATIONAL PHYSICAL LABORATORY.

(*Prepared by* Professor C. E. INGLIS.)

1. As a preliminary to the design of R101, experiments on models were carried out to determine the aerodynamic characteristics of alternative forms for hull and fins, and from the results of these experiments, the design of R101 in its original form was decided.

This preliminary experimental work is set forth in great detail in Reports and Memoranda No. 1168, Aeronautical Research Committee, entitled " Experiments on a Model of the Airship R101," by R. Jones, M.A., D.Sc. and A. H. Bell: September, 1926.

Since no corresponding model experiments had been performed to determine the external aerodynamic forces on R.101 after its form was modified by the introduction of a forty-five foot bay, the Court of Inquiry requested the National Physical Laboratory to undertake such a series of tests, as it was thought that the information derived therefrom might possibly throw some light on the causes of the disaster, and would certainly be required for various aerodynamic calculations the Court had in view.

The results of these experiments were communicated to the Court in a Report from the National Physical Laboratory dated November 26th, 1930, and from that Report the following results have been abstracted.

The model employed was about 43 inches long and 7 inches diameter at its fullest section. The linear scale was 1 to 217·26.

This model was more exact than that used in the original tests, in that the five power cars and the control cabin were included. Furthermore it was made with 30 sides, whereas the model of R101, in its original form, did not take into account the reefing girders, and consequently was constructed with only 15 sides. The hinging of the control surfaces was also more accurately represented, and this modification, though slight in general appearance, had a marked effect on the aerodynamic characteristics of these elevator controls.

This model was subjected to a uniform wind velocity of 50 feet per second in the wind tunnel at the N.P.L. It was held with its axis pitched up or down at various inclinations θ, and for each angle of pitch, the aerodynamic forces and couples acting on the model were determined for a range of elevator angles η.

The positive directions of these angles θ and η are shown in Fig. (1).

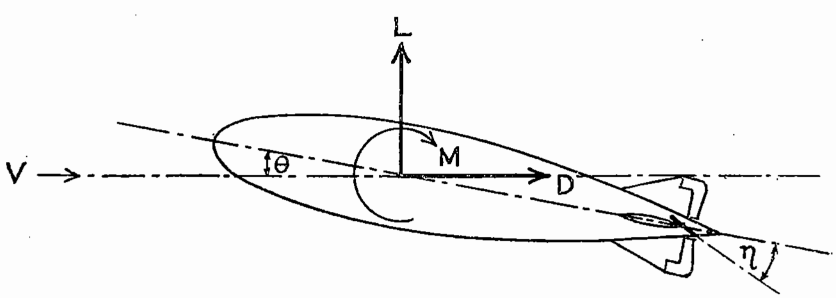


FIG. 1.

The resultant action on the model produced by wind pressure was measured by the following three components :

(1) D, the horizontal force or " drag," acting in the direction of the wind.

(2) L, the vertical force or " lift."

(3) M, the " pitching moment," that is the moment of the aerodynamic forces about a horizontal transverse axis through the centre of buoyancy. This moment is taken to be positive when it tends to tilt the model up by the nose, as shown in the Fig. (1).

The values of D, L and M obtained by the wind-tunnel experiments are set forth in Tables 1, 2 and 3.

These values were all determined for a wind speed of 50 feet per second, and to obtain the corresponding values at a wind speed of V feet per second, these tabulated results must be multiplied by $\left\{\frac{V}{50}\right\}^2$.

For similar models, the values of the forces D and L vary as the square and the values of M vary as the cube of the linear dimensions.

Hence for R.101, the resultant aerodynamic forces for a wind speed of V feet per sec. are these tabulated values of D and L multiplied by $\left\{\frac{V}{50}\right\}^2 \times (217 \cdot 26)^2$, and the pitching moments are the tabulated values of M multiplied by $\left\{\frac{V}{50}\right\}^2 \times (217 \cdot 26)^3$. In this way, from the results given in Tables 1, 2 and 3, the drag, lift and pitching moment for R.101 can be deduced for any given air speed, angle of pitch, and elevator angle, and for a state of steady motion in which the ship is neither changing the magnitude or direction of its air speed or varying its angle of pitch, it is possible to examine how far the elevator controls can with or without alteration of ballast maintain the state of steady motion, in spite of general or local loss of buoyancy owing to gas-bag deflation.

Equilibrium of the Ship with engines stopped under various conditions of gas-bag deflation.

2. It is a matter of simple computation to determine the downward pitching moment and loss of lift consequent on the total or partial deflation of one or more gas-bags in the forward part of the ship. The capacity of these gas-bags is set forth in a footnote at the bottom of page 25 of the Main Report.

The question to be answered was—how far is it possible by merely dropping some of the ballast and retrimming the residue, to maintain the ship on an even keel under various conditions of forward gas-bag deflation, the engines being stopped and the ship floating stationary relative to the air. An answer to this question is contained in Tables 4 and 5.

To neutralize loss of buoyancy it is assumed that water ballast is in the first instance liberated from the forward part of the ship, and if this is insufficient, oil fuel ballast is then released, most of this being discharged from the forward ballast tanks.

One gas-bag completely deflated.

3. A comparison of columns C and D of Table 4, reveals that with the exception of cases 2 and 3, the mere discharge of ballast can over-compensate for the downward pitching moment due to gas-bag deflation, and in these two cases, the comparatively slight deficiency in the restoring moment can be made good by a small retrimming of the residual ballast. In the other cases, the compensation being over done, to maintain horizontal trim, some of the residual ballast will have to be pumped from

Drag measured in lbs. Speed 50 f.s.

Angles of Elevators (η).

Angle of Pitch (θ)		Elevators up −25°	−20°	−15°	−10°	−5°	0°	Elevators down 5°	10°	15°	20°	25°
Pitch up	20°	0·260	0·261	0·267	0·282	0·287	0·301	0·319	0·333	0·355	0·384	0·401
	15°	0·165	0·167	0·168	0·174	0·177	—	0·198	0 211	0·230	0·250	0·261
	10°	0·101	0·102	0·101	0·105	0·104	0·108	0·118	0·126	0·140	0·156	0·162
	5°	0·074	0·072	0·068	0·070	0·068	0·069	0·073	0·079	0·084	0·095	0·100
	2°	0·069	0·064	0·059	0·059	0·057	0·057	0·058	0·064	0·068	0·074	0·079
	0°	0·070	0·063	0·050	0·057	0·054	0·053	0·055	0·056	0·060	0·067	0·071
Pitch down	−2°	0·076	0·068	0·061	0·059	0·054	0·053	0·053	0·054	0·057	0·063	0·066
	−5°	0·091	0·081	0·072	0·068	0·061	0·058	0·057	0·057	0·059	0·062	0·067
	−10°	0·147	0·133	0·115	0·108	0·096	0·088	0·083	0·084	0·083	0·084	0·084
	−15°	0·231	0·213	0·192	0·183	0·164	0·153	0·146	0·138	0·138	0·136	0·135
	−20°	0·347	0·321	0·298	0·288	0·265	0·253	0·242	0·230	0·224	0·219	0·218
	−25°	0·502	0·475	0·448	0·439	0·412	0·389	0·377	0·359	0·355	0·344	0·338
	−30°	0·683	0·659	0·631	0·630	0·600	0·571	0·599	0·535	0·529	0·509	0·511
	−35°	0·896	0·872	0·851	0·855	0·826	0·800	0·780	0·748	0·743	0·731	0·724
	−40°	1·150	1·128	1·097	1·109	1·066	1·034	1·034	0·992	0·998	0·976	0·973

TABLE 1.

Lift measured in lbs. Speed 50 f.s.

Angle of elevators (η).

Angle of pitch (θ)		Elevators up						Elevators down				
		−25°	−20°	−15°	−10°	−5°	0°	5°	10°	15°	20°	25°
Pitch up	20°	0·571	0·581	0·607	0·646	0·662	0·695	0·726	0·751	0·778	0·819	0·832
	15°	0·366	0·384	0·399	0·418	0·436	—	0·496	0·528	0·565	0·590	0·606
	10°	0·178	0·197	0·213	0·230	0·243	0·271	0·300	0·332	0·359	0·393	0·407
	5°	0·025	0·047	0·076	0·026	0·098	0·122	0·142	0·173	0·195	0·226	0·235
	2°	−0·054	−0·027	0·003	0·012	0·029	0·052	0·076	0·103	0·123	0·150	0·160
	0°	−0·099	−0·075	−0·046	−0·028	−0·011	0·009	0·025	0·050	0·069	0·098	0·111
Pitch down	−2°	−0·156	−0·131	−0·097	−0·077	−0·055	−0·035	−0·015	0·015	0·027	0·055	0·070
	−5°	−0·232	−0·213	−0·173	−0·154	−0·132	−0·107	−0·083	−0·060	−0·045	−0·021	−0·006
	−10°	−0·402	−0·383	−0·340	−0·325	−0·287	−0·257	−0·232	−0·201	−0·195	−0·174	−0·162
	−15°	−0·586	−0·560	−0·541	−0·510	−0·468	−0·433	−0·410	−0·376	−0·369	−0·351	−0·338
	−20°	−0·785	−0·753	−0·715	−0·711	−0·669	−0·638	−0·614	−0·580	−0·562	−0·533	−0·529
	−25°	−0·984	−0·965	−0·926	−0·939	−0·891	−0·849	−0·831	−0·785	−0·776	−0·750	−0·727
	−30°	−1·165	−1·147	−1·114	−1·138	−1·093	−1·054	−1·039	−0·994	−0·987	−0·959	−0·941
	−35°	−1·306	−1·298	−1·269	−1·303	−1·259	−1·235	−1·207	−1·169	−1·172	−1·147	−1·128
	−40°	−1·450	−1·433	−1·408	−1·447	−1·410	−1·385	−1·375	−1·344	−1·333	−1·316	−1·302

TABLE 2.

Pitching Moment in lbs. feet. Speed 50 f.s.

Angles of Elevators (η).

Angles of Pitch (θ)		←Elevators up				→		← Elevators down				→
		−25°	−20°	−15°	−10°	−5°	0°	5°	10°	15°	20°	25°
Pitch up	20°	0·352	0·323	0·280	0·255	0·200	0·149	0·092	0·030	−0·017	−0·086	−0·117
	15°	0·352	0·326	0·304	0·286	0·238	—	0·143	0·081	0·032	−0·036	−0·055
	10°	0·337	0·311	0·276	0·272	0·234	0·194	0·146	0·089	0·045	−0·012	−0·031
	5°	0·273	0·234	0·195	0·184	0·155	0·118	0·083	0·039	0·004	−0·050	−0·061
	2°	0·210	0·174	0·135	0·110	0·079	0·039	0·008	−0·032	−0·062	−0·112	−0·136
	0°	0·160	0·124	0·079	0·055	0·020	−0·009	−0·035	−0·075	−0·101	−0·147	−0·167
Pitch down	−2°	0·132	0·089	0·039	0·012	−0·029	−0·062	−0·093	−0·130	−0·156	−0·195	−0·220
	−5°	0·074	0·036	−0·015	−0·051	−0·093	−0·133	−0·168	−0·201	−0·226	−0·263	−0·280
	−10°	0·033	−0·005	−0·056	−0·102	−0·157	−0·205	−0·246	−0·277	−0·299	−0·332	−0·350
	−15°	0·031	−0·012	−0·069	−0·117	−0·176	−0·231	−0·264	−0·313	−0·336	−0·362	−0·375
	−20°	0·057	0·014	−0·051	−0·099	−0·154	−0·216	−0·255	−0·303	−0·333	−0·368	−0·379
	−25°	0·100	0·058	0·001	−0·039	−0·100	−0·164	−0·206	−0·258	−0·295	−0·337	−0·360
	−30°	0·118	0·086	0·048	0·001	−0·046	−0·114	−0·163	−0·209	−0·245	−0·294	−0·321
	−35°	0·110	0·082	0·053	0·020	−0·022	−0·088	−0·131	−0·174	−0·205	−0·245	−0·277
	−40°	0·131	0·102	0·052	0·032	−0·009	−0·067	−0·094	−0·138	−0·169	−0·203	−0·226

TABLE 3.

the aft to the forward tanks, otherwise the ship will become pitched up by the bow. The general conclusion to be drawn from Table 4 is, that provided there is sufficient time, the ship can be made to " float " on an even keel, even under the extreme condition of a forward gas-bag completely deflated. In this connection, however, it should be understood that although the dropping of ballast is an instantaneous process, pumping ballast from one tank into another with a view to retrimming the ship is an operation which may well occupy half an hour or more.

Two gas-bags completely deflated.

4. An examination of Table 5 and a comparison of columns C and D reveals that in most cases the mere release of ballast is insufficient to prevent the ship pitching down by the nose, and to keep the ship on an even keel, a considerable retrimming of ballast would be necessary. In most of the cases, however, this adjustment cannot be made, since, in order to neutralize the loss of lift, it is necessary to release almost the whole of the emergency fuel ballast, and there is none left for retrimming the ship. In these cases horizontal trim is impossible and the ship becomes pitched down by the nose. As the angle of downward inclination increases, the pitching moment causing this inclination decreases, and is met by an opposing pitching moment arising from the fact that the centre of gravity of the ship is about 29 feet below its centre of buoyancy. Accordingly the ship is capable of taking up a new inclined position of equlibrium, the angles of downward pitch being as shown in the right hand column of Table 5.

The cases of two adjacent forward gas-bags half deflated are somewhat less severe than the cases dealt with in Table 4, and it is always possible to retrim the ship so that it can float on an even keel.

In the case where two adjacent forward gas-bags are 75 per cent. deflated, equilibrium with the axis of the ship horizontal cannot be attained in all cases. When gas-bags 3 and 4, 4 and 5, 5 and 6, are 75 per cent. deflated, equilibrium is only attained when the downward inclinations of the ship are 6°, 11° and 5°, respectively.

Steady Flight under Various Conditions of " Heaviness."

5. Having studied the possibilities of the ship merely floating under various conditions of gas-bag deflation, consideration was next given to the question of the aerodynamic control available when the ship is driven forward at a constant air speed of 55 knots (her normal cruising speed), at different angles of pitch θ and with different elevator angles η.

Complete information on this point can be deduced from the figures supplied by the National Physical Laboratory, as set forth in Tables 1, 2 and 3. From these tables it is possible to determine the angle of pitch θ and the elevator angle η to provide at this air speed, a given lift L and a given pitching moment M.

For instance, it will be found that an upward lift of 10 tons combined with a pitching moment of 3,500 tons feet can be achieved by flying the ship pitched up through 8·2°, and with the elevators turned 10° downwards.

An important general conclusion which can be drawn from these tables is that, assuming R.101 is initially 4 tons heavy and then loses further buoyancy owing to the total deflation of any one of the forward gas-bags, there is ample aerodynamic control to deal with the general and local heaviness, using only the elevator control and without having resort to dropping or shifting ballast.

The corresponding case of two adjacent gas-bags deflated was not studied, because constant air speed is a wrong condition to impose. Instead of constant air speed, constant horse-power is the correct assumption, and there is reason to believe that almost up to the instant when the airship struck the ground, the engines were kept running at a constant H.P.,

TABLE 4.

ANY ONE FORWARD GAS-BAG COMPLETELY DEFLATED.

No. of gas-bag deflated.	Loss of lift in tons.	Ballast dropped in tons.		Fuel Ballast left in tons.	D. Pitching Moment due to deflation in Tons Feet.	A. Pitching Moment due to dropping water ballast.	B. Pitching Moment due to dropping Fuel ballast.	C. Combined action of A. and B.
		Water.	Fuel.					
1	0·60	0·60	Nil.	25·20	− 191	198	0	198
2	3·54	3·54	Nil.	25·20	−1026	994	0	994
3	9·47	5·00	4·47	20·73	−2336	1125	999	2124
4	12·65	5·00	7·65	17·55	−2511	1125	1472	2597
5	14·39	5·00	9·39	15·81	−2193	1125	1691	2816
6	15·07	5·00	10·07	15·13	−1634	1125	1691	2816
7	14·53	5·00	9·53	15·67	− 948	1125	1691	2816
8	14·45	5·00	9·45	15·75	− 320	1125	1691	2816

TABLE 5.

ANY TWO FORWARD GAS-BAGS COMPLETELY DEFLATED.

No. of Gas Bags deflated.	Loss of Lift. (Tons).	D Pitching Moment due to deflation. (Tons feet).	Ballast dropped (Tons). Water.	Ballast dropped (Tons). Fuel.	Fuel Ballast left (Tons).	A Pitching Moment due to dropping water ballast (Tons feet)	B Pitching Moment due to dropping fuel ballast (Tons feet)	C Pitching Moment due to combined actions A & B (Tons feet)	Further restoring Moment obtained by re-trimming residual ballast.	Net restoring pitching Moment. (Tons, (feet)	Down-ward angle of pitch.
1 & 2	4·14	−1217	4·14	0	25·20	1050	0	1050	1869	1702	—
2 & 3	13·01	−3362	5·00	8·01	17·19	1125	1518	2643	697	−22	—
3 & 4	22·12	−4847	5·00	17·12	8·08	1125	1384	2509	0	−2338	34½°
4 & 5	27·04	−4704	5·00	22·04	3·16	1125	1049	2174	0	−2530	38°
5 & 6	29·46	−3827	5·00	24·46	0·74	1125	984	2109	0	−1718	24½°
6 & 7	29·60	−2582	5·00	24·60	0·60	1125	958	2083	0	− 499	7°
7 & 8	28·98	−1268	5·00	23·98	1·22	1125	1038	2163	0	895	—

which would give the ship an air speed of 55 knots when travelling at 0° pitch and 0° elevator. If, however, in the stages immediately preceding the disaster, the ship became additionally heavy either generally or locally, the increased angle of pitch and the elevator-angle necessary to counteract the loss of lift and pitching moment may add very considerably to the drag, and with the engines continuing to give the thrust horse-power corresponding to an air-speed of 55 knots under normal conditions, the air-speed must inevitably drop to a marked extent as the heaviness increases.

This reduction of speed on the basis of constant " thrust horse-power " can be computed approximately as follows :—

Let D_o be the drag at 0° pitch and 0° elevator,

Let D be the drag at θ° pitch and η° elevator.

Both these drags corresponding to the same air-speed, say 50 f.s.

If Vo and V are the actual speeds of the ship corresponding to these two different conditions of flight, the resistance to motion in the two cases will be in the ratio $D_o V_o^2 : D. V^2$, and if the horse power expended in overcoming these resistances is the same, $D_o V_o^3 = D.V^3$, or $\frac{V}{V_o} = \left(\frac{D_o}{D}\right)^{\frac{1}{3}}$

An idea of the extent of the change in speed is conveyed in the following table :

Angle of pitch	0°	2°	4°	6°	8°	10°	15°	20°
Air-speed knots ..	55	54	52	48	44	40	32	28

The elevator being in the neutral position in each case.

The statement $\frac{V}{V_o} = \left(\frac{D_o}{D}\right)^{\frac{1}{3}}$ is likely to understate somewhat the loss of speed due to increased drag, because it assumes that the airscrew efficiency is constant, whereas it tends to fall off slightly at lower speeds.

On this assumption of constant " thrust horse-power " instead of constant air-speed Fig. (2) has been deduced from Tables 1, 2 and 3 and from this diagram very important inferences can be drawn.

In this diagram the full line shows the maximum aerodynamic pitching moments available for a corresponding range of aerodynamic lift, the elevators being set to give the maximum effect.

It will be seen that the maximum moment is about 3,300 tons feet, the aerodynamic lift then being about 3 tons.

For lifts above 12 tons, the upward pitching moment which can be provided by the elevator controls falls off very rapidly. From this diagram it is accordingly a simple matter to examine how far it is possible, by elevator control only, to maintain a condition of steady flight when there is loss of lift combined with pitching moment consequent on a forward gas-bag deflation.

Imagine that the ship is initially 4 tons heavy, this heaviness being general and producing no pitching moment. Suppese that in addition gas-bag No. 4 begins to lose gas. The downward pitching moment due to this deflation is directly proportional to the loss of gas, and consequently, when the additional loss of lift corresponds to an amount QN shown on the diagram, the downward pitching moment is represented by PN, where $\frac{PN}{QN}$ is a constant. When the gas-bag is completely deflated, the total aerodynamic lift called for is 16·65 tons and the downward pitching moment to be corrected is 2,511 tons feet. These two quantities define a point A_4 on the diagram, which is well outside the region of possible aerodynamic control, as shown by the full line on the diagram, the limit being reached when the bag is about 60 per cent. deflated. Similar points corresponding to the total deflations of gas-bags Nos. 1, 2, 3, 5, 6, 7, 8 are located on the diagram and it is evident that aerodynamic control alone is insufficient to cope with the complete deflation of any one of the gas-bags Nos. 4, 5, 6, 7, 8.

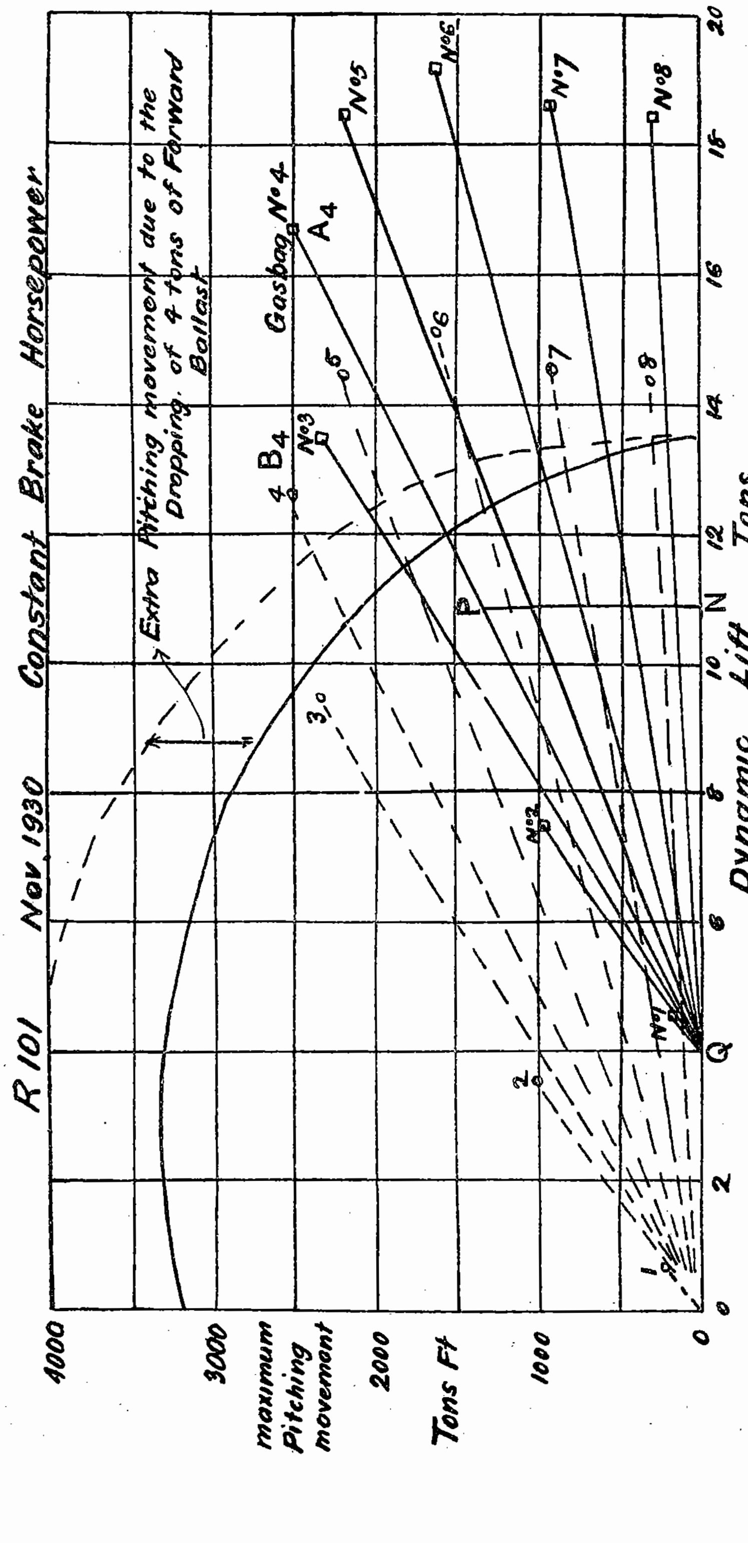

R 101 Nov 1930 Constant Brake Horsepower
Extra Pitching movement due to the Dropping of 4 tons of Forward Ballast
Gasbag No 4
A4
B4
No 3
No 5
No 6
No 7
No 8
No 2
No 1
P
N
Q
maximum Pitching movement
Tons Ft
Dynamic Lift Tons
4000
3000
2000
1000
0
2
4
6
8
10
12
14
16
18
20

FIG. 2.

Dropping of Emergency Ballast.

6. From the control car 4 tons of emergency fuel ballast can be quickly released, and this will provide 700 tons feet of upward pitching moment. If this is done, the curve giving the maximum pitching moment available for the corresponding range of lifts is shown by the dotted curve on the diagram.

The effect of releasing this 4 tons of emergency ballast is to bring the centre of the radiating lines back from Q to the point of zero lift.

The points, of which B_4 is a specimen, give the lift and pitching moment required when these various gas-bags are completely deflated, and it will be seen that in the case of gas-bags 4–8, even the assistance provided by the dropping of 4 tons emergency ballast is insufficient to enable the aerodynamic controls to provide the necessary pitching moment and lift. A state of steady flight is no longer possible, and the ship must inevitably descend. The exact manner in which she makes this descent is an investigation of a far more complicated, and possibly, less precise character.

Analytical Investigations Relating to the Path of Descent of R.101.

7. The immediate cause which forced R.101 to make her final plunge to destruction can only be inferred indirectly by considerations of the behaviour of the ship in her last moments. None of the officers or crew who were actively concerned in the navigation of the ship at the time of the disaster survived to tell their tale, and the subsequent fire destroyed all the material evidence which might have thrown direct light on the cause of the catastrophe. It is well established that the ship made a steep and prolonged dive followed by a brief recovery. Another dive, probably less steep and prolonged than the first, terminated in the ship striking the ground nose down at an angle of probably not less than 15 degrees, the final impact being so little violent that it was barely noticeable in the after engine car. About the time when the second dive started, orders were sent to stop the engines, but the shortness of time prevented this order being carried fully into effect before the crash occurred. It is known also that in these last moments a man was sent forward to release ballast, and it would appear probable that emergency ballast was released from the control car, though there is no direct evidence on this point. The height from which the ship fell was probably not less than 1,000 feet or more than 1,500 feet, and the time from the commencement of the first dive to the final crash is estimated to be between one and two minutes, though even these wide limits of height and time are somewhat speculative.

With these somewhat meagre facts as a working basis, an attempt has been made to reconstruct by mathematical analysis the path of descent of the airship in her final plunge.

Many different assumptions relating to general or local heaviness, wind buffets and increased drag were propounded, and the paths of descent corresponding to these various conditions were worked out mathematically by the aerodynamic scientists of the National Physical Laboratory.

These calculations call for great skill and involve much laborious computation. Fourteen different cases have been worked out, but in this Appendix attention will be directed only to those which seem to throw most light on the causes of the disaster.

After Professor Bairstow had produced his illuminating diagram Fig. (2), which proved that a descent was inevitable if the ship became nose heavy owing to a considerable loss of gas in the forward part of the ship, attention was naturally directed to this as a likely cause of the disaster and it was generally anticipated that since the ship was bound to descend, her local heaviness would cause her to descend nose downwards. Mathematical analysis, applied to a number of different cases, has however disproved this anticipation, and, provided that the ship does not have her nose initially depressed by a buffet of wind or by a wrong use of the elevators, it appears that even a very moderate amount of up elevator will prevent the ship taking up a diving position, and, when she comes to ground, she will do so tail first, which is entirely at variance with the facts.

R. 101. Initial Conditions—

Engines at Cruising Speed. Axis 9·8° up, Elevator $1\frac{1}{2}$° down.
General Heaviness 4 tons. Gasbag No. 5 deflated 8 tons and leakage at 1 ton per min.

Later at t = 100 secs —

Curve A Elevator put up from 0° to 5° at 1° per sec.
,, B ,, ,, 0° ,, 15° ,, ,,
,, C ,, ,, 0° ,, 25° ,, ,,

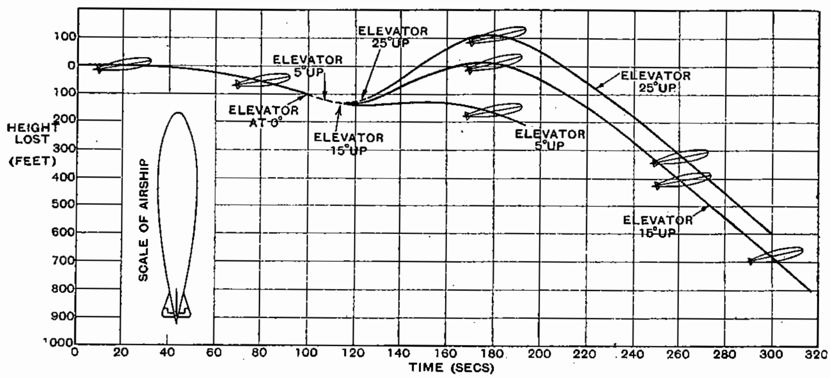


FIG. 3.

This point is brought out clearly by cases 1, 2 and 3 (see Fig. 3). Initially, that is when t = o, the ship is supposed to have become 12 tons heavy, of which 8 tons is due to deflation in gas-bag No. 5, the remainder being general heaviness. It is furthermore assumed that gas-bag No. 5 continues to lose lift at the rate of 1 ton per minute. Initially the ship is flying pitched up 9·8°, with the elevators $1\frac{1}{2}$° down. Under the initial conditions assumed and with the engines running at their normal cruising H.P., the ship has just reached that state of general and local heaviness which makes it impossible for her to maintain height, though at first the rate of descent will be slow.

After 100 secs it is assumed that the height coxswain, to regain height, puts his elevators up at the rate of 1° per sec. Three cases are then considered. In case (1) the elevators are put up to 5°, in case (2) to 15° and in case (3) the elevators are brought into their extreme position of 25°. The subsequent path of the ship is shown by the three curves in Fig. 3. Owing to the kinetic energy possessed by the ship, raising the elevators will cause her temporarily to gain height, but when this energy has been expended, she starts falling again and hits the ground tail first. It will be seen that the amount by which the elevators are put up has little effect on the final descent; an increased use of these controls merely delays the inevitable crash to some small extent.

The predominant aerodrynamic effect is the air pressure due to the vertical downward velocity acting upwards on the underside of the bow portion of the ship, and, with little or no assistance from the elevators, this overbalances the negative pitching moment produced by the deflation of a forward gas-bag.

This tendency to descend tail first would be even more pronounced if the heaviness was all of a general character without any local contribution, and even with two forward gas-bags deflated, the extra speed of descent would bring about such an increase of pitching moment that the descent would again almost certainly be tail downwards.

The inference to be drawn from Fig. 3 is that heaviness, no matter whether it is general or local, does not by itself account for the behaviour of R101 in her final plunge to destruction, and other contributary causes must be studied.

Effect of a gust or use of down elevator.

8. Case 4 (Fig. 4) was worked out to investigate how the ship would behave if initially she was flying with her axis inclined downwards through an angle of 5°, this initial downward inclination having been produced by a buffet of wind or by a downward movement of the elevators. The conditions assumed for heaviness and progressive deflation are the same as in the previous case, but the elevators are supposed to remain in mid-position for the whole period of 125 secs. It will be seen that the ship dives down through a height of over 500 feet, but, in spite of no assistance from the elevators, she never assumes a steep downward inclination. She soon gets her nose up again, and after about 1 minute, apart from loss of height, she is practically flying under the same conditions, as she was at the commencement of Fig. 3. Fig. 4 indicates that even without elevator control, although the ship is very nose heavy, an initial dive does not become seriously intensified. Automatically she succeeds in getting her nose up again and, if the elevators had been put up at an early stage, the recovery from the dive would have been noticeably accelerated.

Recovery from a dive when the airship possesses no heaviness.

9. Case 5. Fig. 5 illustrates the recovery from a steep dive produced by the use of elevators. The ship is supposed to be flying without any heaviness, either general or local, at her normal cruising speed of 55 knots.

By putting the elevators down to 10° in a period of 10 secs. and holding them down for another 10 secs., a steep dive is induced.

The elevators are then brought up to an angle of 25°, this process occupying another 35 secs. It will be seen that even from this exceptionally violent dive, the ship is pulled out after she has dropped about 600 feet, and she then proceeds to regain height with great rapidity.

The initial dive might equally well have been produced by a strong downward buffet of wind striking the nose of the ship, and this case is illuminating, in that it shows how errors in the use of the elevators or down currents of air may produce dives of considerable magnitude, but, as long as the ship is not seriously crippled with heaviness, a proper use of the elevators will enable her to climb again with great vigour. The outstanding feature of the descent of R.101 was that after the first dive, although she momentarily attained a horizontal position, she had evidently lost her power to regain altitude. To use a nautical simile, she had become "water-logged." This circumstance, combined with the fact that her first dive was nose downwards, suggests a combination of adverse conditions, namely, an extensive forward gas-bag deflation combined with a buffet of wind which forced her nose down and started her in a steep dive. The possibility of eddies from the Beauvais Ridge, which was not far distant to windward, makes this latter assumption not unreasonable. The ship was approaching a region where "bumpy" conditions might be anticipated, and the comparative absence of previous dives may be accounted for by the fact that until she reached the scene of the disaster, she had not been flying over country which would be likely to have a disturbing effect on the air currents.

The Motion of R 101 under Certain Conditions.

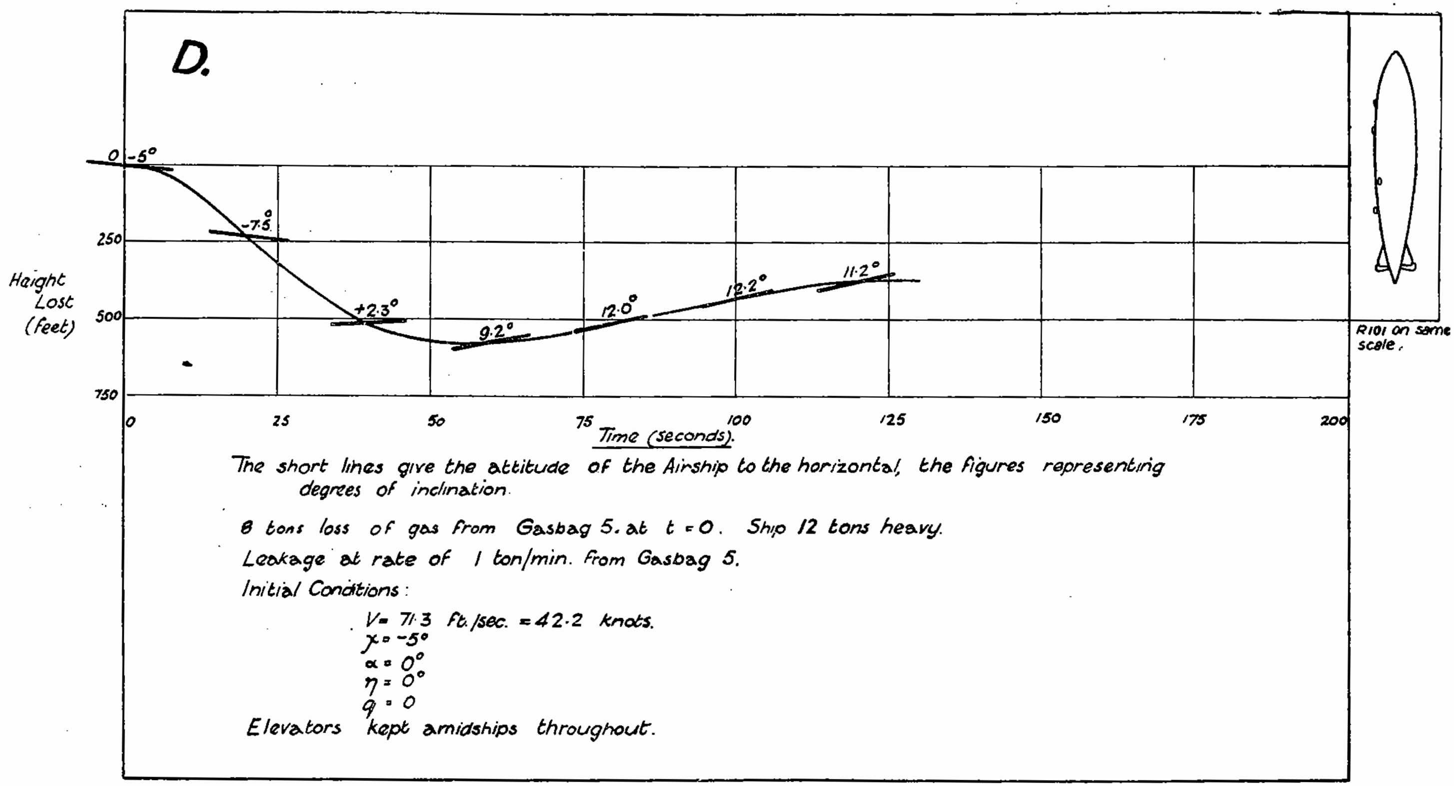
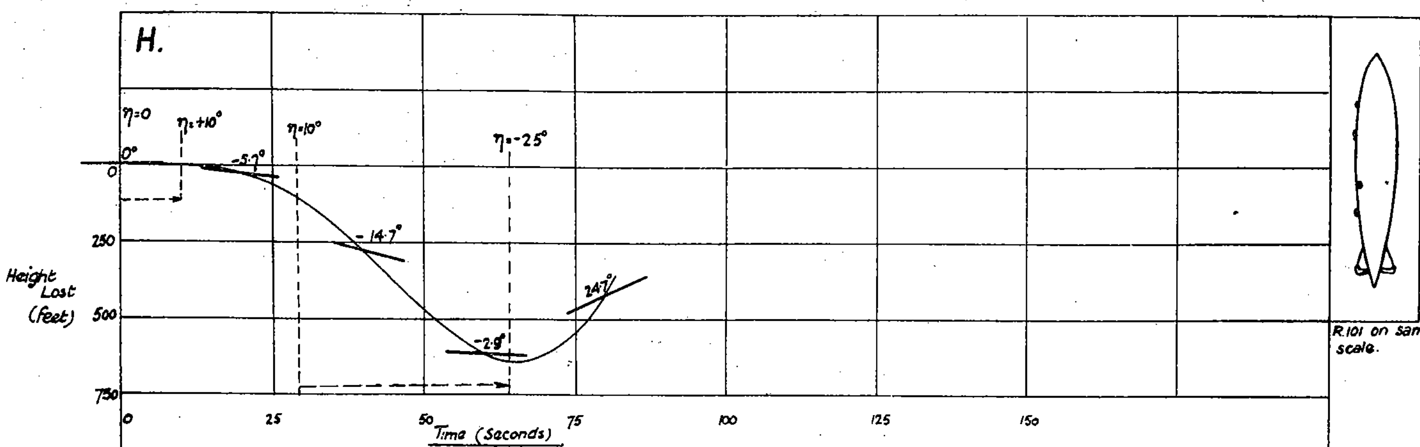


FIG. 4.

The Motion of R.101 under Certain Conditions.



The short lines give the attitude of the Airship to the horizontal, the figures representing degrees of inclination

No loss of gas. No heaviness

Initial Conditions:

$V = 91$ ft./sec. $= 53.3$ knots.
$\chi = 0$
$\alpha = 0°$
$\eta = 0°$
$q = 0$

At $t = 0$ elevators are put down at the rate of 1°/sec to 10° down. Elevators are kept at 10° down until $t = 30$ secs. and are then put up at the rate of 1°/sec. to 25° up.

Aoq+a

FIG. 5.

Dive produced by forward heaviness associated with a downward wind current.

10. Several cases of this description were studied, of which case 6 (Fig. 6) is an example.

In this case the ship is supposed to be 2 tons generally heavy and, in addition, gas-bag No. 3 is assumed initially to have lost 6 tons of lift. It is, moreover, supposed that this escaped gas has not all found its way into the outer air, but some of it, giving a lift of 2 tons, remains trapped inside the outer cover.

When the ship is pitched down by the nose, this trapped gas will find its way to the tail, and it is supposed thereby to give a negative pitching moment of 100 tons feet when the downward inclination of the ship is 5°, rising to 400 tons feet when the inclination of the ship reaches 10°. It is assumed that the gas-bag is losing lift all the time, at the rate of 2 tons per minute, and that the amount of gas trapped inside the outer cover remains constant. Another factor which has been taken into account is increased drag. The most probable cause of a deflated gas-bag is the buffeting it would receive in consequence of a tear in the outer cover. If this rent occurs near the bow, as would be the case if gas-bag No. 3 is affected, a considerable extra drag would result, and to take this possibility into account, a reduced normal air-speed of 45 knots has been assumed. A normal head wind of 40 f.s. is taken, and during the period $t = 10$ secs. to $t = 22$ secs., upon this head wind is superposed a gust, which has a horizontal velocity of 20 f.s., and a downward vertical velocity of 10 f.s. Initially, in order to neutralize an upward pitch, it is assumed that the elevators are 7° down, but when $t = 10$ secs., they are put up 1° per 2 secs. until they reach the neutral position, and then more rapidly at the rate of 1° per sec., until the extreme position 25° up is attained.

Fig. 6 shows the path of descent which theory predicts for this case. By the time the elevators are hard up, the ship will have descended over 800 feet, and though she has by then nearly flattened out, she is still losing height at a speed of about 20 f.s.

If at about this time the engines were shut down and ballast dropped, her subsequent path would be as shown. She would come to ground, nose first, with very little horizontal velocity.

The first dive, illustrated by Fig. 6, would appear to be in good general agreement with the first dive of R101, so far as it is possible to reconstruct it from the evidence available. The final part of the descent, illustrated by Fig. 6, could be modified almost to any extent. It is unlikely that the engines were actually shut off so soon as the figure shows. If the engines were kept running and the elevators were kept full up (in the position they were subsequently found), the ship would make some show of climbing again, crippled though she is by loss of buoyancy. Eventually, she must come to the ground, but, unless the engines are shut off at the fairly early stage shown, under the steady wind conditions which are assumed at this stage of the descent, she will come down tail first. The last moments before the crash, however, hardly admit of exact mathematical treatment, and the assumption of constant and horizontal air velocity in this last stage is probably quite incorrect. When an airship of the huge displacement of R101 is in close proximity to the ground, the air disturbances must be very pronounced, and may very possibly have the effect of dragging the nose downwards. If such is the case, even if the engines were kept running almost up to the last moment, it is quite possible that when nearing the ground she would plunge forward and strand nose downwards. This point might well be the subject of experiment in a wind tunnel, but at present no data are available.

The general agreement between the first dive, illustrated in Fig. 6, and the first dive of R101, supports the conclusion reached in the body of the Report, that it was loss of gas in the forward part of the ship, associated

N. The Motion of R.101 under Certain Conditions

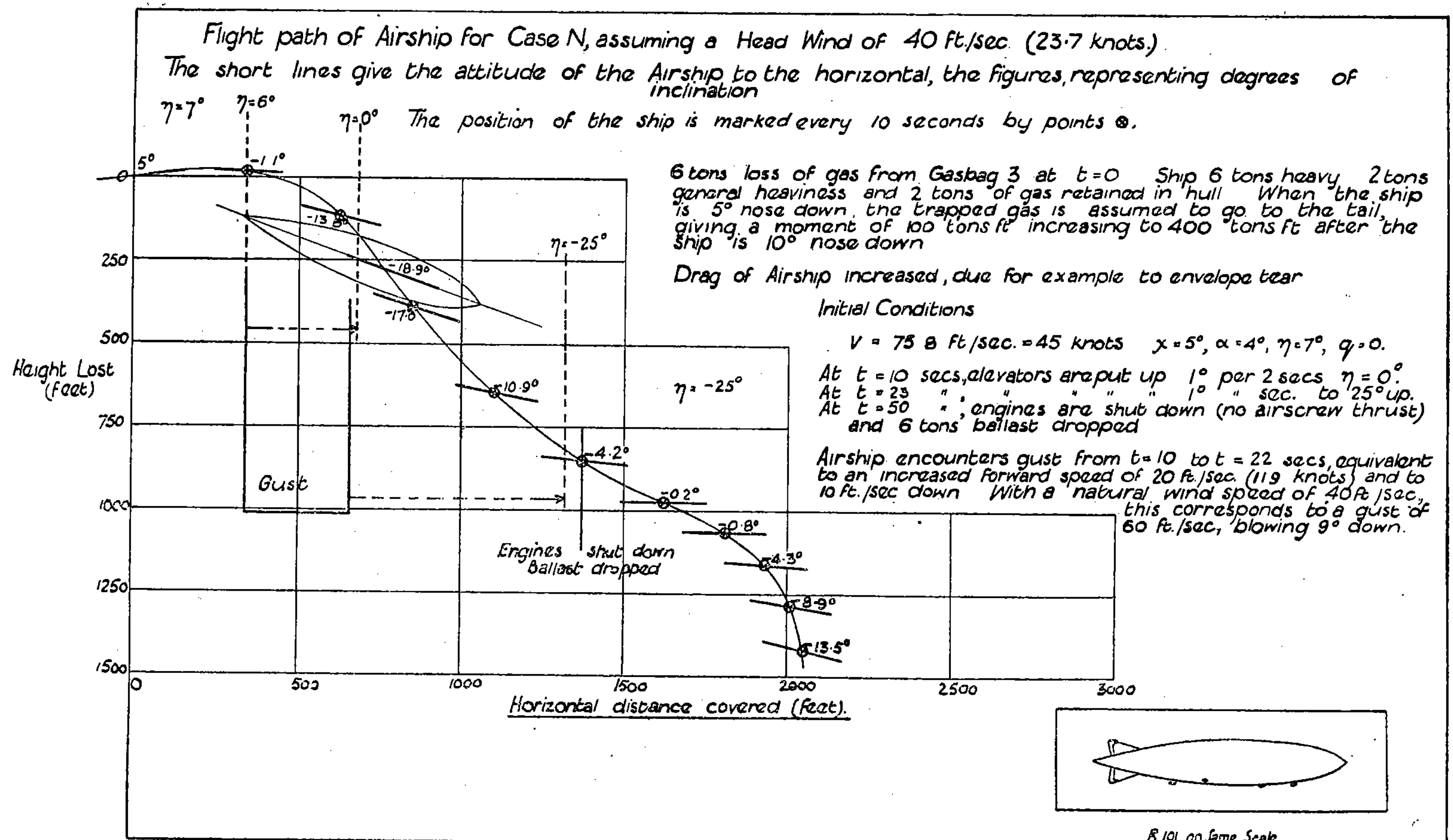


FIG. 6.

with a downward buffet of wind, which were the immediate causes of the disaster. If the ship had been merely generally heavy but otherwise undamaged, on no reasonable assumptions relating to gusts, could she have been driven down to the extent represented in Fig. 6. This point is brought out by Case 7 (Fig. 7).

Dive produced by General Heaviness, associated with a Downward Air Current.

11. In Case 7 (Fig. 7), the ship is assumed to be 6 tons generally heavy, but no progressive leakage of gas is taking place and the ship, apart from being abnormally heavy, is undamaged and is flying at her normal cruising speed of about 50 knots. She is supposed to encounter the same gust as was specified in Case 6, and the elevators are manipulated in precisely the same manner. It will be seen that her power of recovery from the dive started by the gust is remarkable, and her loss of height during the dive is only about 130 feet.

The inference to be drawn from this case is that considerable general heaviness, even when associated with a serious down gust, is not sufficient to account for the disaster to R.101 ; and the heaviness to be fatal must be *nose* heaviness. If loss of speed due to a tear in the outer cover, is added to the other adverse conditions, the loss of control is augmented, but even without taking this last factor into account, mathematical analysis leads to the belief that an airship seriously nose heavy and hit by a down gust, is brought into a condition of extreme peril.

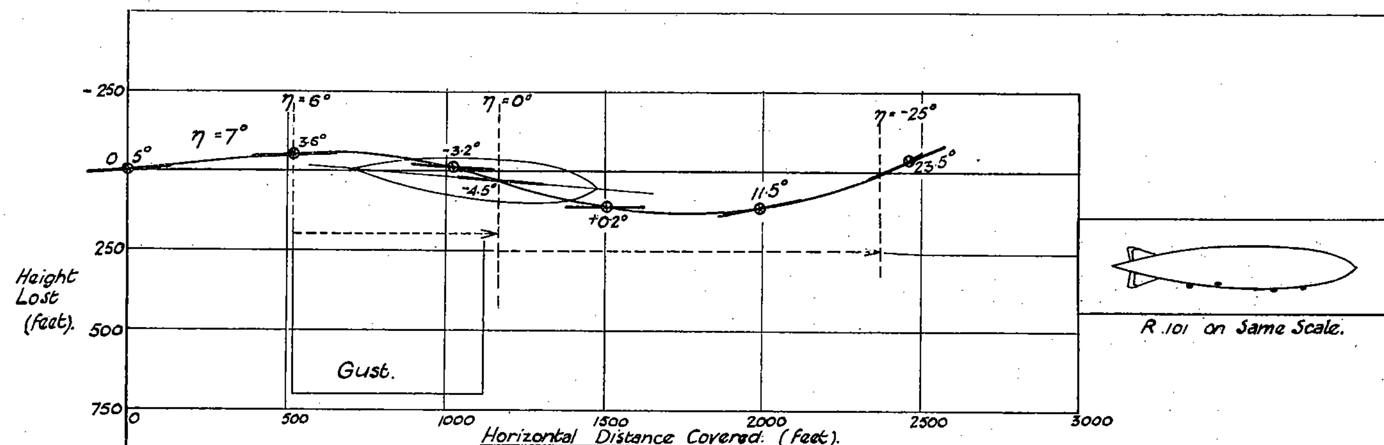
12. In drawing deductions from the mathematical investigations dealt with in this Appendix it is only proper to add that although in recent years the science of aerodynamics as applied to airships has made vast strides, it cannot yet claim to infallibility and, in contradistinction to the aerodynamics of aeroplanes, there is a lamentable dearth of full scale experiments, whereby predictions made by theory can be tested against actual results. The problems presented by the R.101 disaster were to a considerable extent novel in character, and though, in working out these problems, the mathematical processes employed are beyond any suspicion of doubt, some of the data on which the arithmetical computations depend can only be accepted with a due measure of reserve.

The aerodynamic characteristic of an airship in " steady flight " can certainly be determined by wind tunnel experiments by well established methods which, time and again, have been found to yield reliable results, but the data necessary for the study of accelerated and curved flight are difficult to obtain, and in the present state of knowledge, these data can hardly be regarded as certainties. Those who have had the arduous task of performing the calculations outlined in this Appendix, would be the first to admit that though qualitatively correct, quantitatively their results are not likely to be affected by the character of the data, upon which some of their computations depend, particularly the data relating to scale effect.

For instance, a dive associated with a deflated forward gas-bag may perhaps in reality be more difficult to rectify by elevator control than would appear from the results of the previous calculations. This is a point which can only be satisfactorily tested by full scale experiments. Such full scale experiments are conspicuous by their almost complete absence, and it is to be hoped that this deficiency will be remedied in the near future. The only full scale experiments which throw any direct light on the R.101 disaster are some which were carried out in connection with the American airship Los Angeles. With the ship made nose heavy to a considerable extent, it is reported that she was brought into a very critical flying condition, and if her nose was depressed through an angle of $7\frac{1}{2}°$, all her available elevator control and engine power were required to get her nose up again.

N_a

The Motion of R. 101 under Certain Conditions.



Flight Path of Airship for Case N_a, assuming a Head Wind of 40 ft./sec. (23·7 knots.)

The short lines give the attitude of the Airship to the horizontal, the figures representing degrees of inclination.

The position of the Airship is marked every 10 seconds by points ⊗.

Airship is 6 tons generally heavy in trim and is in an undamaged condition with no gas leakage.

Initial Conditions:

V = 92·8 ft./sec. = 55 knots; χ = 5°; α = 4°; η = 7°; q = 0.
At t = 10 secs., elevators are put up 1° per 2 secs. to η = 0°.
At t = 23 " , " " " 1° " sec. to 25° up.

Airship encounters gust from t = 10 to t = 22 secs., equivalent to an increased forward wind speed of 20 ft./sec. (11·9 knots) and to 10 ft./sec. down. With a natural wind speed of 40 ft./sec., this corresponds to a gust of 60 ft./sec., blowing 9° down.

For the time range considered, the meteorological conditions encountered and the handling of the Airship by elevator control are identical with those for Case N.

FIG. 7.

The calculations relating to R.101 under similar conditions do not suggest so much difficulty, and they hardly account for the considerable effort required to pull her out of dives experienced in the Hendon trial, when she was merely heavy generally.

The first of these two discrepancies may well be due to the different aerodynamic characteristics of the two ships concerned, but the second does not admit of this explanation and it introduces an element of doubt concerning the absolute accuracy of the data on which analytical computation have to depend in our present state of knowledge. Finality on this point and many others could only be achieved by a carefully conducted set of full scale experiments with R.100, and though it is to be hoped these experiments will be carried out, to wait for such information would delay the publishing of this Report almost indefinitely.

13. The curve of descent shown in Fig. 6 will err, if it does err, probably in the direction of understimating the effects of a deflated gas-bag and it is possible that a similar path might in reality result from less drastic assumptions relating to loss of gas and increased drag. Such modifications however are only quantitative in character, and do not affect the general conclusion that the causes which forced R.101 to the ground, were loss of gas in the forward part of the ship combined with a down gust and probably increased drag.

14. In conclusion the author would like to put on record the great assistance he has received from Professor Bairstow in compiling this Appendix. Professor Bairstow was responsible for all the calculations leading up to the important results contained in Fig. 2, and he has taken an active part in directing the analytical calculations at the N.P.L. These calculations were the joint work of Dr. R. Jones, Mr. D. H. Williams, Mr. A. R. Collar, and Mr. A. H. Bell, and to these distinguished scientists the highest credit is due for the competent manner in which they carried out the intricate and arduous calculations they were asked to perform.

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