C.A.P. 127

MINISTRY OF TRANSPORT AND CIVIL AVIATION

CIVIL AIRCRAFT ACCIDENT

Report of the Court of Inquiry into the Accidents to Comet G–ALYP on 10th January, 1954 and Comet G–ALYY on 8th April, 1954

LONDON: HER MAJESTY'S STATIONERY OFFICE
EIGHT SHILLINGS NET

MINISTRY OF TRANSPORT AND CIVIL AVIATION

CIVIL AIRCRAFT ACCIDENT

Report of the Court of Inquiry into the Accidents to Comet G–ALYP on 10th January, 1954 and Comet G–ALYY on 8th April, 1954

LONDON: HER MAJESTY'S STATIONERY OFFICE
1955

House of Lords.

1st February, 1955.

SIR,

Your predecessor directed that Public Inquiries should be held into the causes and circumstances of two accidents which occurred in the Mediterranean to Comet aircraft, the first on the 10th January, 1954, to G-ALYP, the second on the 8th April, 1954, to G-ALYY. In pursuance of that direction I was, on the 8th September, 1954, appointed by the Lord Chancellor to be the Commissioner to hold the Inquiry and Sir William Scott Farren, C.B., M.B.E., F.R.S., Professor William Jolly Duncan, C.B.E., D.Sc., F.R.S., and Air Commodore Allen Henry Wheeler, O.B.E., were appointed Assessors.

I now have the honour to present my Reports, each of which has been signed by all three Assessors to signify their agreement with it. With the agreement of the parties the two Inquiries were conducted at the same time in order to avoid unnecessary duplication.

I have attached as appendices to the Report on the accident to G-ALYP:

I. lists of the witnesses who gave evidence at the Inquiry,

II. lists of the parties represented thereat and of those representing them,

III. dates and places of the public hearings.

As will be seen from Appendix II there were present accredited representatives of the Government of Italy, Colonel R. Miniero and Signor R. Roveri and accredited representatives of the Government of the Union of South Africa, Lieutenant-Colonel L. E. Lang and Major J. J. Granzier.

A copy of the transcript of the oral evidence and addresses of Counsel will be available to you and I have handed to the Branch of the Chief Inspector of Accidents all the documents and other exhibits that were put in evidence except that I have returned to the Director of the Royal Aircraft Establishment, Farnborough, the metallic exhibits which emanated from that establishment.

The case was most carefully prepared and very clearly presented on behalf of the Attorney-General. It is right that I should place on record that every assistance within their power was rendered to the Court by the makers of the aircraft, de Havilland Aircraft Company Limited, the operators, British Overseas Airways Corporation and the Air Registration Board. The contentions of all the parties represented were put forward with cogency and force and at the same time with fairness and moderation. All parties displayed a genuine desire to arrive at the true causes of the accidents and to make constructive suggestions which would enable a re-designed Comet aircraft to take the air once more with safety to the public and benefit to the nation.

In exercise of the powers conferred on me by Section 9 (9) of the Civil Aviation (Investigation of Accidents) Regulations, 1951, and with the consent of all parties represented I allowed affidavits from certain witnesses resident in Italy to be used as evidence and these affidavits are included in the documents handed to the Branch of the Chief Inspector of Accidents.

All possible assistance was rendered to the tribunal by the Chief Inspector of Accidents and his staff. In particular he arranged at an early stage in the hearings for the Court and the parties represented to visit the Royal Aircraft Establishment at Farnborough. We saw for ourselves the reconstructed wreckage of aircraft G-ALYP and heard an account of the reconstruction and of the tank experiment, with the tank and the aircraft G-ALYU before our eyes. The Assessors and I are most grateful to the Director for the arrangements he made. Without this experience it would have been impossible for us adequately to appreciate the evidence which was afterwards given.

In Inquiries of this kind a legal Commissioner must always be very dependent on his expert advisers. I think this was particularly so in the present investigation having regard to the suspected cause of the accidents. Be that as it may, I cannot too strongly express my deep sense of gratitude for the help I have derived from the expert knowledge and practical experience of my Assessors. I am glad to find that there is no material point on which they have failed to agree with one another and I have felt no difficulty in accepting the advice they tendered to me.

I cannot conclude this letter without expressing my very sincere thanks to Mr. J. N. B. Penny, barrister-at-law, who was specially appointed secretary to the tribunal and has been of great assistance to me throughout the proceedings.

I have the honour to be, Sir,

Your obedient Servant,

(Signed) COHEN

The Right Honourable J. A. Boyd-Carpenter, M.P.,
Minister of Transport and Civil Aviation

CONTENTS

REPORT ON THE ACCIDENT TO COMET G–ALYP

REPORT ON THE ACCIDENT TO COMET G–ALYY

THE CIVIL AVIATION ACT, 1949

THE CIVIL AVIATION (INVESTIGATION OF ACCIDENTS) REGULATIONS 1951

Report of the Public Inquiry into the causes and circumstances of the accident which occurred on the 10th January, 1954, to the Comet aircraft G-ALYP

AIRCRAFT: Comet G-ALYP ENGINES: Four de Havilland Ghost 50

REGISTERED OWNERS AND OPERATORS: British Overseas Airways Corporation

CREW: Captain A. Gibson—Killed
First Officer W. J. Bury—Killed
Engineer Officer F. C. Macdonald—Killed
Radio Officer L. P. McMahon—Killed
Steward F. L. Saunders—Killed
Stewardess J. E. Clarke—Killed

PASSENGERS: 29—All Killed

PLACE OF ACCIDENT: Over the Mediterranean off Elba.

DATE AND TIME: 10th January, 1954, at about 1000 G.M.T.

All times in this Report are G.M.T.

PART I
INTRODUCTORY

(a) *Definitions*

1. In this Report the following expressions bear the following meanings:—

" A.R.B." means the Air Registration Board incorporated as a company limited by guarantee under the Companies Act, 1929, on the 26th February, 1937.

" A.S.B." means the Air Safety Board appointed by the Minister of Transport and Civil Aviation.

" de Havillands " means the de Havilland Aircraft Company Limited.

" R.A.E." means the Royal Aircraft Establishment controlled by the Minister of Supply.

" B.O.A.C." means British Overseas Airways Corporation.

(b) *The Air Registration Board*

2. The primary object of A.R.B. is to carry out such administrative and advisory functions with regard to the design, construction and maintenance of aircraft and matters connected therewith as may from time to time be delegated to A.R.B. by the Minister of Transport and Civil Aviation. Under its Articles of Association A.R.B. is to consist of two members appointed by the Minister and sixteen other members. Of these sixteen four must represent operators of aircraft, four must represent constructors of aircraft, four must represent insurers engaged in aircraft insurance business and the remaining four are co-opted. It is provided that of the two members to be nominated by the Minister one is to be an independent person and the other a person who has had not less than five years' professional experience as a pilot of civil aircraft. It is further provided that the co-opted members are to be persons representative of some interest connected with civil aviation.

3. By section 7 of the Civil Aviation Act, 1949, which reproduces section 2 of the Air Navigation Act, 1936, it is provided that the Minister may by order provide for delegating to a body appearing to him to be constituted as is A.R.B. under its Memorandum and Articles, such of the administrative functions of the Minister with respect to the matters mentioned in the subsection as may be specified in the order and for entrusting to that body such advisory functions in connection with any of such matters as may be specified.

4. In pursuance of this section the Minister by the Civil Aviation (Air Registration Board) Order of 1951 (which replaces Orders made under the

1936 Act) delegated a number of his administrative functions to A.R.B. and entrusted to it certain advisory functions. Under section 1 of the Order the Minister delegated to A.R.B. the following functions (inter alia):—

"(*a*) the formulation and publication of technical requirements as regards the design, construction and maintenance of aircraft and engines, components, accessories, instruments, equipment and apparatus of aircraft;

(*b*) the investigation of aircraft (including their engines, components, accessories, instruments, equipment and apparatus (excluding radio apparatus) and the manner of the installation of the same) for the purposes of the issue and renewal of certificates of airworthiness or of validations of such certificates and for the purposes of the variation of particulars and conditions specified in such certificates or any flight manual or performance schedule issued therewith;

(*c*) the making of recommendations to the Minister as to the issue of certificates of airworthiness and of validations of such certificates and as to the variation of particulars and conditions specified in such certificates or any flight manual or performance schedule issued therewith;

(*d*) the renewal of certificates of airworthiness and of validations of such certificates and to such extent as may be determined by the Minister in writing the variation of particulars and conditions specified in such certificates or any flight manual or performance schedule issued therewith;

(*e*) the making of any investigation required in connection with an application for a special permission for an aircraft to fly without a certificate of airworthiness being in force in respect thereof and the making of recommendations to the Minister as to the giving of such a special permission;

(*f*) the approval of engines for aircraft;

(*g*) the making of inspections of organisations of persons or firms desiring to furnish reports or certificates as to compliance by aircraft and engines, components, accessories, instruments, equipment and apparatus of aircraft with airworthiness requirements, the approval of any such firm or persons as qualified to furnish such reports of certificates, and the acceptance of such reports or certificates;".

5. The Chairman of A.R.B. is the Rt. Hon. Lord Brabazon of Tara. The members of the Council are identical with the members of the Board. The Council are advised by a technical staff of about 125 of whom about 84 are employed on inspectional duties. The Chief Executive Officer is Mr. R. E. Hardingham and the Chief Technical Officer of the Board is Mr. W. Tye.

6. To enable A.R.B. to discharge its functions it prepares and from time to time publishes detailed requirements which inform manufacturers of the minimum conditions with which, *prima facie*, they have to conform if they are to obtain a Certificate of Airworthiness. To assist A.R.B. in the preparation of these requirements they have appointed an "Airworthiness Requirements Co-ordinating Committee" which includes representatives of the Ministry of Supply, R.A.E., manufacturers of aircraft, operators of aircraft and A.R.B. itself.

7. Requirements are not, however, treated by A.R.B. as being as immutable as the laws of the Medes and Persians. On the one hand, during the development of a new type, requirements more exacting than those prescribed in the published regulations are often imposed or adopted by the manufacturer concerned. On the other hand, on occasions certain deviations from the prescribed conditions are accepted by A.R.B. provided that they are satisfied that the safety of the aircraft is not thereby jeopardised.

(c) *The Air Safety Board*

8. A.S.B. is a purely advisory body and has no statutory authority behind it. It was appointed in November, 1946, with the following terms of reference: "To keep under continuous review the needs of safety in British civil aviation and to recommend measures calculated to promote safety in respect of both (*a*) the operation of British civil aircraft throughout the world, and (*b*) the efficiency of the system of ground facilities provided for civil aircraft of all nations operating over the United Kingdom." Its members are appointed by the Minister and at the material date consisted of Air Chief Marshal Sir Frederick Bowhill, Lord Brabazon, Sir Leonard Bairstow, Air Commodore Banks and Mr. (now Sir) Arnold Hall.

(d) *The Royal Aircraft Establishment*

9. R.A.E. is controlled by the Minister of Supply. The main establishment is at Farnborough but there are branch establishments in other parts of the country. In this Report I am mainly concerned with the work done at Farnborough. The Director of R.A.E. is Sir Arnold Hall. The Head of the Structures Department is Dr. P. B. Walker. The only other member of

the staff who need be mentioned by name is Mr. E. L. Ripley who was responsible for the work in connection with the reconstruction and investigation of the wreckage recovered after the accident. I should, however, add that R.A.E. has its own flight testing facilities which were fully used in the investigations which took place after the accident.

(e) *The de Havilland Aircraft Company Limited*

10. de Havillands were the manufacturers of the Comet aircraft and the engines were made by a subsidiary company, the de Havilland Engine Company Limited. Mr. R. E. Bishop is the Chief Designer of de Havillands and his Chief Assistant is Mr. C. T. Wilkins. Mr. R. H. T. Harper is the Chief Structural Engineer and Mr. H. Povey is the Director in charge of Production. de Havillands have an Inspection Department entirely separate from their Production Department and the independence of the Inspection Department is secured by the provision that it reports direct to the Managing Director and is not in any way under the control of the Production Department. de Havillands have been approved under paragraph 1(*g*) of the Civil Aviation (Air Registration Board) Order of 1951 as qualified to furnish reports and certificates as to compliance with airworthiness requirements.

PART II

HISTORY OF THE COMET PROJECT

11. Mr. Bishop stated that at the end of the war de Havillands were faced with the problem of recommencing the manufacture of civil aircraft. During the war they had been building only military aircraft. They decided that it would be inadvisable merely to build another version of the conventional aircraft; they had had some years' experience with jet fighters and concluded that with the help of their engine company they should be able to produce a useful civil aircraft which would be a step ahead of the current type. With this end in view they commenced design by the end of September, 1946. Some idea, however, of the amount of work involved is indicated by the fact that it was not until the 27th July, 1949, that the first prototype Comet made its first flight. de Havillands were, however, fortunate that B.O.A.C. and the Minister of Supply were willing to enter into a contract for the purchase of Comet aircraft without waiting for the prototype to be available. This enabled de Havillands at once to do preliminary work in the Production Department. The contract was entered into on the 21st January, 1947 and under it B.O.A.C. started their proving flights in April, 1951.

12. At some date in 1951 it was arranged that the first two prototypes should be delivered to the Ministry of Supply but that the remaining aircraft to be supplied under the contract should be delivered to B.O.A.C. and that the approval of the Ministry of Supply to them should no longer be required.

13. A.R.B. issued a number of special category certificates of airworthiness to enable the requisite tests, both in this country and overseas, to be carried out, but it was not until early in 1952 that a full Certificate of Airworthiness was issued. This enabled the passenger service to be started and it was actually commenced on the 2nd May, 1952. The personnel for the service had received intensive training. B.O.A.C. had established a school for the training of pilots and crews and made full use of a special school which had been established by de Havillands for the training not only of pilots and crews, but also of station engineers. By the 8th April, 1954, when the Comet fleet of B.O.A.C. was grounded after the disaster near Naples, Comet aircraft had flown almost 25,000 hours, representing, on the basis of 400 miles per hour, a mileage of 10,000,000 miles.

14. Dealing more specifically with the technical aspect of the development of the project between September, 1946, and the 2nd May, 1952, de Havillands' outlook and practice underwent virtually no change. In order to provide an economically satisfactory payload and range, at the high cruising speed which the turbo-jet engines offered, it was essential that the cruising height should be upwards of 35,000 ft.—double that of the then current air-liners—and that the weight of the structure and equipment should be as low as possible.

15. Throughout the design they relied upon well established methods, essentially the same as those in general use by aircraft designers. But they were going outside the range of previous experience and they decided to make thorough tests of every part of the cabin structure. They had not only to prove to their own satisfaction that their design was basically sound, but also to investigate the effect, on the large variety of materials involved, of the extreme conditions which would be met. They gave special attention to the structural integrity of the pressure cabin. The difference* between the internal and external pressure ($8\frac{1}{4}$ lb./sq. in) was about 50 per cent. greater than that in general use and there was in addition a larger difference between the internal and external temperatures.

16. Their policy of testing in the laboratory was not a novel one, nor indeed were they alone

* This difference is sometimes referred to hereafter as 'P'.

in their belief in it. They recognised, however, that testing alone is not sufficient. Every test is to some extent a compromise, since the conditions to be met in service can seldom be represented completely in the laboratory and in many cases are not accurately known. The result must, therefore, be reviewed in the light of calculations based on fundamental knowledge, and on general experience and practice.

17. For the design of the basic structure of the cabin they adopted a multiple of the working pressure difference, P, in excess of current requirements in any country. The British Civil Airworthiness Requirements (B.C.A.R.) called for a " proof " pressure of $1\frac{1}{3}$ P (under which the cabin must show no signs of permanent deformation), together with a " design " pressure of 2 P (at which the material may reach its ultimate strength). These requirements were the same as those of the International Civil Aviation Organisation (I.C.A.O.) and also those of this country for military transport aircraft. de Havillands used a design pressure of $2\frac{1}{2}$ P and tested the cabin to 2 P. Two test sections of the cabin were built. The front part, 26 ft. in length, extended from the nose nearly to the front spar of the wing, and included typical windows, hatches and door. The centre part, 24 ft. in length, extended from a few feet in front of the front spar to a few feet aft of the rear spar, covering the large cut-out containing the wing structure.

18. Their reasons for adopting these substantially higher figures were two. They believed, and this belief was shared by A.R.B. and other expert opinion, that a cabin which would survive undamaged a test to double its working pressure, 2 P, would not fail in service under the action of fatigue* due to the pressurisation to working pressure, P, on each flight, and to other fluctuating loads to which it is subjected in operations.

Secondly, they considered that it would ensure a larger margin of safety against the possible failure of windows, doors, and hatches. These are contingencies which had been shown by experience to be a serious risk, for even if nothing worse happens, the resulting loss of pressure may be rapid.

19. So much importance did they attach to this latter consideration that they made many tests of window panes to very high pressures. In addition, they applied pressures of between P and 2 P some 30 times to the test section of the front part of the cabin together with a series of 2,000 pressurisations to rather over P. These tests were not intended as a test of the fatigue resisting properties of the structure, but rather as providing an assurance that the cabin would be satisfactory as a pressure vessel. But they undoubtedly contributed to de Havillands' confidence in the soundness of the cabin.

20. Simultaneously with the design and testing of the pressure cabin, all other parts of the structure were receiving treatment based on the same outlook—design to at least the current requirements, coupled with exhaustive tests. The wing is of special interest, since it is here that requirements specifically directed to resistance to fatigue first became important. During the period 1949 to 1951 there had been growing among all aircraft designers and users a realisation that the life of the essential structure of an aircraft is not unlimited. The effects of atmospheric turbulence had produced unexpected and relatively early failure of the wings of certain transport aircraft. Gusts are most severe near the ground and in the tropics. Methods had been devised, and have since been improved and extended, for determining their frequency and intensity. In the light of this knowledge, repeated loading tests* of the wings of transport aircraft became accepted as necessary. Tests of the Comet's wing were made in close co-operation with R.A.E.

21. Until about the middle of 1952 the likelihood that the fatigue resistance properties of a pressure cabin demanded further precautions, either in design or by test, than were provided by the current static strength requirements had not been realised. The matter first came to de Havillands' notice through Mr. Harper's association with the problem on Service (R.A.F.) transport aircraft, as a member of the Joint Airworthiness Committee (J.A.C.) of the Ministry of Supply. Draft Requirements (Paper 579, Oct., 1952) called for a static test to 2 P, a proof test to $1\frac{1}{3}$ P, together with repeated loading tests of $1\frac{1}{4}$ P applied 10,000 times.

22. At about the same time A.R.B. were reviewing the civil position. In due course they issued proposals in Paper No. 230 (19th June, 1953) which called for the same static test to 2 P and proof test to $1\frac{1}{3}$ P but raised the number of applications of $1\frac{1}{4}$ P to 15,000. At the same time the paper suggested that certain structural parts, such as riveted joints, door and window frames, etc., might have to be designed to 3 P (on the

* There is attached hereto as Appendix IV a note on the subject of fatigue in metals and its bearing on the design of engineering structures which has been prepared for my assistance by my Assessors.

* In which the appropriate load is applied and removed many times, simulating the effects of gusts, or any other cause of variation of load

ultimate strength of the material), in order to meet these requirements. It also stated that the figure of 15,000 was intended to cover the number of applications of P during the life of an aircraft, and that the test pressure of $1\frac{1}{4}$ P was intended to cover the phenomenon of " scatter "* in the fatigue strength of different cabins built to the same design.

23. The result of these developments was that in July, 1953 de Havillands reconsidered the position of the Comet's cabin. Up to that time no Comet had exceeded 2,500 hours flying—say 800 pressurised flights. In order to satisfy themselves of its safety, and also to discover its probable safe working life, they carried out repeated loading tests of the test section of the fore part of the cabin, applying the working pressure P about 16,000 times. By September, 1953, this specimen had withstood 18,000 applications of P in addition to some 30 earlier applications of pressures between P and 2 P.

24. These tests were ended by a failure of the skin in fatigue at the corner of a window, originating at a small defect in the skin. But the number of pressurisations sustained was so large that, in conjunction with the numerous other tests, it was regarded as establishing the safety of the Comet's cabin with an ample margin.

25. Meanwhile, on the 2nd May, 1953, Comet G-ALYV had crashed in a tropical storm of exceptional severity near Calcutta. An inquiry was directed by the Central Government of India and was held under Rule 75 of the Indian Aircraft Rules 1937. The Court reported on the 26th May, 1953, that the accident was caused by structural failure of the airframe during flight through a thundersquall. In the opinion of the Court the structural failure was due to overstressing which resulted from either:—

(i) Severe gusts encountered in the thundersquall, or

(ii) Overcontrolling or loss of control by the pilot when flying through the thunderstorm.

Fatigue failure of the cabin was not then suspected as a cause and in my opinion the evidence adduced in the course of the present Inquiry affords no sufficient reason for doubting the conclusion of the Indian Court.

PART III

THE ACCIDENT

26. Comet G–ALYP (sometimes hereinafter called Yoke Peter) left Ciampino Airport, Rome, at 0931 hours on the 10th January, 1954, on a flight to London. After taking off the aircraft was in touch with Ciampino control tower by radio telephone and from time to time reported its position. These reports indicated that the flight was proceeding according to the B.O.A.C. flight plan and the last of them, which was received at 0950 hours, said that the aircraft was over the Orbetello Beacon. The Captain of another B.O.A.C. aircraft, Argonaut G–ALHJ, gave evidence of communications which passed between him and Yoke Peter. The last such message received by the Argonaut began " George How Jig from George Yoke Peter did you get my " and then broke off. The Captain of the Argonaut gave it as his opinion that the message was not merely interrupted by another aircraft but that transmission ceased after the word " my " and he estimated that the message was received by him at approximately 0951 hours. Shortly after 1000 hours the Ciampino Traffic Control Clerk heard a sound which he suggested might have been an unmodulated transmission from Yoke Peter.

27. The evidence of four witnesses from Elba as to things seen and heard by them on the 10th January suggests that Yoke Peter must have crashed into the sea at about 1000 hours and it therefore appears that something happened to the aircraft with catastrophic suddenness which may have accounted for the interruption of the transmission of the last message to the Argonaut. It is also clear from the evidence of the Elba witnesses that part of Yoke Peter fell into the sea in flames.

28. The chart, which is Figure 1 of this Report, was prepared from all the information available and produced by a Navigating Officer from B.O.A.C. The estimated flight track of the aircraft and the position in which bodies and wreckage were found can be seen on the chart and the witness gave it as his opinion that at 0951 hours the aircraft was probably approaching a height of 27,000 feet.

PART IV

THE AIRCRAFT

29. Yoke Peter was designed and constructed by de Havillands and was of the type properly described as DH106 series 1, commonly known as the Comet I. It was designed for high speed long distance, passenger and freight transport at high altitude and was propelled by four de Havilland Ghost 50 turbo-jet engines mounted within the wings, each engine developing a static

* See Appendix IV.

thrust of 5,000 lb. The crew and passenger compartments were pressurised, so that when flying at 40,000 ft. a cabin pressure equivalent to atmospheric pressure at an altitude of 8,000 ft. was maintained. The cabin pressure was regulated to a maximum pressure difference between cabin and outside atmosphere of 8·25 lb/sq. in. and a safety valve was set to open at a pressure difference of 8·5 lb/sq. in. The dual flying controls were power operated by hydraulic servo control units. The fuel for the engines was kerosene carried in a centre section tank made up of four inter-connected bag tanks and in four integral wing tanks. The authorised maximum all-up weight was 107,000 lb. Yoke Peter first flew on the 9th January, 1951, and was granted a Certificate of Registration No. R.3162/1 on the 18th September, 1951, in the name of B.O.A.C. as owner. A Certificate of Airworthiness No. A.3162, valid until the 12th March, 1953, was granted on the 22nd March, 1952. The aircraft was delivered to B.O.A.C. on the 13th March, 1952, and from that date was operated by B.O.A.C. On the 2nd May, 1952, having by then flown a total of 339 flying hours in experimental, test and training flights on behalf of de Havillands and B.O.A.C. it entered scheduled passenger service and was the first jet-propelled passenger carrying aircraft in the world to do so.

30. On the 11th March, 1953, the Certificate of Airworthiness was renewed for one year and was, therefore, valid at the time of the accident. On the 11th November, 1953, after the aircraft had flown 3,207 hours and following a repair to the passenger entrance door the fuselage was subjected to a proving test to 11 lb/sq. in. The airframe and engine log books show that the airframe and engines had been regularly inspected and maintained in accordance with the Approved Maintenance Schedules and that the number of flying hours of each engine since its last complete overhaul was well within the approved life.

31. In accordance with the Approved Maintenance Schedules a Check I inspection was completed on the 6th January, 1954, at London Airport and a Certificate of Maintenance, signed by properly licensed airframe and engine maintenance engineers and valid for 75 flying hours, was issued on the 7th January, 1954. At the time of the accident the aircraft had flown only 40 hours since the issue of the Certificate of Maintenance and its total flying life was 3,681 hours. An Aircraft Radio Station Certificate of Serviceability was issued in respect of Yoke Peter on the 7th January, 1954, with the remark " no items unserviceable."

PART V

THE CREW

32. Captain Alan Gibson, D.F.C., who was in command of Yoke Peter at the time of the accident was aged 31 years and 3 months. He held Airline Transport Pilot's Licence No. 22713, valid until the 24th February, 1954, which entitled him to fly in command of Comet aircraft and he had a valid Instrument Rating. Captain Gibson also held Flight Navigator's Licence No. 1442 which was valid until the 19th February, 1954. He entered the employment of B.O.A.C. under contract in 1946 having previously been employed by B.O.A.C. on secondment from the Royal Air Force. While in the Royal Air Force Captain Gibson had a total flying experience of 1,348 hours of which 1,175 were flown in command. He had flown a total of 4,062 hours by day and 1,156 hours by night with B.O.A.C. and most of these were flown as first pilot. He had flown Comets for 84 hours by day and 48 hours by night as second pilot and for 79 hours by day and 80 hours by night as first pilot. During the six months preceding the accident he had flown 79 hours by day and 80 hours by night as first pilot of Comets and 47 hours by day and 31 hours by night under supervision.

33. While with B.O.A.C. Captain Gibson was concerned in an accident involving the forced landing of a Hermes aircraft in 1951 and was complimented by the Operations Manager for his conduct on that occasion. He was successful in both his flying checks during the period when he was flying Comets and I am satisfied that he was fully equipped to carry out his normal duties as a pilot and as a captain and to deal with emergencies.

34. The second pilot of Yoke Peter was First Officer William John Bury whose age was 33 years and 10 months. He held Airline Transport Pilot's Licence No. 27251 valid until the 8th April, 1954, and a valid Instrument Rating. In addition he held Flight Navigator's Licence No. 2583 valid until the 9th October, 1954. He had flown a total of 1,917 hours in the Royal Air Force of which 1,735 were as first pilot, all in piston engined aircraft. With B.O.A.C. he had flown 2,355 hours by day and 643 by night as second pilot and 11 hours by day and 1 hour by night as first pilot and altogether had flown 153 hours by day and 109 by night in Comets, all as second pilot. I am satisfied that First Officer Bury was fully equipped to carry out his normal duties and to support his captain in emergencies.

35. The Engineer Officer was Mr. Francis Charles Macdonald who was aged 27 years and 11 months. Since joining B.O.A.C. on the 21st

January, 1952, he had 439 hours flying as Engineer Officer in Hermes aircraft and 281 hours in Comets of which 225 hours were flown during the six months preceding the accident. Mr. Macdonald's Flight Engineer's Licence was No. 428 and had expired on the 11th December, 1953. During its validity this licence included Comet aircraft. Had he applied to renew his licence he would have been required to give Log Book evidence of six hours flying as engineer-in-charge including six flights during the 12 months preceding the date of application and would have been required to pass a medical examination.

36. On joining B.O.A.C. Comet Fleet Mr. Macdonald obtained an endorsement to his licence which made it valid in respect of Comet aircraft and he completed a form giving details of his licence. In completing this form he stated, wrongly, though no doubt in good faith, that his licence was valid until the 24th April, 1954. He himself made no application to renew the licence before its expiry nor was he given any reminder to do so by B.O.A.C. This matter is further referred to in paragraph 147 of this Report.

37. I am satisfied that Mr. Macdonald's flying experience was sufficient to support an application for renewal of his licence but I have no evidence as to his medical fitness. However, I have no reason to suppose that he was in fact unfit at the time of the accident.

38. The Radio Officer was Mr. Luke Patrick McMahon who was aged 32 years and 2 months. He held a First Class Flight Radio Telegraphy Operator's Licence No. 1235 which was valid until the 16th October, 1954, and had done 2,946 flying hours with B.O.A.C. in various aircraft before the 3rd October, 1952, and 629 hours in Comets thereafter. During the six months preceding the accident he had flown 207 hours in Comets. I am satisfied that he was a capable officer.

39. The other members of the crew were Steward Frank Leonard Saunders and Stewardess Jean Evelyn Clarke, both of whose services had at all times been entirely satisfactory.

PART VI

THE PASSENGERS AND CARGO

40. Yoke Peter carried a total of 29 passengers, all of whom were killed in the accident. The cargo carried did not include any items which could have been relevant to the cause of the accident. The comparison between the amount of cargo known to have been carried and that shown in the Load Distribution and Trim Sheet showed a discrepancy of 27 kilograms in hold 2A. Moreover, no load was shown on the Load Distribution and Trim Sheet for hold 3, whereas there was evidence that 15 kilograms of baggage were placed in that hold. I am satisfied, however, by the evidence of Mr. B. J. Folliard that these errors in the Load Distribution and Trim Sheet would have left the loading and trim of the aircraft well within the prescribed safe limits.

PART VII

PRE-FLIGHT INCIDENTS

41. The last three flights made by Yoke Peter prior to that which ended in disaster were from Karachi to Bahrein, Bahrein to Beirut and Beirut to Rome. During refuelling at Karachi a defect developed in the port wing refuelling-valve actuator and in order to complete the refuelling of the port wing tanks the Engineer Officer of Yoke Peter adopted a procedure known as " off-load " refuelling which is authorised for use in such an emergency. It involves holding the refuelling switch in the " off-load " position* and releasing it when refuelling is complete. In fact the Engineer Officer did not release the switch in time and about five gallons of fuel escaped from the air vent on the under surface of the mainplane. There was no repetition of this incident at Bahrein but at Beirut, after the Engineer Officer had explained to the ground engineer, who was assisting him with the refuelling, what had happened at Karachi, a further incident occurred. When the Engineer Officer returned to the port wing after inspecting the starboard tanks he noticed fuel emerging from the port air vent. The refuelling switch was in the neutral position from which fact, and from the fact that fuel was obviously entering the tank, he deduced that somebody, intending to put the switch to the " off-load " position, from which it should automatically have returned to neutral when released, must have failed to do so and that the switch, instead of returning to neutral, had remained half open. He attempted to close the switch by moving it to the full " off-load " position and releasing it but this had no effect and the flow of fuel was eventually stopped by shutting down the bowser.

42. As a result of this incident the actuator was removed and as no replacement was available it was tested, found satisfactory and refitted. These incidents were reported by the Engineer Officer to Mr. Macdonald when the aircraft was handed over at Rome. The practice of " off-load " refuelling is further referred to in paragraph 111 of this Report.

* The normal purpose of this position is to enable the tanks to be emptied.

43. Two other items were also unserviceable during the flights from Karachi to Rome. These were the No. 1 engine hydraulic flow warning light and the automatic temperature control selector. The former device is designed to draw the attention of the pilot to a possible failure of the engine-operated hydraulic pump. On this occasion, when the flow warning light appeared faulty, the operation of the pump was tested by other means and found satisfactory. The automatic temperature control selector is intended to control automatically the temperature of the crew and passenger compartments. When it was found to be faulty the temperature was controlled manually. I am satisfied that neither of these faults, both of which were drawn to the attention of Mr. Macdonald, can have endangered the aircraft in any way.

Part VIII

WEATHER CONDITIONS AT THE TIME OF THE ACCIDENT

44. From take-off at Rome at 0931 hours on the 10th January, 1954, to the time of the accident at approximately 27,000 ft. near Elba Comet G-ALYP experienced essentially good weather conditions. The climb was made through only thin and broken layers of cloud with no rain and with negligible icing conditions. At the time and position of the accident it is probable that some turbulence in clear air may have existed due to the proximity of a narrow high velocity wind current called a "jet stream". Such turbulence, if encountered, would be less than aircraft frequently experience in turbulent cloud conditions. It can, therefore, be assumed that the state of the weather was not a contributory cause of the accident.

Part IX

ACTION TAKEN AFTER THE ACCIDENT AND PRIOR TO THE ACCIDENT TO COMET G-ALYY

(a) *Local salvage and medical investigation*

45. At 1150 hours on the 10th January, 1954, the Harbour Authority at Portoferraio in the Isle of Elba was informed of the occurrence of the accident, being told that an aircraft had exploded in the air and crashed in flames into the sea south of Cape Calamita roughly in the direction of the island of Monte Cristo. With commendable promptness Lieutenant-Colonel Lombardi, the Officer Commanding the Harbour Authority of Portoferraio, despatched all available craft to the scene of the accident with a doctor and nurse on board and he himself put to sea after he had made all the necessary arrangements. In these salvage operations 15 bodies, various mail bags and some aircraft wreckage and personal effects were recovered. The ships had been assisted in their search by the collaboration of aircraft. On the two following days the search was continued. No more bodies were found but various pieces of wreckage and articles were recovered.

46. Under Lieutenant-Colonel Lombardi's directions the bodies were taken to the local cemetery at Porto Azzurro and devoutly placed in the chapel there. At the request of the examining magistrate at Portoferraio an examination of the bodies recovered was carried out by Professor Antonio Fornari who was acting under the direction of Dr. Folco Domenici, Director of the Institute of Forensic Medicine in the University of Pisa. Professor Fornari gave evidence before me and he put in a report which had been prepared by him and Dr. Domenici. The substance of their report is to be found in the conclusions at p. 60 of the translation of the report and may be summarised as follows:—

(1) Death was caused by impact against parts of the aircraft.

(2) There were serious lesions resulting from explosive decompression and deceleration.

(3) The probable point of impact between the bodies and the structure of the aircraft was the forepart of the fuselage, perhaps in the vicinity of that part of the fuselage which lies above the engines.

(4) There were burns on the bodies of all the victims but they presented post-mortem characteristics from which the inference was that the burns took place after death.

(b) *Action taken by the Ministry of Transport and Civil Aviation*

47. News of the accident was received by the Accidents Investigation Branch of the Ministry of Transport and Civil Aviation at 1200 hours on the 10th January, 1954, and both the Senior Inspector of Accidents, Mr. Nelson, and the Senior Investigating Officer, Mr. Morris, left for Italy that evening.

48. On arrival Mr. Nelson got into touch with the Commission which had been convened by the Italian aviation authorities and went with the Commission to Elba. Some days later it was agreed that the responsibility for the investigation of the accident should be handed over to the Accidents Investigation Branch of the British Ministry of Transport and Civil Aviation but Colonel Miniero and Signor Roveri, who have attended

this Inquiry, were appointed accredited representatives to the British investigators and gave them every possible assistance. The Minister of Transport and Civil Aviation was also in touch with the Admiralty and it was arranged that the Commander-in-Chief Mediterranean, Admiral Earl Mountbatten, would cause an intensive search to be made for the wreckage. The Chief Inspector of Accidents, in accordance with normal practice, arranged for the wreckage recovered to be sent to and examined at R.A.E. Mr. Nelson and Mr. Morris remained in Elba, examined the wreckage recovered and arranged for its transport back from Elba to the mainland and thence to Rome, whence it was flown direct to the United Kingdom, but certain very large pieces had to be sent by sea.

(c) *Naval search for wreckage*

49. Commander Forsberg was placed in charge of the operations. Special vessels, H.M.S. *Barhill* and H.M.S. *Sea Salvor,* were fitted up to carry 200 tons of heavy moving gear. An observation chamber, television gear, an 8 toothed grab and other equipment were obtained from England and the necessary modifications to the vessels were made in the dockyard at Malta. This was all done in under a fortnight and the two vessels and H.M.S. *Wakeful,* in which the television equipment was installed, arrived off Elba on the 25th January, 1954.

50. The search was prosecuted at depths varying between 70 fathoms and 100 fathoms. It is noteworthy that this was the first occasion on which television equipment had been used for this purpose. The first date on which anything was located on the bottom by television was the 12th February, 1954. I need not recount in detail the history of the search. Suffice it to say that by the 23rd March, 1954, only the floating wreckage, the pressure dome, and parts of the rear fuselage and the engines and wing centre section had been recovered and that thereafter the search continued until by the end of August, 1954, about 70 per cent. of the empty weight of the aircraft, made up of about 70 per cent. of the structure, 80 per cent. of the power plant and 50 per cent of the equipment, had been recovered. I have included as Appendix V a table, which was put in evidence, showing the dates of recovery of the main portions of the wreckage and the dates on which they reached Farnborough. Diagrams* (Figures 2 and 3) give a striking impression of the amount of material which was ultimately recovered, though they relate only to the external structure. Figure 4 is a photograph showing the reconstruction of the fuselage and tail unit from the wreckage and Figure 5 is a photograph showing the reconstruction of the front fuselage.

51. The amount of wreckage recovered was greatly in excess of the expectations entertained in March, 1954, when the decision to allow the Comets to fly again was taken. A remarkable fact was the small amount of damage which had been caused to the structure either by immersion in sea water or in the process of salvage.

(d) *The Abell Committee*

52. Immediately on receiving news of the accident B.O.A.C. had decided to suspend their normal Comet passenger services, for the purpose of carrying out a detailed examination of the aircraft of the Comet operational fleet in collaboration with A.R.B. and de Havillands and to this end the Chairman of B.O.A.C. had called a meeting at London Airport for the 11th January, 1954, which was attended by representatives of B.O.A.C., the Accidents Branch of the Ministry of Transport and Civil Aviation, de Havillands, the de Havilland Engine Company Limited and A.R.B. As a result of that meeting a committee under the chairmanship of Mr. C. Abell, the Deputy Operations Director (Engineering) of B.O.A.C., and composed of representatives of A.R.B., B.O.A.C. and de Havillands, was appointed to consider what modifications were necessary before B.O.A.C. could properly seek the agreement of the Minister of Transport and Civil Aviation to the resumption of passenger services by Comet aircraft. The Committee proceeded to consider what possible features or combination of features might have caused the accident. According to the evidence of Mr. Abell, they came to the view that possible main causes of the accident were as follows:—

(*a*) Flutter of control surfaces. This is a term used to describe a type of vibration of a surface, which may be dangerous and may arise from one or more of several causes such as the failure of some part of the mechanism connecting the control surface to the hydraulic power unit which operates it in flight, or to the development of play or backlash in the mechanism. It was decided to make a special inspection of the whole of the mechanism and of the control surfaces and mass-balance arms.

(*b*) Primary structural failure. They considered, in particular, the possible effects of gusts, in causing abnormally high loads, and surveyed all parts of the structure of

* Figures 2 to 19 have been reproduced, with slight alterations, from the R.A.E. Report (Accident Notes 260 to 270) with the consent of the Director.

which there was any suspicion in the light of previous experience.

(*c*) Flying controls. For each hydraulic power unit operating a control surface there is an output circuit connected to the control surface, and an input circuit connected to the pilot's control in the cabin. Many possible sources of malfunctioning both of the hydraulic power units themselves and of these mechanical circuits were examined and special investigations initiated.

(*d*) Fatigue of the structure. They had in mind more particularly fatigue of the wing, because about the time of the Elba accident cracks had appeared near the edge of the wheel-wells, on the under-surface of the wing of the first prototype, which was under test at R.A.E., after the equivalent of about 6,700 flying hours. They re-examined also one or two other parts of the structure at which they felt fatigue effects might be appearing.

(*e*) Explosive decompression of the pressure cabin. They had no reason to suspect the primary structure of the cabin itself. They reviewed the records of damage by, for example, the steps used to load the aircraft, and the methods of repairing such damage by schemes approved by de Havillands. Their main concern, however, was the window panels, where they thought it necessary to consider possible defects which might cause weakness not revealed in the tests made during design at de Havillands.

(*f*) Engine installation. Their main preoccupation here was with the possibility of fire and investigations were made at a number of points in order to remove every cause of possible fire risk which they could imagine.

53. As a result of the inspections and tests which followed the meetings of the Committee, a large number of modifications were made both to the power plants and to other parts mentioned above. At the conclusion of their work the Committee still regarded fire as the most likely cause of the accident. But one modification deserves special mention since it shows the care which was taken to avoid the possibly serious consequences of failure of a turbine blade, although there existed no evidence of such a failure in all previous experience. The only recommendation specifically directed to fatigue related to the wing as mentioned above. One modification and two special inspections were called for. Mr. Abell said that the possibility of fatigue in the wing structure due to gusts was believed to be much more likely than fatigue in the pressure cabin, since this is subject to much less frequent changes of load. At this stage neither Mr. Bishop nor Mr. Harper of de Havillands suspected that the failure of the cabin structure by fatigue or otherwise was a primary cause of the accident. They still regarded the 18,000 repeated loadings as removing any doubt about the fatigue life of the cabin.

(e) *Resumption of Comet services*

54. On the 17th February, 1954, Mr. Abell forwarded to the Operations Director of B.O.A.C. a report and papers showing in detail all the inspections, investigations, modifications and other work which had been carried out since the Comet aircraft had been temporarily removed from service by B.O.A.C. on the 11th January, 1954. On the 19th February the Chairman of B.O.A.C. forwarded the above-mentioned report and papers to the Minister of Transport and Civil Aviation stating in the course of his letter that, on the assumption that no further indication of the cause of the accident emerged prior to the completion of the inspection and modification work, B.O.A.C. considered that all such steps as were possible before putting the aircraft back into passenger service would have been taken.

55. The position was also considered by A.R.B. On the 4th April Lord Brabazon wrote to the Minister saying:—

> "Although no definite reason for the accident has been established, modifications are being embodied to cover every possibility that imagination has suggested as a likely cause of the disaster. When these modifications are completed and have been satisfactorily flight tested, the Board sees no reason why passenger services should not be resumed."

56. In the meantime the Minister of Transport and Civil Aviation, who had not revoked the Certificate of Airworthiness of the Comet fleet, had asked A.S.B. for advice on the resumption of the Comet passenger services. On the 5th March Air Chief Marshal Sir Frederick Bowhill, the Chairman of A.S.B., minuted the Minister as follows:—

> "2. The Board has considered all the available information resulting from recent investigations and has noted the nature and extent of the modifications planned as a result. It realises that no cause has yet been found that would satisfactorily account for the Elba disaster, and whilst the Calcutta disaster is completely accounted for if the aircraft is supposed to have encountered a gust of very great

severity (which would have broken any other aircraft) we cannot eliminate that the accident might have been due to some other cause which was possibly common to both disasters. Nevertheless, the Board realises that everything humanly possible has been done to ensure that the desired standard of safety shall be maintained. This being so, the Board sees no justification for imposing special restrictions on Comet aircraft.

3. The Board therefore recommends that Comet aircraft should return to normal operational use after all the current modifications have been incorporated and the aircraft have been flight tested."

57. Acting on this advice the Minister gave permission for flights to be resumed and the first Comet aircraft to resume passenger service took the air on the 23rd March, 1954.

PART X

THE ACCIDENT TO G-ALYY (YOKE YOKE)

58. On the 8th April, 1954, Comet aircraft G-ALYY, which was on charter to South African Airways, crashed near Naples while on a flight from Rome to Cairo. I am making a separate Report on that accident. It is sufficient for the purpose of this Report to record that the accident occurred at approximately the same height and after approximately the same lapse of time after departure from Rome as in the case of Yoke Peter. On receiving news of the accident B.O.A.C. decided immediately to suspend all Comet services until more was known and on the 12th April, 1954, the Parliamentary Secretary to the Ministry of Transport and Civil Aviation informed the House of Commons that the Minister, after consulting A.R.B. and A.S.B. and discussing the matter with the Chairman of A.R.B., had withdrawn the United Kingdom Certificate of Airworthiness from all Comet aircraft.

PART XI

INVESTIGATION OF THE ACCIDENTS TO G-ALYP AND G-ALYY

(a) *Investigation by R.A.E.*

59. The loss of Yoke Peter and Yoke Yoke presented a problem of unprecedented difficulty, the solution of which was clearly of the greatest importance to the future, not only of the Comet, but also of Civil Air Transport in this country and, indeed, throughout the world. Accordingly, shortly after the Naples accident, the Minister of Supply instructed Sir Arnold Hall the Director of R.A.E. to undertake at R.A.E. a complete investigation of the whole problem presented by the accidents and to use all the resources at the disposal of the Establishment. This provided an opportunity of showing what can be done by a close collaboration between a private firm and R.A.E. with the unique facilities at its disposal. It will be seen hereafter that full use was made of that opportunity by R.A.E. and de Havillands.

60. R.A.E. made a complete review of the conclusions which had been reached by the Abell Committee, and particularly of the implications arising from the fact that there had been two accidents in what appeared to be similar conditions, each occurring at about the time when the aircraft was nearing the top of its climb. They thought it necessary to satisfy themselves about the structural integrity of the aircraft, in particular of the cabin and the tail and to consider in more detail possible sources of explosion and loss of control. They also considered that flight tests would be required in order to investigate the possibility of flutter of control surfaces (see para. 52 (*a*)). It soon became evident that it was probable that more wreckage would be recovered than had at first been expected. The wing centre section was received on the 5th April (the engines had been recovered and sent by air to de Havillands on the 21st March), and the front part of the cabin arrived on the 15th April. But at the time when their attention became directed to fatigue of the pressure cabin they were influenced chiefly by the apparent similarity of the circumstances of the two accidents, and by the fact that the modifications carried out after Elba seemed to rule out many of the other possible causes.

61. On the 18th April Sir Arnold Hall decided that a repeated loading test of the whole cabin ought to be made. He said that he regarded this as one of a number of lines of inquiry which had to be pursued and that he felt it to be necessary to study every possible cause in detail.

62. The normal method of testing pressure cabins up to the point when they fail under pressure is similar to that used for vessels such as boilers. They are filled with water, and more water is pumped in until the desired difference between the internal and external pressure is reached. This method has two advantages over the use of air. Water is relatively incompressible, so that failure when it occurs produces only a mild form of explosion. The origin of the failure can be determined and the structure can generally be repaired and tested again. If air were used instead of water, the failure would be catastrophic (equivalent in the case of the Comet's cabin to the explosion of a 500 lb. bomb). Such a test

would be dangerous, the cabin would be destroyed, and the evidence of the origin of the failure would almost certainly be lost.

It is however necessary to prevent unrepresentative loading of the cabin structure by the weight of the water. This is ensured in practice by immersing the whole cabin in a tank, and filling the tank and the cabin simultaneously with water. Pressure in the cabin is then raised by pumping in water from the space outside it.

Cycles of loading, to the same or different levels of pressure as desired are applied by a suitable routine of pumping.

63. By a remarkable effort, to which de Havillands and the firms who built the tank (see Figure 6) contributed to the full and by the use of all the resources of R.A.E., repeated loading tests began early in June on aircraft G–ALYU (Yoke Uncle). The object of the tests was to simulate the conditions of a series of pressurised flights. To this end the cabin and wings were repeatedly subjected to a cycle of loading as far as possible equivalent to that to which they would be subjected in the period between take-off and landing. In addition to one application of cabin pressure, fluctuating loads were applied to the wings in bending to reproduce the effect of such gusts as might be expected in normal conditions, although the contribution of gust loads to the stresses in the cabin structure, compared with that made by the internal pressure, was in general small. Moreover, the programme of tests included, at intervals of approximately 1,000 " flights " a proving test in which the pressure was raised to $1\frac{1}{3}$ P (11 lb./sq. in.). It must be understood that there are other sources of fluctuating load and, therefore, of fatigue to which no precise value can be attached. No attempt was made to represent these in the test. Examples are vibration due to irregular airflow, vibration due to the engines and the jet efflux and fluctuating loads occurring during take-off and landing.

64. Yoke Uncle had made 1,230 pressurised flights before the test and after the equivalent of a further 1,830 such flights, making a total of 3,060, the cabin structure failed, the starting point of the failure being the corner of one of the cabin windows (see Figures 7 and 8). The fact that the failure occurred during one of the proving tests to 11 lb/sq. in. is not thought significant since the crack would have spread in very much the same way after a few more applications of the working pressure. Examination of the failure provided evidence of fatigue at the point where the crack would be most likely to start, namely near the edge of the skin at the corner of the window (see Figures 9 and 10). This was revealed by the discolouration due to algae in the water which made it clear that the crack had endured several pressurisations before it spread catastrophically. It is important to note here that the sources of fatigue mentioned above, which were not reproduced in the tank test, all tend to increase the burden of fatigue and that, therefore, the life of a fuselage deduced from the test is longer than would be expected in service. It is not possible to do more than estimate the magnitude of this effect but it was suggested by Dr. Walker that a " life " of 3,060 flights in the test might be equivalent to about 2,500 in practice.

65. It is convenient to note here that Comet G–ANAV, which had been sent to R.A.E. to undergo flight tests (unpressurised) on a number of matters which could only be explored in flight, made its first flight on the 23rd June. A large amount of miscellaneous wreckage was arriving at R.A.E. during the whole of this period and was being sorted out and examined by the Accidents Investigation Section under Mr. Ripley.

66. The failure of the cabin of Yoke Uncle marks the point at which the character of the investigation changed to one in which the problem of fatigue in the structure of the cabin began to dominate all others, although many possible sources of trouble were continually investigated during the whole of the summer. In the main, their results were negative so far as the accidents were concerned, though they revealed points which needed and will receive attention. The inference suggested by the tank test, that the primary failure of Yoke Peter was the bursting of the pressure cabin, was confirmed by a close examination of the wreckage and by the experiments referred to in the next following paragraphs of this Report.

67. The character of the damage caused to the structure was such that it became possible to determine with a high degree of probability the manner in which the various fragments struck the sea, mainly because of the very high local pressures produced by the impact with the sea. Moreover, it rapidly became clear that the intense fire which had existed was confined virtually to the centre part of the wing, leaving the outer parts of the wing and the front and rear parts of the cabin untouched. These considerations led to the conclusion that it was probable that the main part of the aircraft fell into the sea in a small number of relatively large pieces, one of which was on fire (see Figure 11). Most of these pieces had fallen in a surprisingly small area. This conclusion was in agreement with the evidence of the farmer at Elba, who saw fragments, one of which was on fire, falling into the sea. This led to a line of experiment which produced remarkable results. Models were made of the Comet in light

wood, suitably ballasted, and projected in the air at the appropriate speed. They were released from a kite balloon at a height above the ground corresponding to that at which it was believed the Comet structure failed, reduced in proportion to the scale of the model. The model was so constructed that it would break at the point where the failure of the cabin was suspected, namely in the neighbourhood of the wing. The outer parts of the wing (only one of which had been recovered), were also separated from the centre part. The descent of the fragments was photographed, and it was found that they fell in a manner which agreed with the deductions which had been made from the evidence mentioned above.

68. Simultaneously with this work, further experiments in the water tank were made on the cabin of Yoke Uncle, after the first failure had been repaired by de Havillands. Until then, owing to the need to discover whether the cabin had, against all previous belief, a relatively short life under repeated loading, no attempt had been made to measure the stress in the material of the skin at points where it might be expected to be higher than the average. One reason for this omission was that the number of places coming within this description is large, and it would have taken a long time to instal the necessary strain gauges and other associated equipment. But it now seemed highly probable that the stress near the corners of the windows was higher than had been believed by the designers, and the strain gauges were therefore fixed to the surface of the skin, at various positions near the corners of typical windows, including the window corresponding to the one which had failed but on the other side of the cabin.

69. A discussion of the evidence bearing on the reliability of the estimates of the stress at the edge of the window will be found in paragraphs 118 to 129. It is sufficient here to say that I am satisfied that the highest stress in the skin, at the edge near the corner of the window of Yoke Uncle, was probably over 40,000 lb./sq. in. when the pressure difference was $8\frac{1}{4}$ lb./sq. in. and that the general level of the stress in the skin in these regions was significantly higher than had been previously believed. In the light of known properties of the aluminium alloy D.T.D. 546 or 746 of which the skin was made and in accordance with the advice I received from my Assessors, I accept the conclusion of R.A.E. that this is a sufficient explanation of the failure of the cabin skin of Yoke Uncle by fatigue after a small number, namely, 3,060 cycles of pressurisation.

70. In considering the possible bearing of this result on the accidents at Elba and Naples, it is necessary to recognise that there are inevitable differences between individual aircraft structures built to the same drawings. The nature and extent of these depend on a number of factors such as variations in the thickness of metal sheet of nominally the same gauge, and local regions of high stress due to the methods employed in joining the various parts, such as rivets, bolts, etc. If a number of such structures are tested under repeated loading, there will be appreciable differences* between the number of cycles of application of given loading before failure occurs. Experience suggests that there will be a variation of at least 9 to 1 in the number of cycles necessary to produce failure when the general level of stress is high, and the number of cycles undergone before failure therefore low. If a large number of specimens could be tested, it would undoubtedly be found that the weak and the strong were relatively few in number, and that the majority would be more or less evenly distributed round a mean value. But it is impossible from a single test to say where, in the total range to be expected from general experience, a particular specimen lies.

71. At the time of the Elba accident Yoke Peter had made 1,290 pressurised flights and at the time of the Naples accident Yoke Yoke had made 900 pressurised flights. Sir Arnold Hall said in evidence that in the light of the experiment on Yoke Uncle, and of the measurements and calculation of stress referred to above, he considered that the cabin of Yoke Peter had reached a point in its life when it could be said to be in danger of failure from fatigue, and that the cabin of Yoke Yoke would similarly be in danger. Dr. Walker said that he did not regard the picture presented by the three failures (on the assumption that these were all due to the same fundamental cause) as surprising, since the three results taken together are consistent with general experience of the strength under repeated loading of a number of nominally identical structures, in which the stress level is high. They lie within a range of just over 3 to 1, whereas experience suggests a total range of at least 9 to 1.

72. At this stage in R.A.E.'s attack on the problem, it seemed unlikely that any more wreckage would be recovered which would throw light on the problem which was now obviously the chief one. But after a further review of the whole of the circumstances of the flight of the aircraft and the distribution of the wreckage on the sea bed, R.A.E. reached the conclusion that search in a wider area was justified. Whatever the cause

* See Appendix IV.

of the bursting, it seemed probable that the disruption of the aircraft would have resulted in some relatively large pieces of the structure being blown clear. These might well have fallen some distance away from the main pieces of wreckage, all of which, as mentioned above, were found within a remarkably small area. It was therefore decided to make a search of an area some miles long in the sea below the path of the aircraft working towards Rome from the area where the main items were recovered. As the depth of the sea increased rapidly in this direction, the only practicable method was trawling.

73. As a result of the new search R.A.E. received a piece of cabin skin, which had been found by an Italian fishing boat. It was identified as coming from the centre of the top of the cabin approximately over the front spar of the wing (see Figure 12).* It contained the two windows in which lie the aerials which are part of the A.D.F. (Automatic Direction Finding) equipment. At the same time R.A.E. received a part of the aileron of the port wing (see Figures 13 and 16) and a part of the "boundary layer fence" fitted to the leading edge of the port wing not far from the tip (see Figures 14 and 16).

74. The latter parts provided important evidence about the bursting of the cabin. There were marks on them which were identified as made by pieces from the cabin itself. Taken together with the paint mark on the leading edge of the centre section not far from where the outer wing broke off, which was identified as caused by the piece of the cabin wall containing the first window (escape hatch) (see Figures 15, 16 and 12), they established that the cabin burst catastrophically in the neighbourhood of the front spar of the wing when the aircraft was flying substantially normally.

75. By examination of the piece containing the A.D.F. windows and the adjacent pieces (see Figure 12) it was established that it was here that the first fracture of the cabin structure of Yoke Peter occurred. In general terms, it took the form of a split along the top centre of the cabin along a line approximately fore and aft passing through corners of the windows as shown in Figure 17. The direction in which the fracture spread was determined by examination of the lines of separation of the material.

76. A development drawing of the wreckage recovered from the part of the cabin over the wing spar is shown in Figure 18. Apart from the area on top of the cabin around the A.D.F. windows, which is shown cross-hatched, the remainder was recovered with, and in many cases remained attached to, either the front fuselage, the wing centre section, or the rear fuselage. These three groups are distinguished by different hatchings, as indicated in the diagram. In the light of all this evidence, I accept R.A.E.'s conclusion that the first fracture of the cabin occurred near the rear A.D.F. window and spread fore and aft from it.

77. I do not consider it possible to establish with certainty the point at which the disruption of the skin first began. But I consider that it is probable that it started near the starboard aft corner of the rear A.D.F. window, at a point where examination by experts showed that fatigue had existed, at the edge of the countersunk hole through which a bolt passed (see Figure 19).

78. The only alternative point suggested was the opposite (port forward) corner of the same window. Here the fracture passed through a small crack in the reinforcing plate, about 0·2 in. long, made accidentally during the building of the aircraft. This had been dealt with by de Havillands in accordance with their procedure for dealing with any departure from the strict requirements of their drawings which might appear during the manufacture of their aircraft. All such matters were required to be reported to the Technical Office, and each was dealt with as a special case by a qualified expert. In this case approval was given to the use of the normal process of "locating" small cracks in the skin of an aircraft by drilling small holes at their ends. Advised by my Assessors I see no reason to doubt that this would have been a satisfactory method of dealing with the crack in question had it not been for the fact that the stress in this region was relatively high. It was suggested that such a crack might be a possible place of origin of fatigue but no witness was able to identify any evidence of fatigue at the material point.

79. It is my opinion that the fundamental cause of the failure of the cabin structure was that there existed around the corners of the windows and other cut-outs a level of stress higher than is consistent with a long life of the cabin, bearing in mind the unavoidable existence of points, within the areas of generally high stress, at which it will be still further raised by relatively local influences, such as the countersunk hole near the starboard rear corner, and the small crack with its "locating" hole near the port forward corner. I find it impossible to say, definitely, on any evidence before me, which of these operated first. But, since the existence of fatigue near the bolt hole is established, I think it the more probable.

* Figure 12 includes two other pieces recovered earlier.

(b) *Investigation by the de Havilland Engine Company Limited*

80. The R.A.E. investigation did not deal with the engines. The history of their recovery and investigation is as follows.

81. The centre section of the wing of Yoke Peter was recovered from the sea on the 15th March. It was severely damaged by fire and by impact with the water. It contained the four Ghost engines substantially intact with the exception that the turbine disc of No. 2 engine (port inner) was missing. The shaft on which it had been mounted had broken near the hub to which it was bolted and it had escaped through a large gash in the exhaust cone. The disc has not been recovered.

82. The engines were removed and examined superficially by an engineer from de Havilland Engine Company Limited. They were then sent by air to that company's works where they arrived on the 21st March and were dismantled and examined in detail.

83. Dr. Moult, Chief Engineer of the de Havilland Engine Company Limited, said in evidence that there were no signs consistent with seizure of any engine, or of any excessive internal heat, or of any failure having occurred before the break-up of the aircraft. The extensive fire damage was all external to the engines. The four compressor impellers were intact on their shafts.

84. The turbine discs from Nos. 1, 3 and 4 engines showed no signs of failure. No blades were missing from them. In No. 2 engine, there was no evidence of penetration of the shroud ring surrounding the turbine, either by a blade or by the complete disc. There was no evidence of failure of any blade in any of the engines.

85. Examination of the hubs to which the turbine discs of Nos. 1, 3 and 4 engines were bolted showed that all were on the point of failing. Cracks were found in the same regions as those which had resulted in the fracture of No. 2 engine, which led to the loss of the disc.

86. The remarkable similarity of the damage to the turbine shafts of all four engines pointed to a common cause external to the engines, and further examination showed that the most probable cause was a sudden and very rapid rotation of the whole wing about a transverse axis, nose downwards, while the engines were still running normally. Such a rotation, being about an axis at right angles to the engine shafts, would produce gyroscopic couples tending to bend the shafts in a sideways direction, that is, in the plane of the wing. Since the clearances between the discs and the stationary parts surrounding them are small, signs of rubbing would be expected in definite regions. Examination showed such signs in each engine.

87. From this evidence the conclusion was reached that the engines had run, though only for a short time, possibly a few hundred revolutions, after a sudden nose-down rotation of the wing, and had not stopped suddenly. Further examination showed other evidence consistent with this, namely the absence of any deformation in the splines on the turbine shafts. This also suggested that by the time the whole of the centre section, including the engines, hit the surface of the sea, the engines were no longer rotating.

88. The whole of the remaining extensive damage to the engines was considered to be due to impact with the surface of the sea. It was in the main confined to the upper parts of the engines, and was therefore consistent with the deductions from the examination of the centre section of the wing itself, which showed everywhere evidence of the wing having hit the sea upside down.

89. In order to investigate the conditions which were now thought to have caused the failure of the turbine hubs, tests were made on a Ghost engine supported in a framework which was pivoted about a horizontal axis some distance above the engine, so that it could swing in a vertical plane, like a pendulum. The engine was run at normal speed, and was pulled sideways, thus raising it from its lowest position. When released, it accelerated under the combined influence of its weight and the thrust from the jet. The rate of rotation round the transverse axis could be varied by releasing it from different heights. It was found that when this reached a value of nearly 180° a second (corresponding to the centre section of the wing turning upside down in about one second) the turbine disc hub broke and the engine slowed down and stopped without any further substantial damage. Examination showed the same type of failure, and symptoms, as were found on the four engines of Yoke Peter.

90. The examination of the engines, combined with the striking evidence of this experiment, confirmed de Havillands in the view that no part of the engines was in any way the cause of the failure of the aircraft. Dr. Moult said that in their previous experience of Ghost engines of the same type as those used in the Comet, they had had no records of any blade failures. The modification made to the aircraft as a result of the Abell Committee's discussions, consisting of fitting high tensile steel plate round certain parts of the engines in the plane of the turbine discs, was regarded by him as possibly a wise precaution, in view of the need to guard against every source

of trouble which could be imagined. At the time it was put into effect, with the other modifications decided by the Abell Committee, the engines from Yoke Peter had not been examined.

91. In the light of all this evidence and these considerations, I accept Dr. Moult's conclusion that there was no failure of any part of any engine which could have been the cause of the failure of Yoke Peter. The fire which damaged the engines externally was in my opinion subsequent to and not a cause of the disintegration of the aircraft.

PART XII

THE R.A.E. REPORT

92. The Report (which was part of the evidence before the Court) is divided into 12 parts. The first part contains an outline of the investigation and states the opinion R.A.E. formed as to the cause of the accident. I have included the first part, which is intelligible without reference to the other parts, as an appendix to this Report (Appendix VI). Para. 4 thereof which states the opinion of R.A.E. is in the following terms:—

" We have formed the opinion that the accident at Elba was caused by structural failure of the pressure cabin, brought about by fatigue. We reach this opinion for the following reasons:—

- (i) The low fatigue resistance of the cabin has been demonstrated by the test described in Part 3, and the test result is interpretable as meaning that there was, at the age of the Elba aeroplane, a definite risk of fatigue failure occurring (Part 3).
- (ii) The cabin was the first part of the aeroplane to fail in the Elba accident (Part 2).
- (iii) The wreckage indicates that the failure in the cabin was of the same basic type as that produced in the fatigue test (Parts 2 and 3).
- (iv) This explanation seems to us to be consistent with all the circumstantial evidence.
- (v) The only other defects found in the aeroplane (listed in Section 3) were not concerned at Elba, as demonstrated by the wreckage.

Owing to the absence of wreckage, we are unable to form a definite opinion on the cause of the accident near Naples, but we draw attention to the fact that the explanation offered above for the accident at Elba appears to be applicable to that at Naples."

It should be added that the medical evidence as to the state of the bodies recovered was consistent with the conclusion thus reached.

93. The " other defects " mentioned in sub-para. (v) quoted above are:—

- (*a*) relatively low resistance of the wing to fatigue;
- (*b*) possibility of fuel from the fuel tank venting system entering the trailing edge area of the wing near the jet pipe shrouds;
- (*c*) risk of internal damage during refuelling to the outer wing tanks under conditions which, though abnormal, may sometimes have occurred in practice.

94. I shall return to these defects after I have stated my opinion on the major conclusion of the Report.

PART XIII

THE COURT'S CONCLUSIONS AS TO THE CAUSE OF THE ACCIDENT

(a) *The main finding in the R.A.E. Report*

95. The opinions expressed in the Report were supported by the evidence of Sir Arnold Hall, Dr. Walker and Mr. Ripley. Their conclusions were accepted by de Havillands and B.O.A.C. All parties appearing at the Inquiry paid a warm, and in my opinion well-deserved, tribute to the Report and to all who had co-operated in the work done at R.A.E. As I have already indicated and for the reasons I have given I have accepted the main conclusion of the Report that the cause of the accident to Yoke Peter was the structural failure of the pressure cabin brought about by fatigue.

(b) *The alternative suggestion made by Mr. B. Jablonsky*

96. The only rival suggestion was made by Mr. Jablonsky. His experience of structural problems in aeronautics has been concerned mainly with propellers having blades of highly compressed wood. He is, therefore, familiar with adhesives, and with the problems which have to be overcome in using them to make components.

97. In the construction of the Comet wide use is made of a metal-to-metal adhesive known as Redux, mainly for the purpose of attaching members, generally known as " stringers ", to the skin both of the wing and of the cabin. In the cabin there are about forty stringers more or less evenly spaced around the circumference and running longitudinally. They are not structurally continuous from end to end, the largest uninterrupted length being about 25 ft. de Havillands were pioneers in using Redux for such purposes in aircraft structures, and have had long experience of it. It is in effect an alternative to the conventional riveting.

98. Mr. Jablonsky's argument proceeded on the following lines:—

(*a*) The skin of the cabin is exposed under service conditions to a large variation in temperature. He suggested a range of 80°C on the ground in the tropics to −55°C at about 40,000 ft. The rate of climb of the Comet is fairly high and the temperature of the skin might change over this range in about 30 minutes. The stringers, however, although inside the skin, are outside the insulating lining of the cabin and therefore not exposed to the full temperature of the warm cabin air. His argument contemplated a difference in temperature between skin and stringer of as much as 60° or 70°C. This would have the result that the skin would contract relative to the stringer, in the direction of the cabin's length. The adhesive would, therefore, be subjected to a shear stress which might be sufficient to cause it to fail.

(*b*) Even if this did not cause the adhesive to fail statically (that is on the first occasion when such a difference of temperature between the skin and the stringers occurred) frequent repetition of the shear stress might produce fatigue in the adhesive, and cause it to fail.

(*c*) Mr. Jablonsky recognised that the dependence on temperature level of the properties of Redux is well known. He suggested, however, that frequent and rapid variations of temperature would reduce its strength substantially.

(*d*) It is generally recognised that the satisfactory use in engineering structures of any form of adhesive (or, indeed, of processes essentially similar, such as the welding or soldering of metals) can be ensured only by the development and maintenance of higher standards of workmanship and process inspection than are necessary in the use of riveting. While Mr. Jablonsky recognised that de Havillands' production technique for Redux had been developed after many years' study of its properties, and that their experience of its use in other aircraft had been highly satisfactory, he suggested that it was not a process sufficiently reliable for use in the primary structure of a pressure cabin.

99. Mr. Jablonsky said in evidence that in his inspection of the wreckage at R.A.E. he had seen examples of failure of the " glue line " which had satisfied him that weakness in it was primarily responsible for the failure of the structure of the cabin.

100. I deal below with these points separately:—

(*a*) During the experiments made in flight on Comet G–ANAV at R.A.E., measurements were made of the difference in temperature between the skin and the stringers in typical positions in steady flight at cruising altitude. They led to the conclusion that the maximum probable steady difference in temperature is about 10°C. I am advised that the shear stress in the Redux caused by the relative contraction between the skin and the stringers due to a temperature difference of this order would be well within its capacity.

Mr. Jablonsky did not agree that any reliable inference about the conditions on an operational climb could be drawn from these experiments. I recognise that this comment has some force but I base my conclusions on this aspect of his criticism on the more general considerations set out in paragraphs 101, 102 and 103 below.

(*b*) No evidence was submitted of the effect, on the fatigue strength of a Redux joint, of the level of temperature of the adhesive. But I am advised that the wide experience of its use by de Havillands in the structures of other aircraft, where alternations of load on the glue line have certainly existed in numbers far in excess of any likely to have been experienced in the cabin structure of the Comet, and over a wide range of temperature of the Redux itself, is satisfactory evidence that this is not a probable cause of failure of the Redux joints in the Comet's cabin.

(*c*) de Havillands made special tests to investigate the effect on typical joints of repeated alternation of temperature between 60°C and −50°C. I am advised that these show that alternations of temperature within this range have no appreciable effect on the strength of a Redux joint.

(*d*) At my request, de Havillands submitted a statement which summarised the history and present state of their production methods in the use of Redux, with particular reference to its application to the construction of the Comet. Mr. Povey, the Director responsible for production, gave evidence on the point. I am advised that this statement and evidence show that de Havillands fully appreciated the importance of this aspect of the use of an adhesive in essential structural components, and that the methods they have devised, including process control and inspection, tests of samples of every joint, and periodic stripping of complete stringers from the skin, provide all the assurance that could reasonably be required.

101. However, the final test of a process of this type is recognised to be experience in service. No evidence was produced of any failure of de Havillands' methods of dealing with the same problem in aircraft such as the Hornet and the Dove, in both of which Redux is widely used. Moreover, inspection of Yoke Uncle at R.A.E., both before and after it was tested under repeated loading, showed no signs of any deficiency in the glue line. It must be remembered that before it was delivered to R.A.E. for tests, this aircraft had done 3,521 hours of flying on B.O.A.C. services, experiencing the conditions of temperature, and of temperature variation between the skin and the stringers, contemplated by Mr. Jablonsky.

102. Finally, examination of the wreckage led Mr. Ripley to conclusions, contrary to those inferred by Mr. Jablonsky, for reasons which he explained in detail.

103. It has been established to my satisfaction that the rear part of the fuselage, substantially intact, hit the surface of the sea at high speed, open end downwards. This caused the equivalent of an explosion in it, whose effects were naturally most acute near the open end (see Figures 3 and 4). I am advised that the failure, under these circumstances, of the adhesion between the skin and the stringers cannot be regarded as evidence of the failure of the adhesive to meet the requirements of the normal use of the aircraft. There was in this neighbourhood abundant evidence of the failure of all the methods of attaching the various structural components to one another. Moreover, the numerous places where the skin had parted from the stringers exposed the glue line to examination and Mr. Ripley said that he had been unable to find any sign of any unsatisfactory features in the process employed by de Havillands, or of any weakness in the adhesive.

104. In the light of these considerations I have no hesitation in rejecting Mr. Jablonsky's suggested alternative cause of the failure of the cabin.

(c) *Mr. Tye's evidence*

105. The only other witness who did not completely accept the suggestion advanced in the Report was Mr. Tye. He did not dispute that the primary cause of the accident was the bursting of the cabin structure, but he expressed himself as not entirely satisfied that fatigue was the cause of that disruption. He appears to have proceeded on the basis that the 9,000 hours (3.000 flights) at which Yoke Uncle burst could be regarded as a fair average life for the fuselage and to have been impressed by the improbability, on this basis, of both Yoke Peter and Yoke Yoke failing from fatigue after only about 3,000 hours (1,000 flights). He was unable, however, to suggest any other cause. He admitted that he could find no evidence either (a) of excessive internal pressure in the cabin or (b) of excessive stresses in the cabin structure due to external action such as gusts or failure of the control system. He agreed also that he could not name any alternative cause of the failure which R.A.E. had failed to consider.

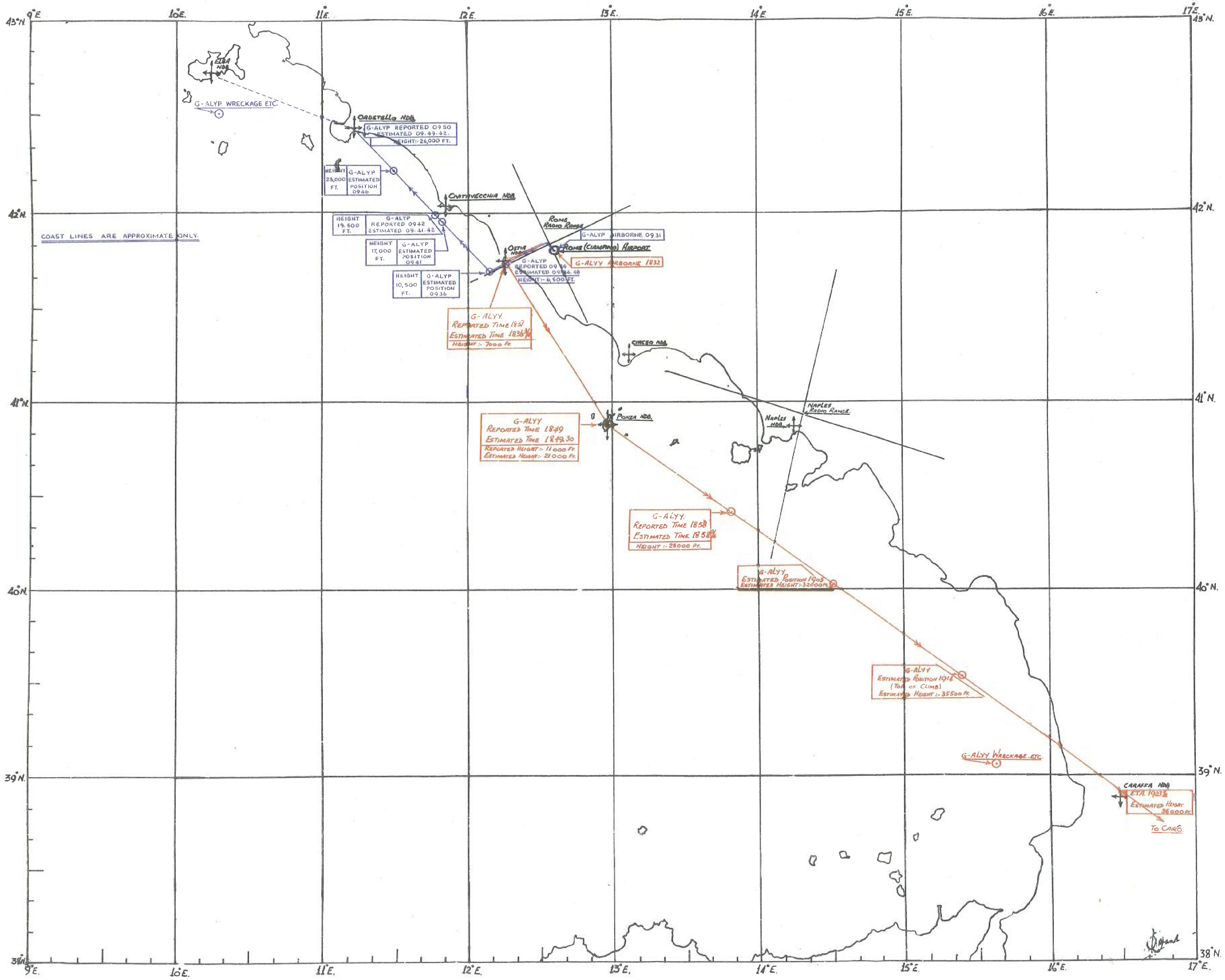
106. Bearing in mind that Mr. Tye is the Chief Technical Officer of A.R.B. and as such will be responsible for advising A.R.B. when an application is made for a new Certificate of Airworthiness for Comet aircraft, his caution is understandable, but I have the duty of expressing my conclusion on the evidence. I rely in this connection on an answer given by Mr. Tye to Sir Lionel Heald which seems to me to represent the proper approach for me to adopt in the circumstances of the case. Mr. Tye said " I think in concluding on the likelihood of the cause one has to take the thing as a whole ; one has to take the tank test evidence and say that that shows that fatigue is possible, although on my argument not necessarily probable, that is the tank test by itself ; one then has to look at the other half of the matter, namely, all the other possible causes, and if in the process of eliminating possible causes you become completely confident that you have eliminated every other possible cause, then you are driven to say that the possible fatigue rises to the most probable cause." Applying these observations to what was done in the course of the investigations by R.A.E. and by the de Havilland Engine Company Limited and to the evidence given in the Inquiry before this Court, I unhesitatingly come to the conclusion that R.A.E. were right in their conclusion that the accident at Elba was caused by structural failure of the pressure cabin in the region of the A.D.F. window, brought about by fatigue. In reaching this conclusion I am fortified by the advice I have received from my Assessors.

(d) *The possibility of over-pressurisation*

107. I considered nevertheless that although the R.A.E. Report contained a full investigation of the equipment used for controlling the pressure in the cabin, including both an examination of the possible causes of mal-functioning and of the condition of the equipment recovered from the

CHART OF AIRCRAFT TRACKS G-ALYP AND G-ALYY

FIG 1.



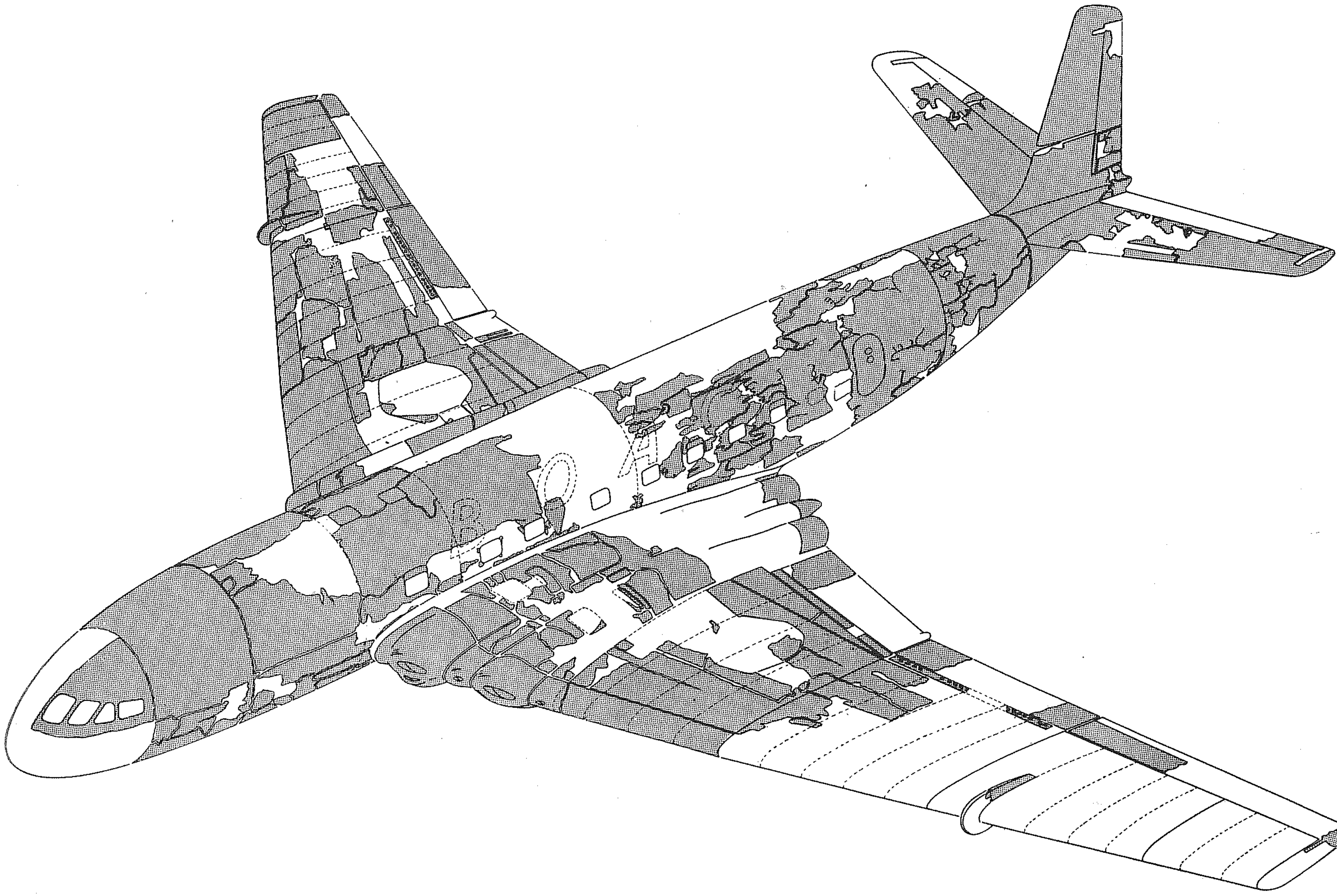


FIG. 2. DIAGRAM SHOWING AMOUNT OF WRECKAGE RECOVERED—G-ALYP.

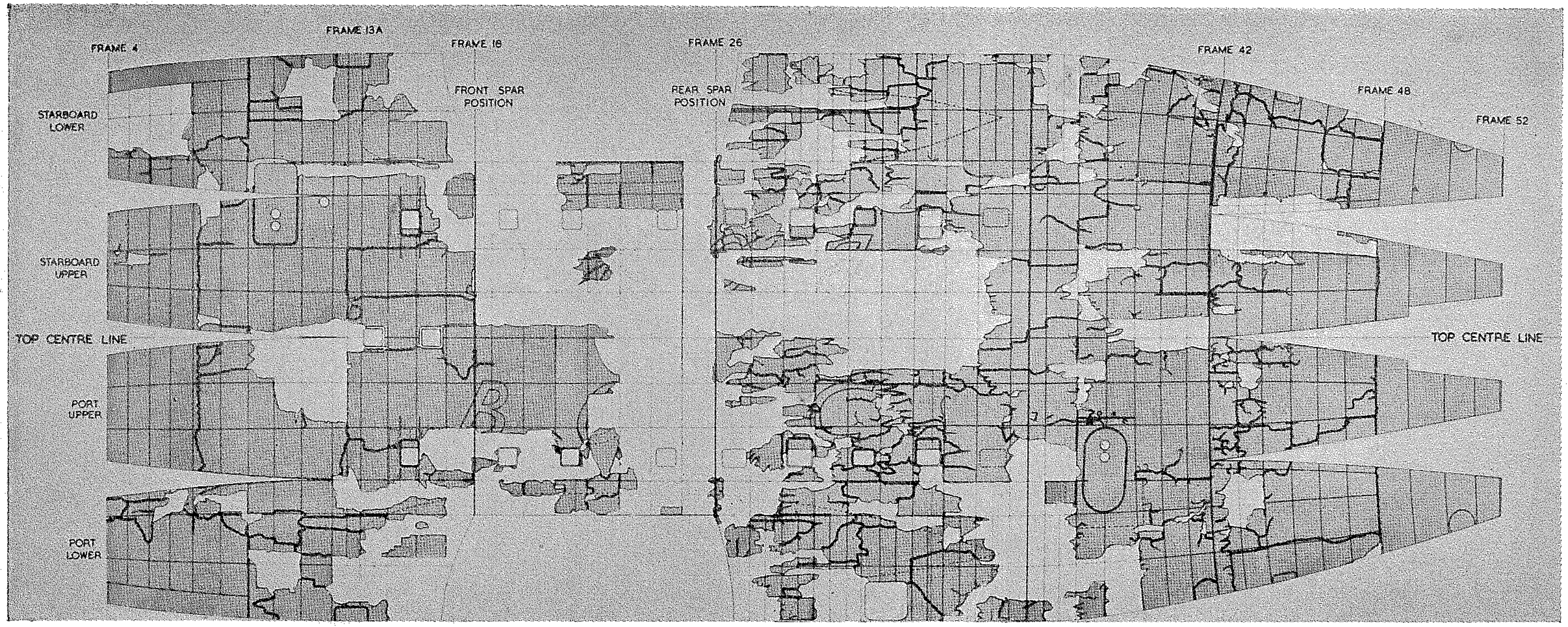


FIG. 3. DEVELOPMENT DRAWING OF FUSELAGE SHOWING AMOUNT OF WRECKAGE RECOVERED—G-ALYP.

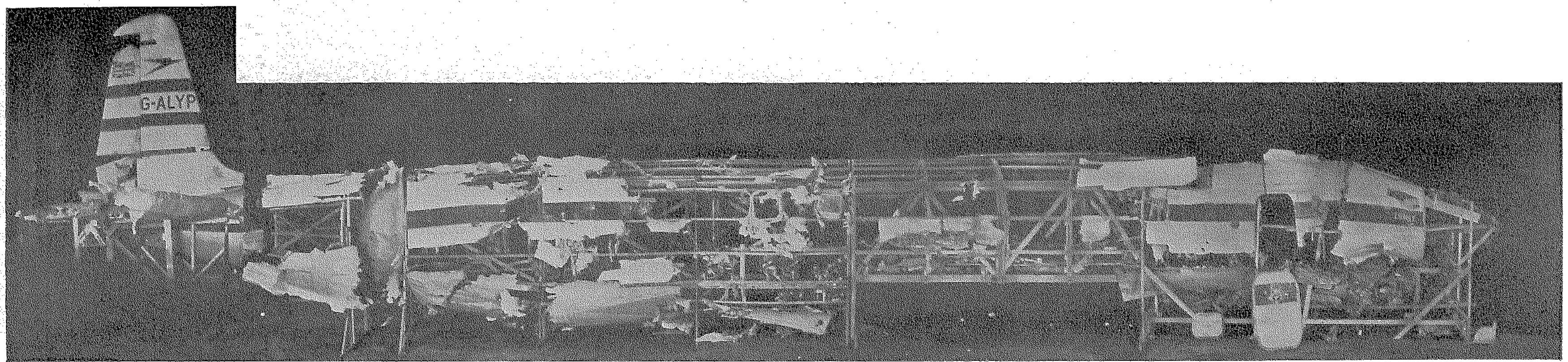


FIG. 4. RECONSTRUCTION OF FUSELAGE AND TAIL UNIT WRECKAGE—G–ALYP.

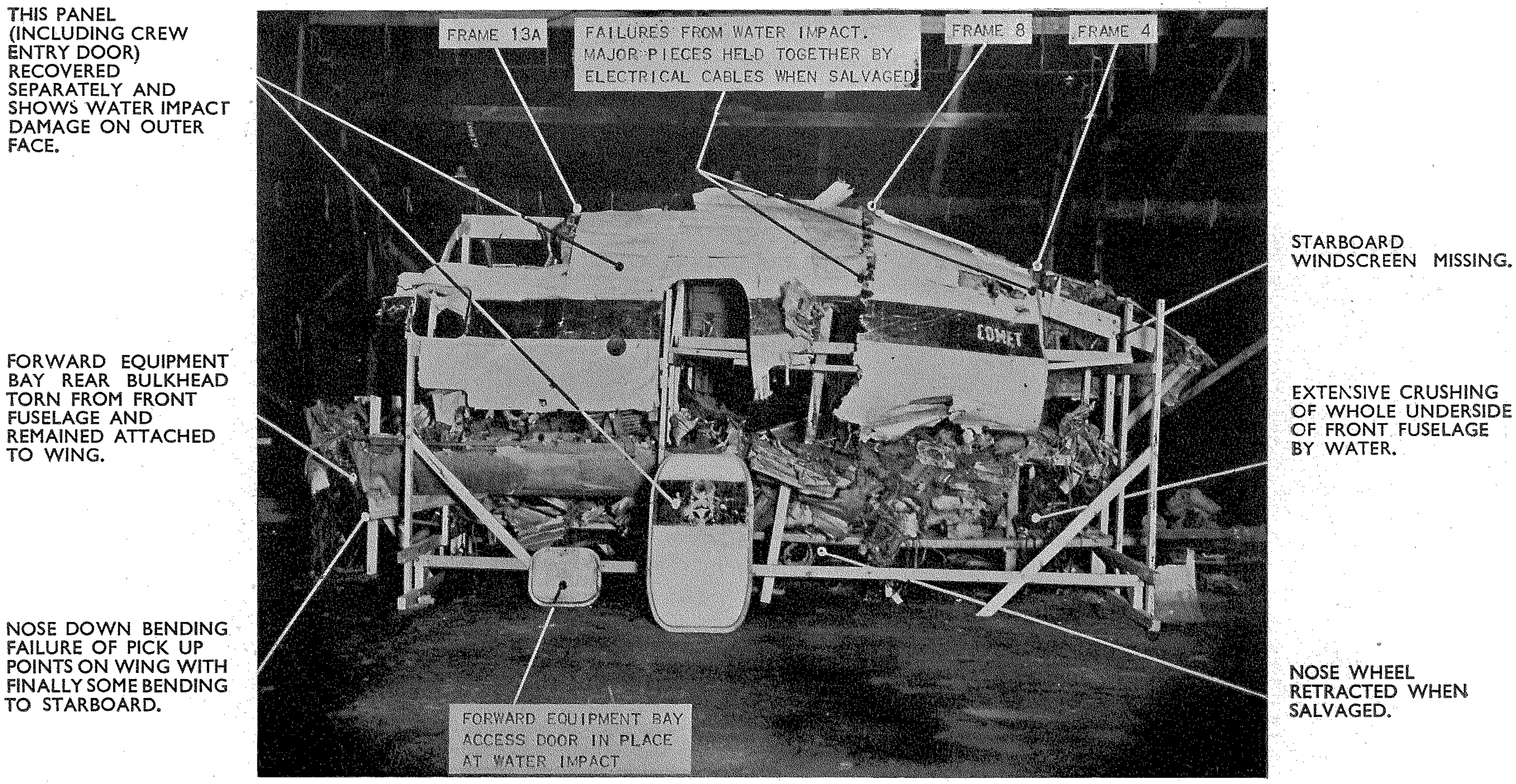


FIG. 5. FRONT FUSELAGE—VIEW ON STARBOARD SIDE—G-ALYP.

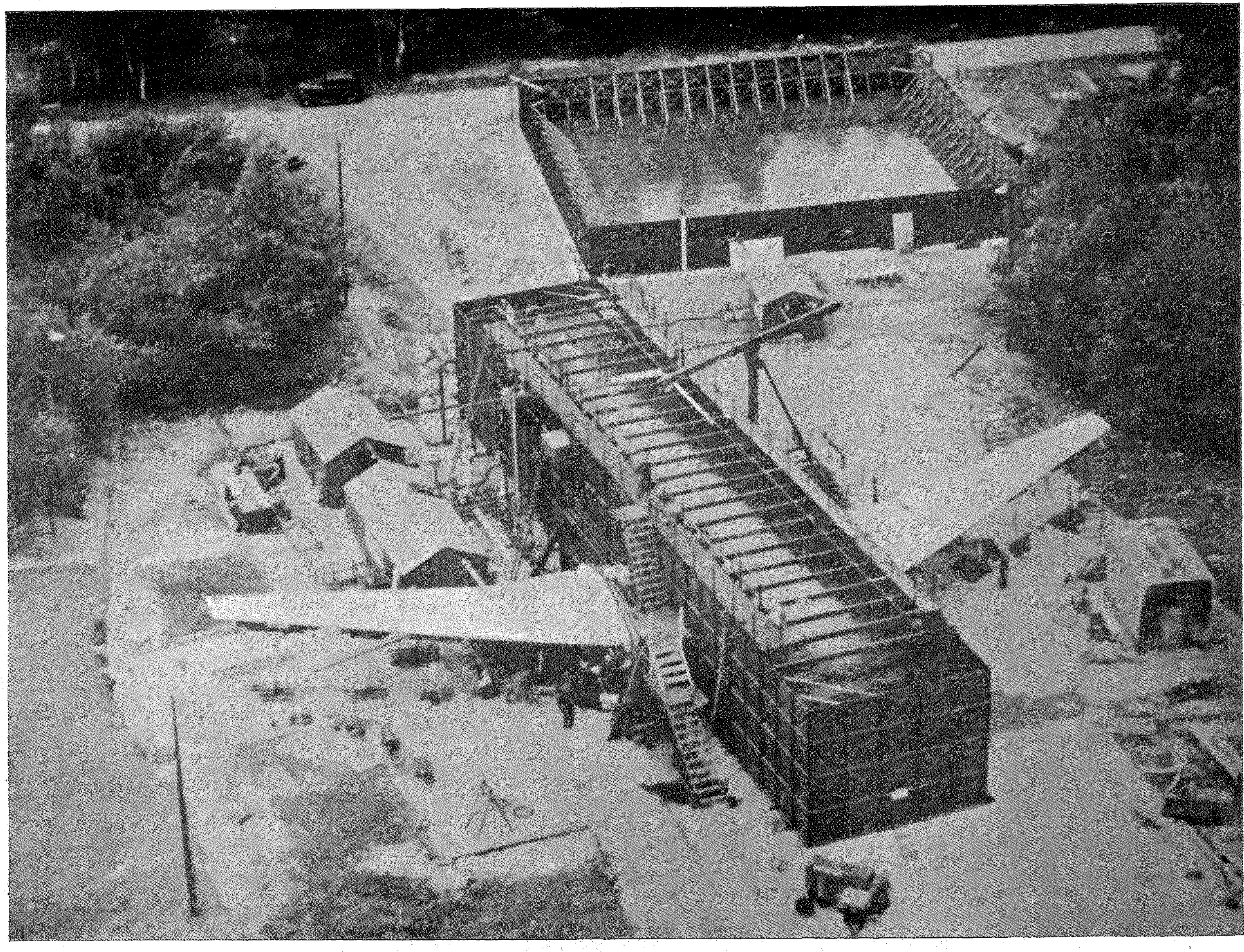


FIG. 6. AERIAL VIEW OF COMET G–ALYU IN TESTING TANK.

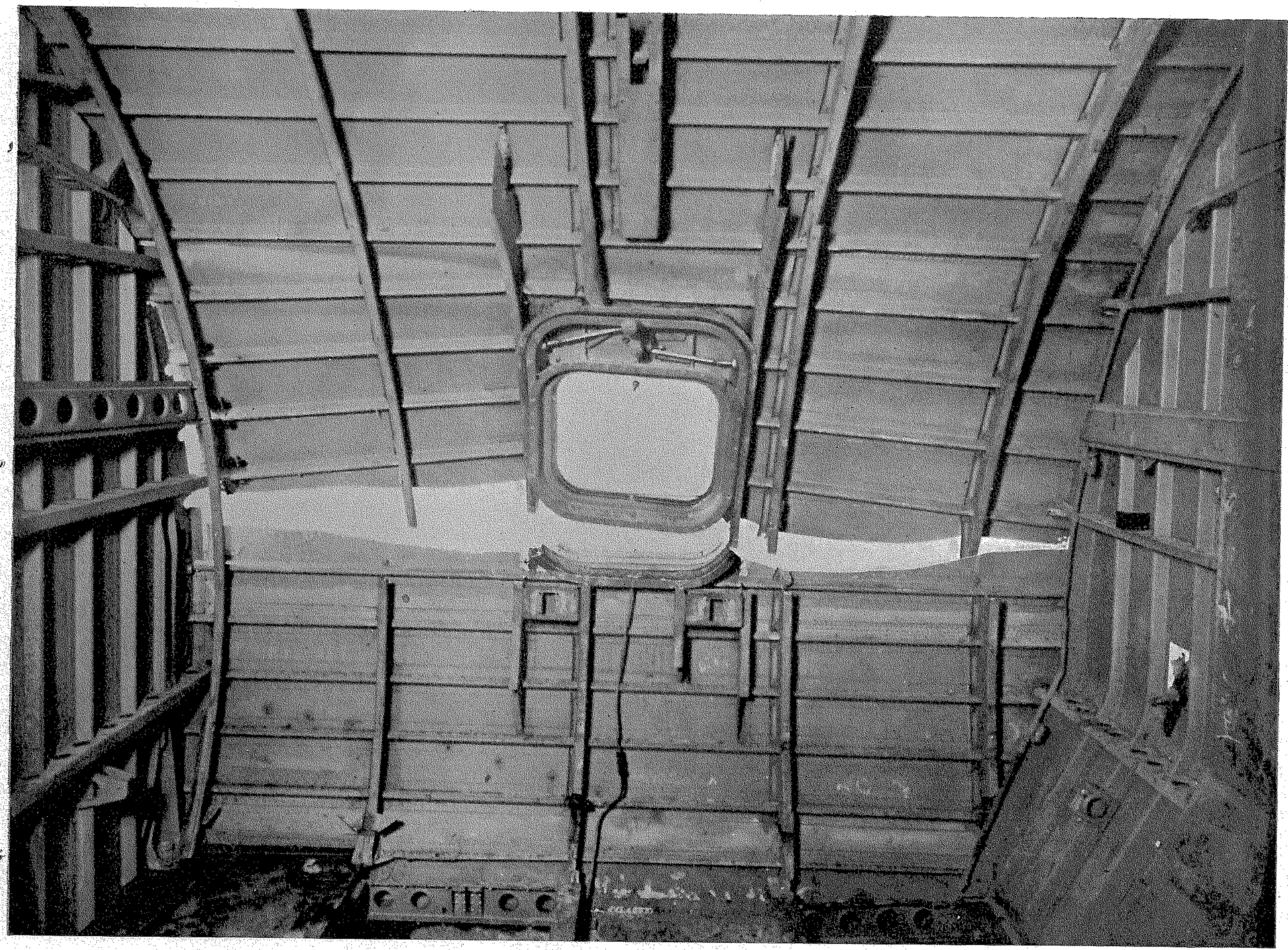


FIG. 7. VIEW FROM INSIDE OF FAILURE AT THE FORWARD ESCAPE HATCH ON THE PORT SIDE—COMET G–ALYU

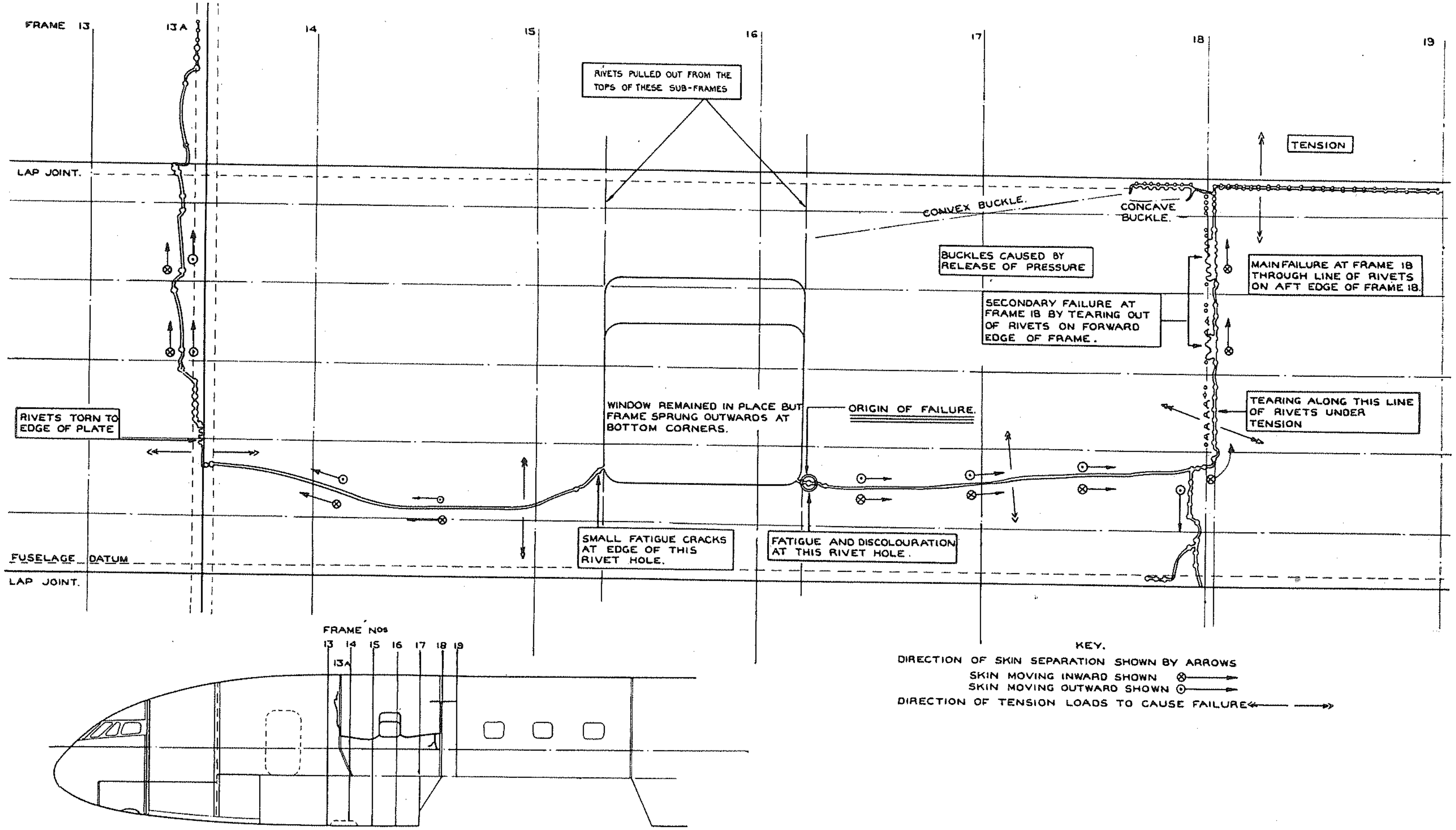
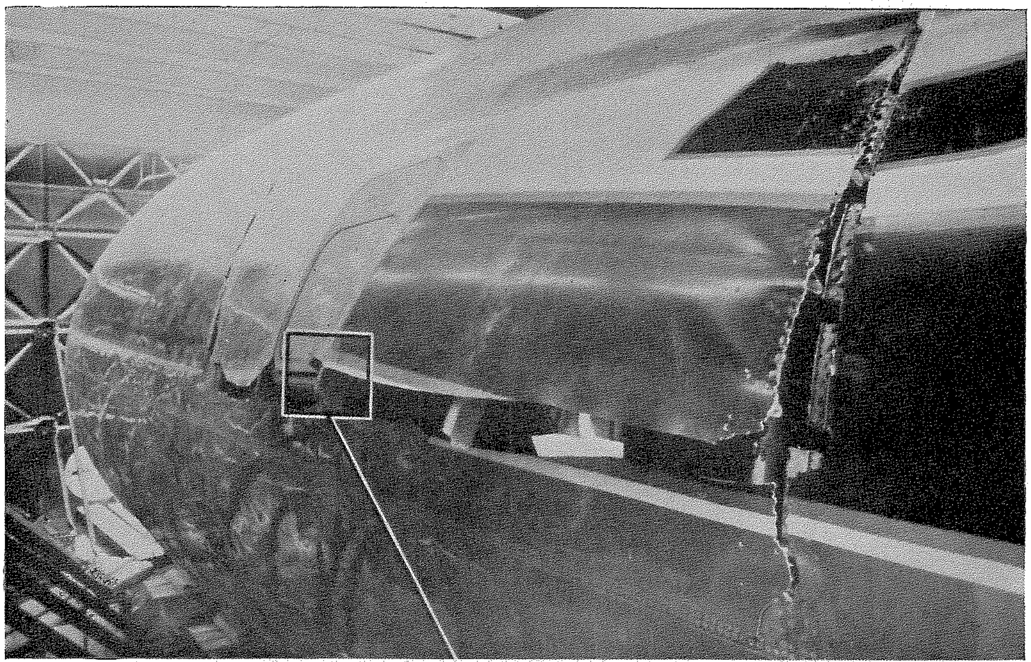
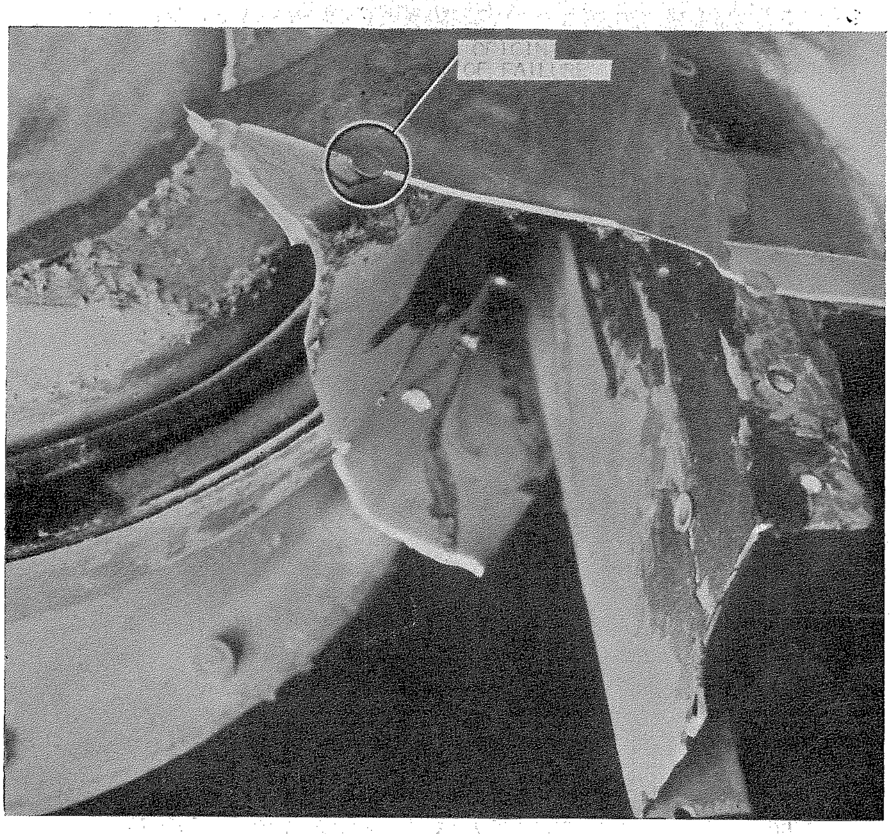


FIG. 8. THE PROGRESS OF THE FAILURE OF THE FORWARD ESCAPE HATCH ON THE PORT SIDE—COMET G-ALYU.

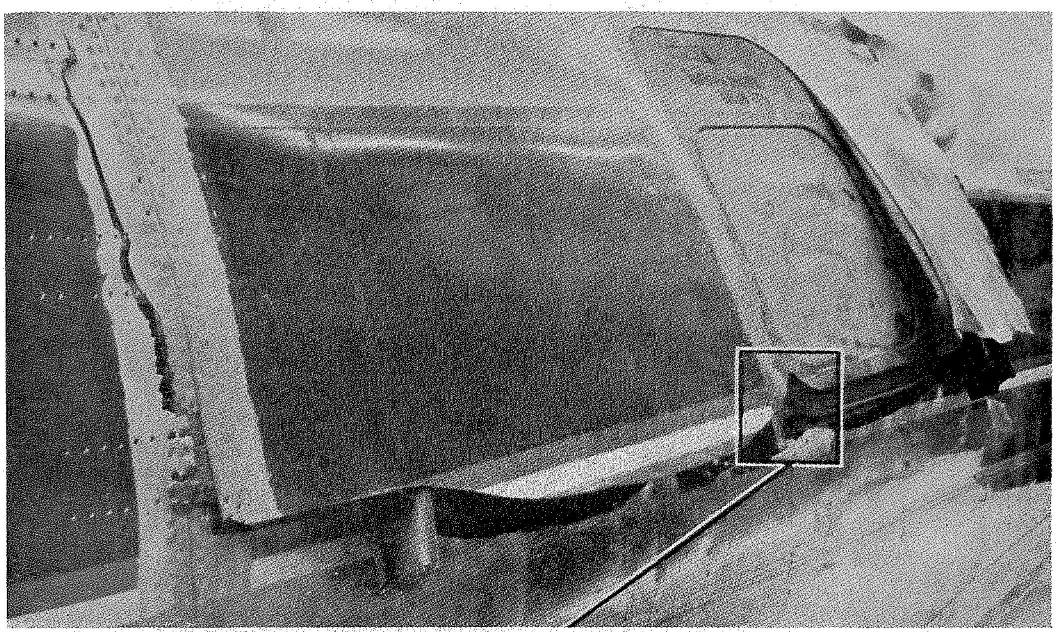


a. GENERAL VIEW LOOKING FORWARD.

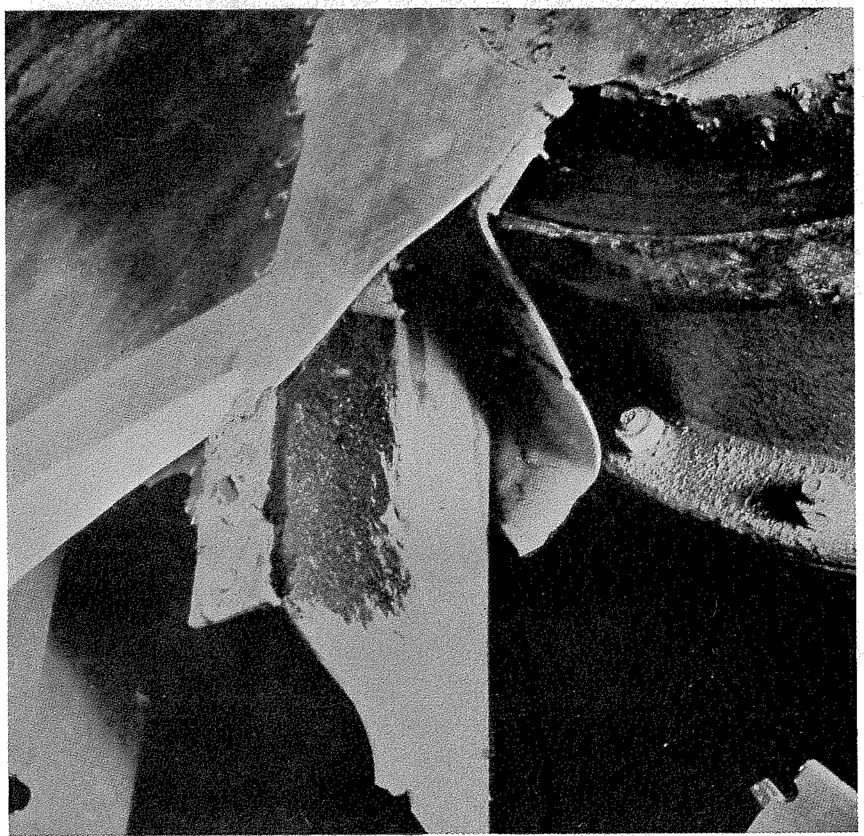


b. CLOSE-UP OF SKIN AT BOTTOM REAR CORNER OF ESCAPE HATCH.

FIG. 9. FAILURE OF FRONT FUSELAGE AT 10.4 lb/in^2 (3057 TOTAL FLIGHTS)—G–ALYU.



a. GENERAL VIEW LOOKING AFT.



b. CLOSE-UP OF SKIN AT BOTTOM FRONT CORNER OF ESCAPE HATCH.

FIG. 10. FAILURE OF FRONT FUSELAGE AT 10.4 lb/in^2 (3057 TOTAL FLIGHTS)—G–ALYU.

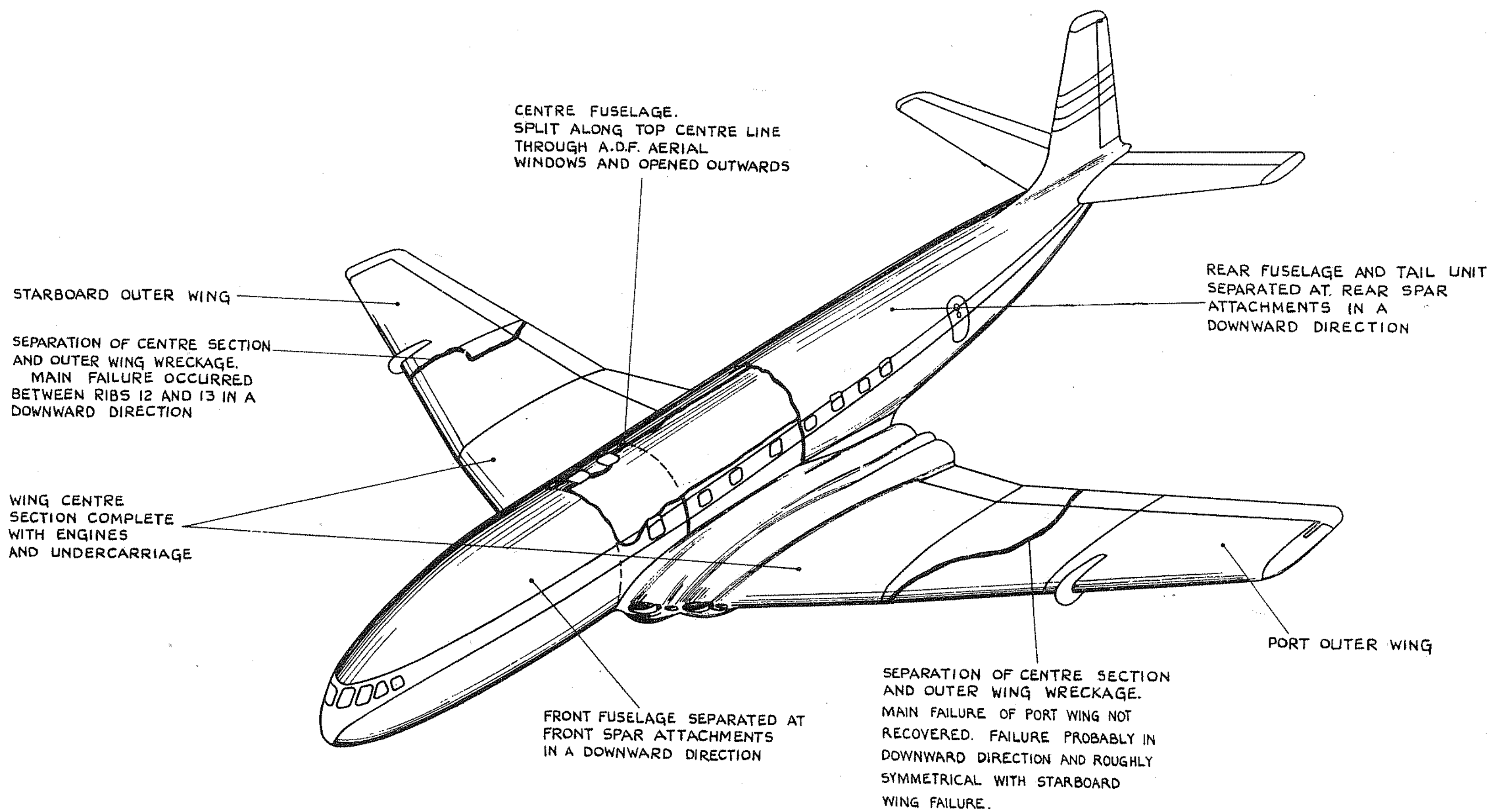


FIG. 11. LOCATION AND DIRECTION OF MAIN FAILURES—G-ALYP.

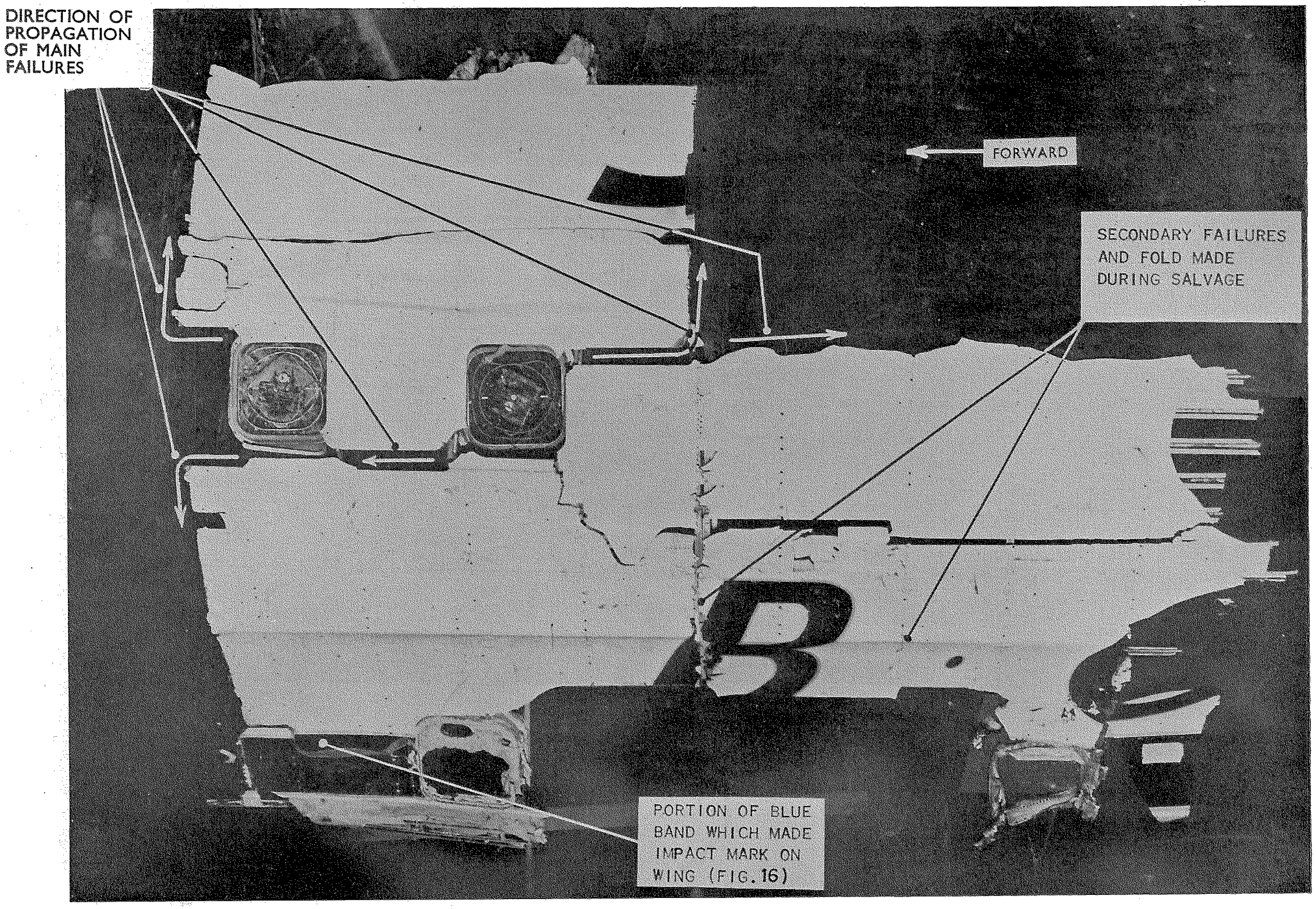
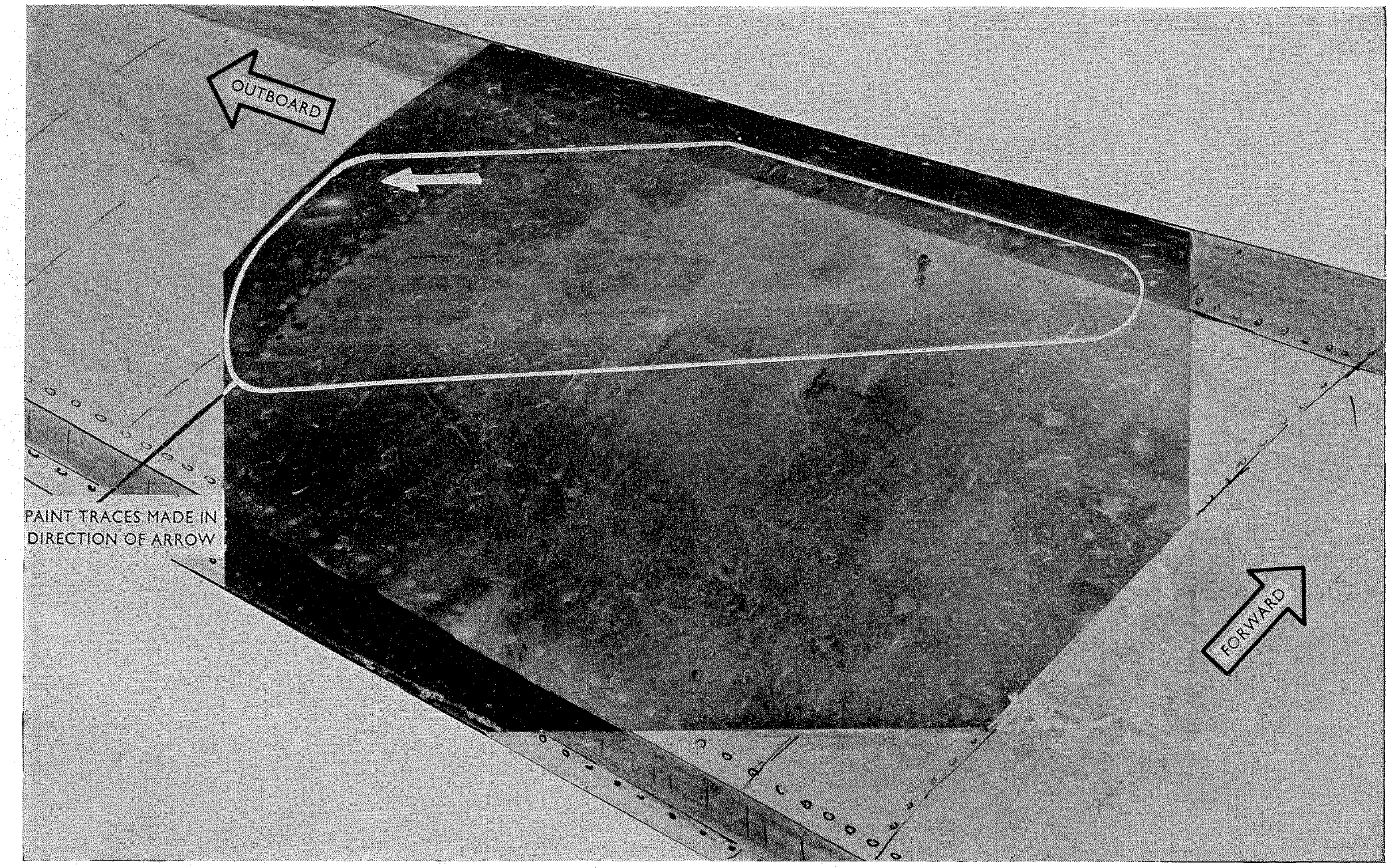


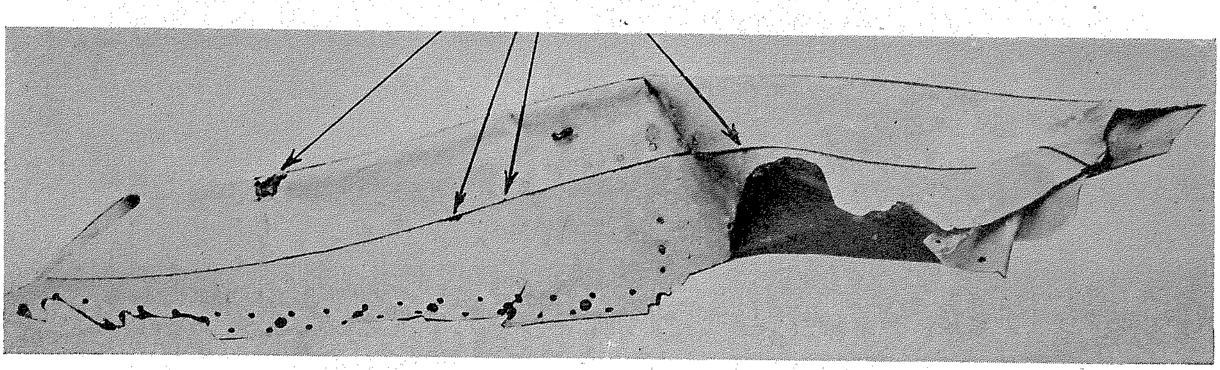
FIG. 12. PHOTOGRAPH OF WRECKAGE AROUND ADF AERIAL WINDOWS—G–ALYP.



(FOR LOCATION ON AILERON SEE FIG. 16.)

FIG. 13. PAINT TRACES OVER PORT AILERON UPPER SURFACE—G–ALYP.

PARTICLES OF FIBREGLASS AND WOOD JAMMED INTO SKIN AND UNDER LAP JOINT PROBABLY FROM FUSELAGE CABIN FLOORING



GENERAL PATTERN OF METALLIC SCORES AND PAINT TRACES OVER INBOARD FACE PROGRESSING FROM WING SKIN TO UPPER EDGE OF FENCE

NO COMPARABLE DAMAGE ON OUTBOARD FACE OF FENCE

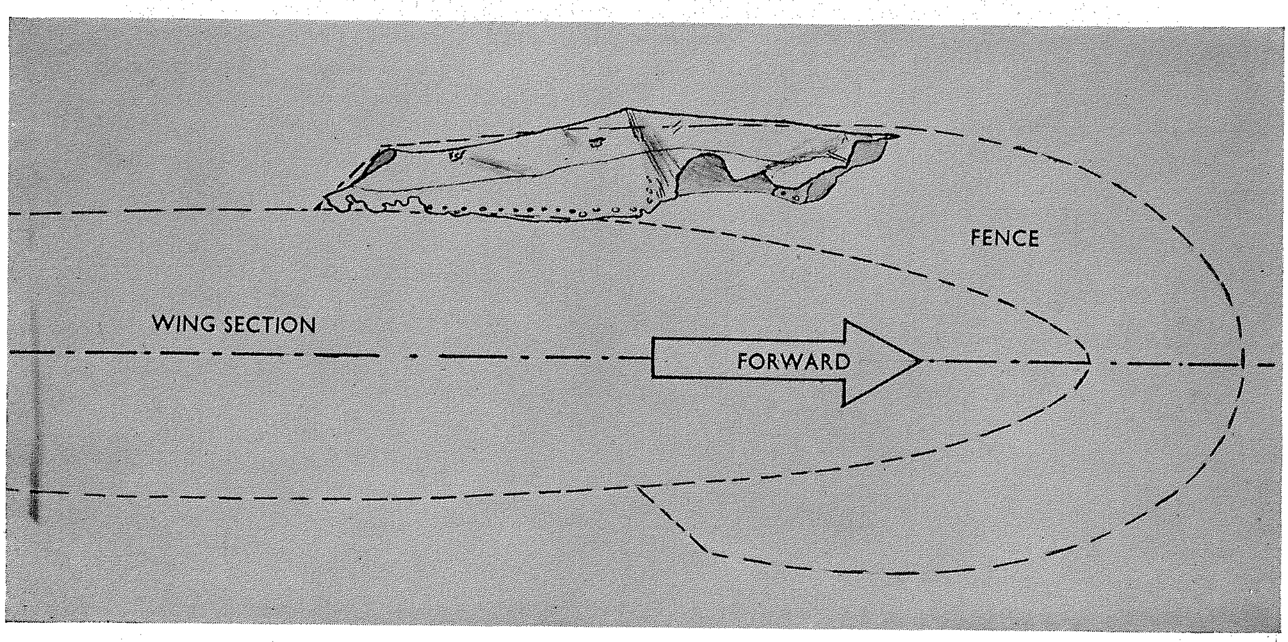
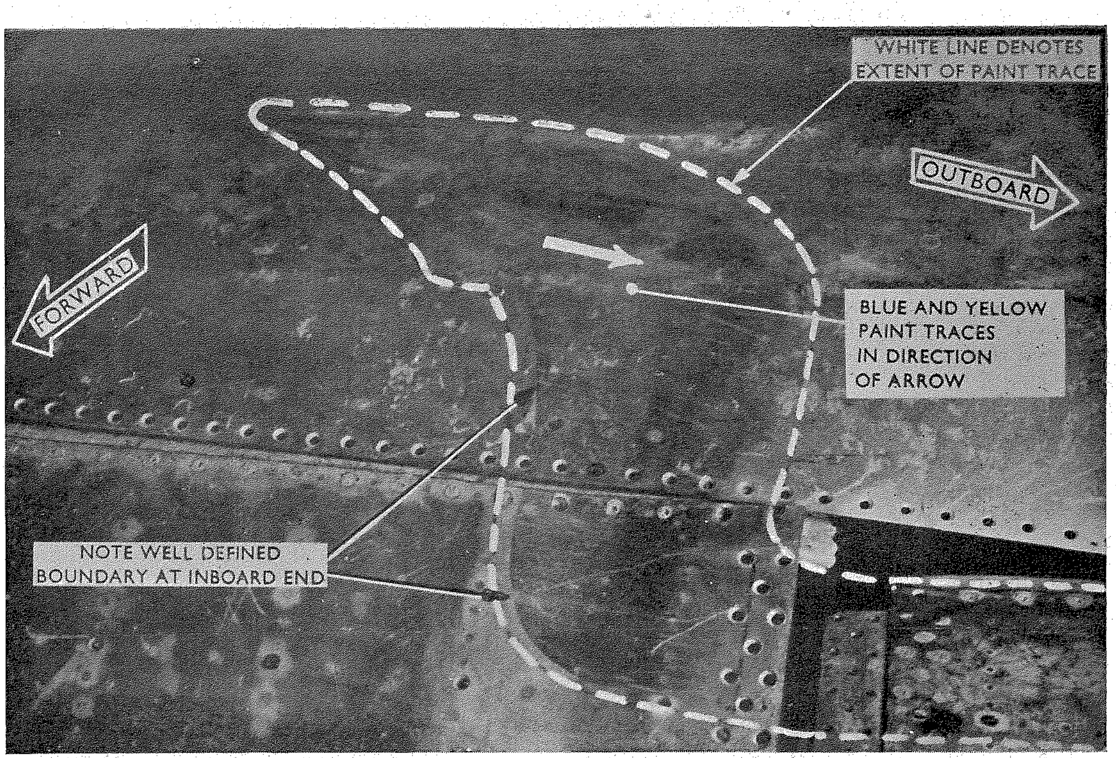
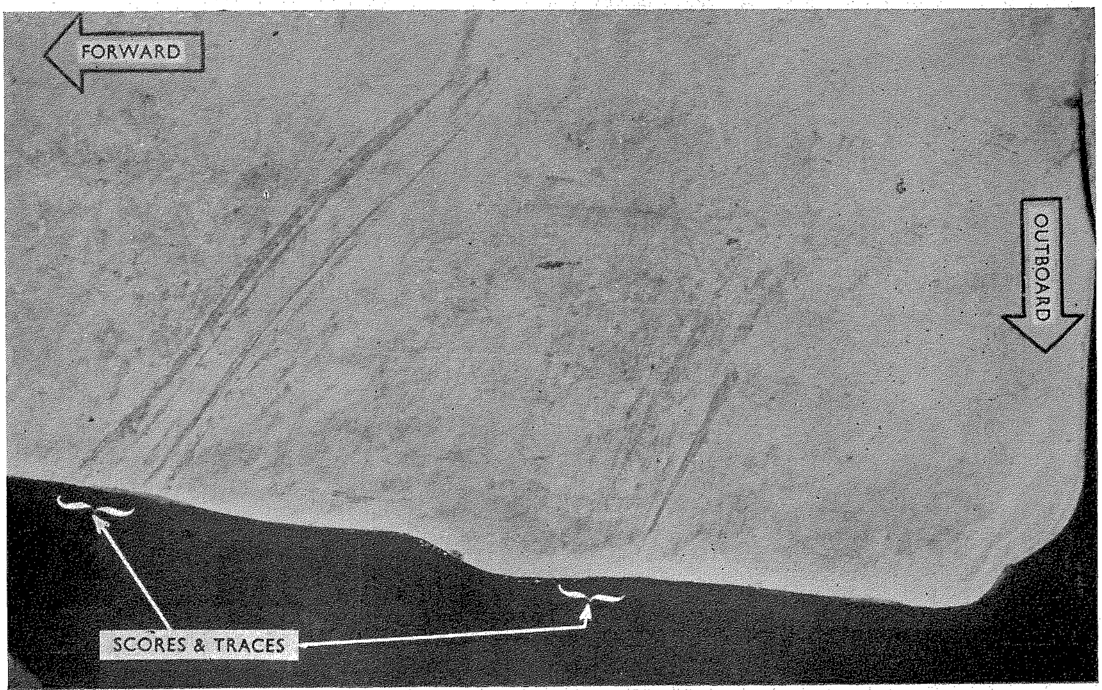


FIG. 14. PORT BOUNDARY LAYER FENCE, IMPACT DAMAGE TO INBOARD FACE—G-ALYP.



PAINT TRACES MADE BY PORTION OF CABIN WALL
(FOR LOCATION SEE FIG. 16).



HEAVY METALLIC SCORING WITH BLUE PAINT TRACES CONTINUOUS OVER FRACTURE EDGE
(FOR LOCATION SEE FIG. 16).

FIG. 15. PAINT TRACES ON PORT WING UPPER SURFACE—G-ALYP.

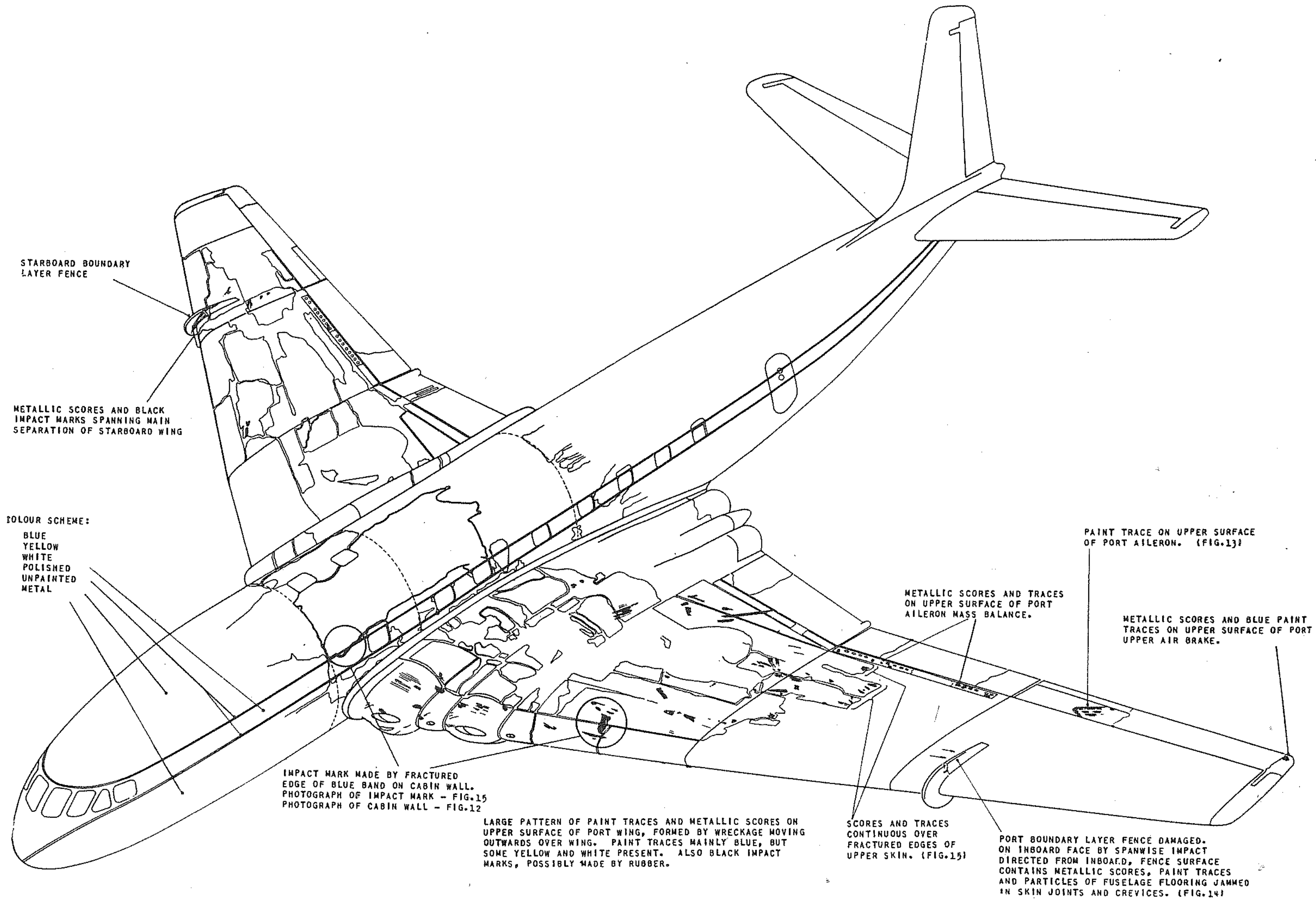


FIG. 16. IMPACT DAMAGE TO UPPER SURFACES OF WINGS—G-ALYP.

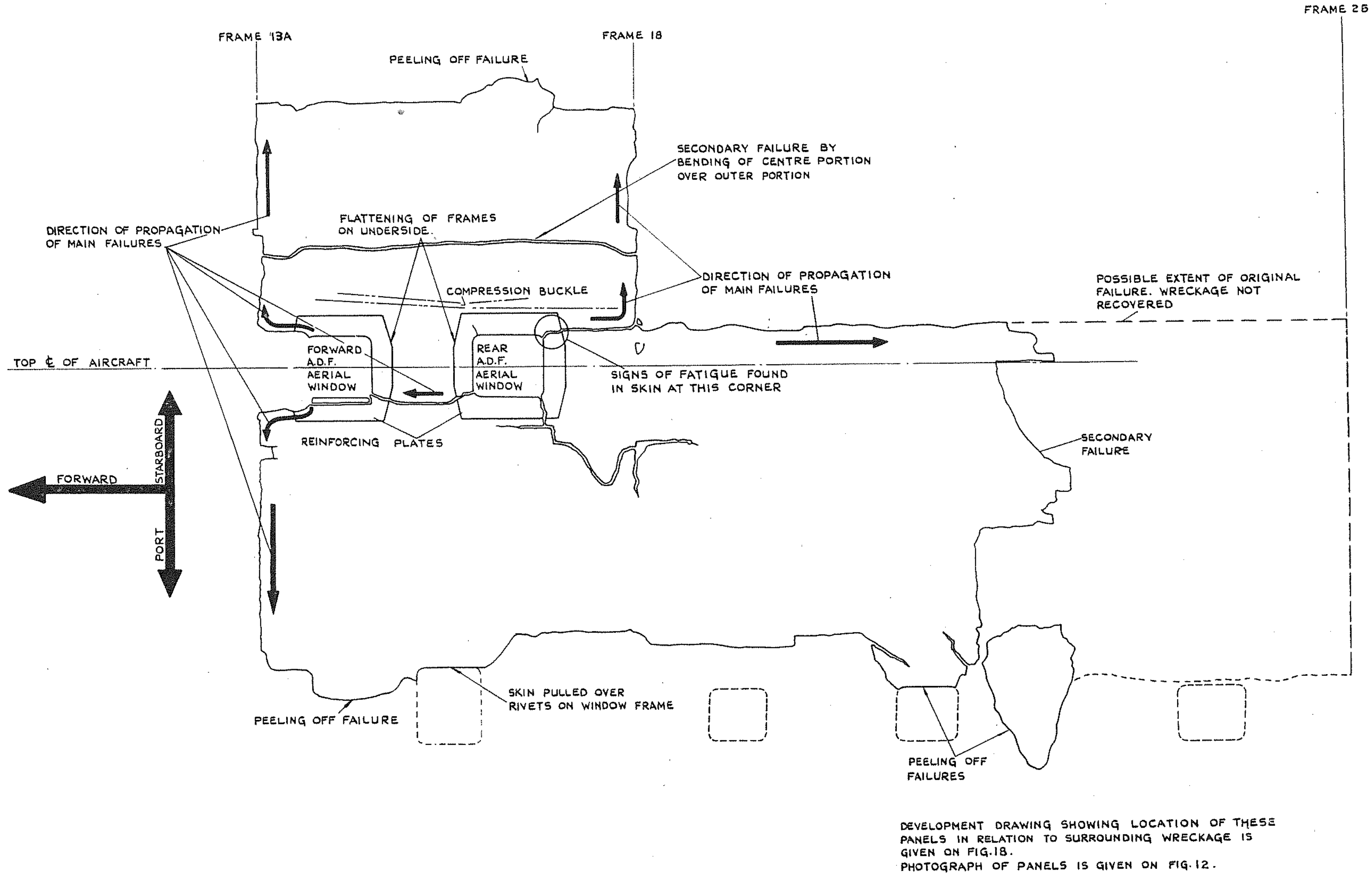


FIG. 17. SALIENT FEATURES OF DISRUPTION OF PRESSURE CABIN—G-ALYP.

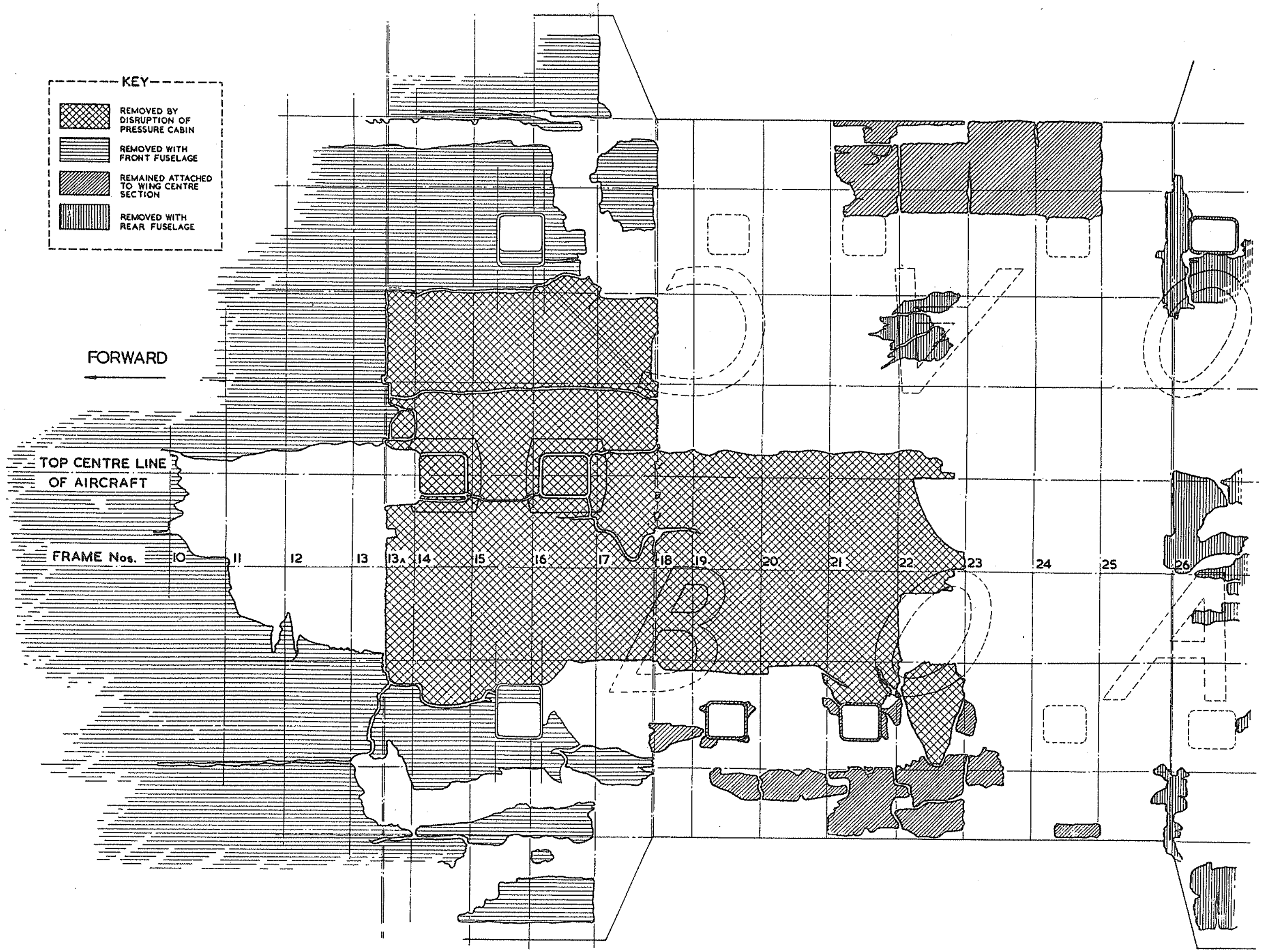
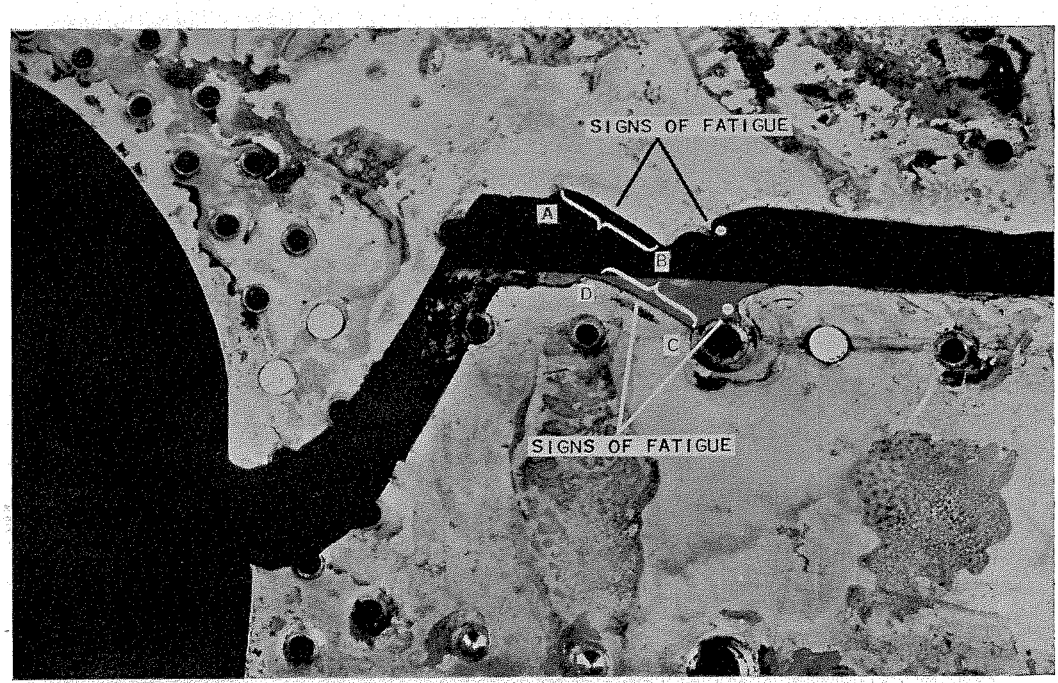
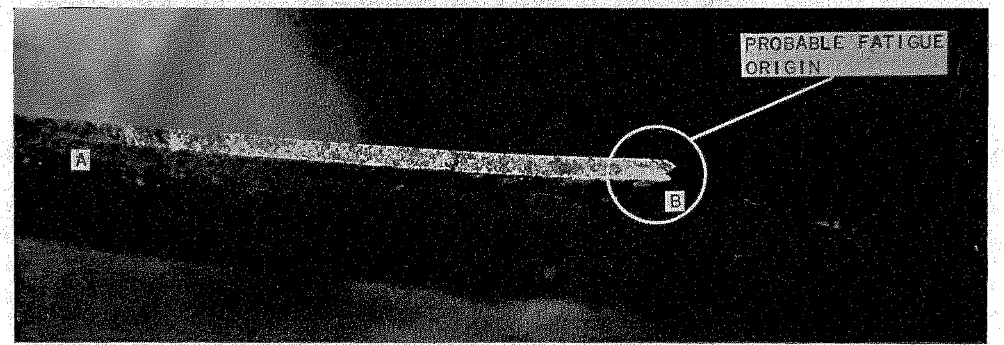


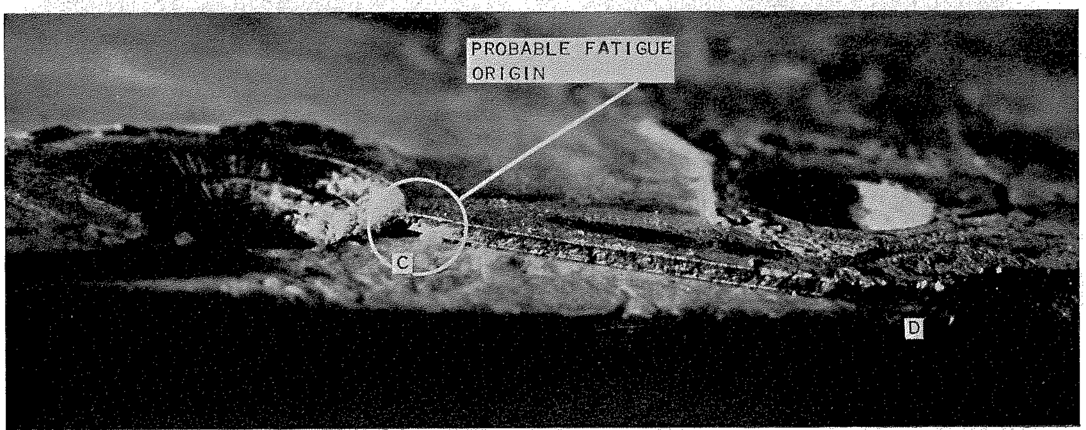
FIG. 18. DEVELOPMENT DRAWING OF WRECKAGE AROUND ADF AERIAL WINDOWS—G-ALYP.



(a) PLAN VIEW OF FAILURE IN SKIN.



(b) VIEW OF EDGE A B.



(c) VIEW OF EDGE C D.

FIG. 19. SIGNS OF FATIGUE IN SKIN AT STARBOARD REAR CORNER OF REAR ADF AERIAL WINDOW—G-ALYP.

wreckage, de Havillands should be asked to produce further evidence directed towards establishing that the precautions taken in the Comet installation, to ensure that the pressure could not rise appreciably above the normal working pressure, were reliable. Mr. Wilkins, an Assistant Chief Designer of de Havillands, who was responsible for this aspect of the design, gave evidence on the matter, and a statement was produced by de Havillands summarising the method of operation of the essential controlling and safety valves. Messrs. Normalair Limited, the firm responsible for the pressurisation control equipment, also produced full information about the essential parts. Taken together with the R.A.E. Report, this additional evidence satisfies me that the possibility of the development of excessive internal pressure in the cabin, of an amount sufficient to endanger its structure, was so remote that it can be excluded as a probable cause of the bursting of the cabin.

(e) *Certain defects referred to in the R.A.E. Report*

108. I turn now to the other defects discovered by R.A.E. and already referred to in paragraph 93 of this Report. I see no reason to differ from the conclusion reached by R.A.E. that none of these defects was in any way the cause of the accident.

109. It is clear that the separation of both port and starboard outer wings from the centre section (see Figure 11) was not the primary cause of the accident, for there is ample evidence from the distribution of paint marks and scratches on both wings that they were made by parts of the cabin structure, and form a pattern (see Figure 16) which is consistent only with the whole wing having been intact when they were made. For the same reason, the known point of fatigue weakness in the wing skin near the edge of the wheel-wells is not suspect. Moreover the fracture of the wings occurred some distance outside this region.

110. As regards escape of fuel from the fuel tank venting system, examination of the wreckage disclosed that fire did not start until after the disruption of the cabin. It is clear, therefore, that escape of fuel from the tank vents during take-off or climb had nothing to do with the accident.

111. Turning to refuelling, the danger apprehended could only occur by a concatenation of five events. The risk was, therefore, said to be a remote one and in any event in the present case R.A.E. state that examination of the Elba wreckage made it plain that even if the aircraft had sustained damage of the type indicated in Part 6 of the R.A.E. Report (which deals with this subject), such damage was not the cause of the accident to Yoke Peter. There had, however, been a recorded instance of trouble due to this cause and it is to be observed that de Havillands have indicated their intention of devising a method of removing the possibility of damage of this kind (see Appendix VIII).

(f) *The possibility of damage by jet efflux*

112. During the operation of B.O.A.C. services, there had been some experience of small damage to the cabin skin, due to the buffeting by the efflux from the jet engines. This damage was partly in front of and partly behind the pressure dome of the cabin. As soon as it was observed, a systematic inspection was made of all Comets, and where any signs of cracking were detected a repair was made according to a scheme specially devised by de Havillands. Internal inspection showed that the buffeting was also causing slight loosening of the joint between the stringers and the skin in this region, and rivets were therefore inserted in order to ensure that this would not give rise to danger.

113. This point of possible weakness was under continuous observation. The steps taken to deal with it may be considered to be satisfactory, particularly since, where the repair had been carried out, no further trouble occurred.

114. It is, however, recognised by de Havillands that a situation in which it is known that such cracks are likely to occur is unsatisfactory, and among the improvements they intend to make on future Comets is one which they believe will reduce the cause of this damage, namely, a slight change in the direction of the jet pipes at their exits, with the object of diverting the jets away from the sides of the cabin.

PART XIV

RESPONSIBILITY

(a) *Introductory*

115. No suggestion was made that any party wilfully disregarded any point which ought to have been considered or wilfully took unnecessary risks. But, in the course of the evidence, questions were put which make it necessary for me to consider a number of points in the light of the conclusion I have already expressed as to the cause of the accident.

(b) *Criticism of de Havillands' design work*

116. Dealing first with the period prior to the commencement of the scheduled passenger service on the 2nd May, 1952, the calculations made

by de Havillands were criticised and it was suggested that the tests they carried out were inadequate to guard against the risk of fatigue in the cabin structure. In support of this contention particular reference was made to certain calculations included in paragraph 4 of Part 3 of the R.A.E. Report and to other calculations produced by Sir Arnold Hall in the course of his evidence. It is, however, to be observed that the primary object of de Havillands was to lay the foundation for extensive tests which they regarded as the soundest basis for the development of a project rather than to arrive at a precise assessment of the stress distribution at the corners of the cabin windows.

117. I do not think that they can justly be criticised for this approach to the problem. In arriving at this conclusion I have been assisted by a Memorandum which has been prepared for me by my Assessors and which confirms the impression I formed from the evidence of the witnesses that de Havillands were proceeding in accordance with what was then regarded as good engineering practice. I am also satisfied that in the then state of knowledge de Havillands cannot be blamed for not making greater use of strain gauges than they actually did or for believing that the static test that they proposed to apply would, if successful, give the necessary assurance against the risk of fatigue during the working life of the aircraft. The Memorandum to which I have referred is included as paragraphs 118 to 129 of this Report.

(c) *Memorandum by Assessors*

118. During the design of the Comet de Havillands did not make use of calculations in an attempt to arrive at a close estimate of the stress distribution near the corners of the cabin windows. We have examined such of their calculations as had a bearing on this question; these led to the stress of 28,000 lb./sq. in. mentioned by Mr. Harper. It is clear that this stress refers to an area of the skin in the neighbourhood of the corners, and may fairly be said to be an average value over a width of 2 or 3 inches. de Havillands believed that their method was satisfactory for the purpose they had in mind, namely, the design of a test specimen. They did not consider that a closer estimate of the highest value of the stress could be made by any method which they would regard as reliable. They preferred to rely on tests of specimens designed on the basis of their calculations.

119. Since their estimate of the general level of stress in the region investigated was less than half the ultimate strength of the material (about 65,000 lb/sq. in.) they were confident that they could demonstrate by static test that there would be no failure at twice the working pressure, and that there would be a considerable reserve in hand. Their tests of panels about 3 ft. square, including a window, substantiated this view.

120. We note, however, that in these tests the panel was supported on the face of a stiff steel "pressure box", and not in conditions truly representative of those which existed near the window in the pressure cabin itself. It is not possible to say what the effect of this would be. de Havillands were reassured by the results of the tests, in which the specimen withstood nearly 20 lb./sq. in. without failure.

121. de Havillands used the same approach to the design of the whole pressure cabin. The static tests which they made on the two parts of the pressure cabin, respectively 26 and 24 ft. long, gave them confidence in the integrity of the whole cabin. Since they believed, with general support from then current practice and opinion, including that of A.R.B., that this basis of design and static tests would give ample assurance against risk of failure under repeated applications of the working pressure, and other known causes of fatigue, they felt that the cabin was good for the life of the aircraft (say 10,000 pressurised flights, or 10 years).

122. Here again, however, we note that the test sections of the cabin differed from the cabin as fitted to the aircraft in several respects. In the first place, each was incomplete, and incapable of sustaining pressure if it had not been fitted with a stiff bulkhead at the open end or ends. It is not possible to say whether the constraint which these bulkheads imposed on the structure would make it stronger or weaker than when it formed part of a complete cabin. But it must be recognised that the stresses in the structure near the bulkheads would be appreciably affected by the constraint, and the reliability of deductions about the strength of the cabin would thereby be reduced. Secondly, neither section was fitted with the complete number of windows, etc. Moreover, the windows of special interest in this Inquiry, which were in the front test section, were rather near the bulkhead mentioned, so that the stresses in the skin round them might have been appreciably different from those in similar places in the complete cabin.

123. The increasing attention which de Havillands gave, during the period mid 1952 to end 1953, to the fatigue life of pressure cabins has been mentioned in paragraphs 21 to 24. In their repeated loading tests the front test section

of the cabin survived 16,000 applications of just over the working pressure. They felt confident that the Comet's cabin would have a safe life well beyond their target of 10 years in service.

124. The repeated loading test on Yoke Uncle at R.A.E. led to an unexpected failure after some 3,000 applications of load. Though this was about three times the life of Yoke Peter at Elba or Yoke Yoke at Naples it was surprisingly short, and led directly to the inference that there were high local stresses. Steps were, therefore, taken at R.A.E. to measure the stresses near the corner of the window, using strain gauges placed as near as possible to the edge of the skin where the failure started. These measurements led to an estimated stress of 43,000 lb/sq. in. at the edge at the normal pressure difference of 8¼ lb./sq. in.

125. This estimate of the stress was regarded by de Havillands as unreliable, partly because the process of deriving it from the experimental measurements involved some extrapolation, but also because it would imply that in their own test to twice the working pressure, there was a local stress of double this amount, namely 86,000 lb/sq. in., which is some 30 per cent. above the ultimate strength of the material. This apparent paradox can be explained by recognising that it neglects to take account of the effect of the ductility of the material in relieving "stress concentrations" (see on this subject paras. 148 to 153 below).

126. Calculations were made by Sir Arnold Hall to explore the problem in the light of such theoretical solutions as were known of the problem of stress distribution, round a cut-out of the shape of the cabin windows, in a cylindrical shell of metal under pressure. These calculations were not put forward as exact, but, with due allowance for the fact that the window frame, and the cabin stringers and hoop frames, would influence the result, they supported the reasonableness of the estimate made from measurements on Yoke Uncle.

127. It is our view that the two results taken together point strongly to the conclusion that the stress in the skin at the edge of the window near the corner was far higher than had been suspected by de Havillands, and was probably over 40,000 lb/sq. in. under the normal pressure difference.

128. In the course of the Inquiry much attention was paid to an estimate, given in Part 3, para. 6 of the R.A.E. Report on the tests on Yoke Uncle, of the stress which might be predicted on the basis of their measurements by strain gauges, as probably existing in flight. The figure "70 per cent. of the ultimate strength" was obtained by adding to the 43,000 lb/sq. in. (mentioned above) due to the working pressure, another 2,700 lb/sq. in. due to other known loads, leading to a total of 45,700 lb/sq. in. This was contrasted with de Havillands' own estimate of 28,000 lb/sq. in. It has already been pointed out that de Havillands' figure relates to an average over a considerable distance near the corner of the window, and due only to the working pressure, whereas the estimate made by R.A.E. relates to a particular point where the stress would be expected, on general grounds, to reach a maximum. A direct comparison between them is therefore misleading. Having regard to the different approach the two figures cannot be said to be inconsistent.

129. It is natural that de Havillands and R.A.E. should have approached the problem of the "safe life" of the pressure cabin of the Comet from different points of view. de Havillands were the designers and looked at the problem as designers would, having confidence in their methods based on their experience. R.A.E. had had virtually no previous knowledge of the design background of the Comet, since it is a civil aircraft and their connection with it before the 8th April, 1954, was primarily advisory in character and was wholly concerned with fatigue of the wings. In the early stages of the Inquiry there was, therefore, a sharp disagreement between them on the interpretation of their calculations and tests. These differences of opinion diminished in the course of the Inquiry as greater mutual understanding developed. While there are still minor points on which they do not quite see eye to eye, a situation which is by no means unusual in technical problems of such difficulty, there is now no longer any substantial disagreement between them. Our own interpretation of the situation, so far as it can be determined by existing evidence, is set out above, and we believe that it would be accepted by de Havillands and R.A.E.

(d) *Criticism of de Havillands' repeated loading tests in* 1953

130. Another criticism of de Havillands was connected with the repeated loading tests carried out by them in 1953. When the R.A.E. test revealed the short life of the cabin structure of Yoke Uncle the question arose as to how to reconcile the result of that test with the result of these earlier repeated loading tests. Sir Arnold Hall suggested that the explanation might well be that the 1953 tests were carried out on a nose section which had previously been subjected to static tests up to a differential pressure of 16½

lb/sq. in. and that the effect of such a test might be to prolong the life of the specimen subjected to it. Mr. Harper said that he was aware of this possibility but he considered that if there was any increase in life of the nose section attributable to pre-loading the tests so amply covered the life of the aircraft both at the time of the tests and for the immediate future that de Havillands could safely accept the test as satisfactory. In the then state of knowledge I think this conclusion was reasonable.

(e) *de Havillands' method of dealing with cracks*

131. There is one other question bearing on responsibility to which I must refer. This concerns certain cracks, revealed by the examination of the wreckage (see para. 78), which had occurred in the process of manufacture and had been dealt with by location. Sir Arnold Hall said that such manufacturing cracks might form foci for fatigue and thus shorten the life of the structure. It was suggested in cross-examination that the fatigue which led to the disintegration of Yoke Peter had originated in these cracks, that they ought not to have been dealt with as they were and that accordingly some responsibility ought to attach to de Havillands for allowing the aircraft which contained them to be put into service.

132. It will be convenient to deal with the subject of cracks generally before giving my opinion on the specific question of responsibility mentioned above. This course may also enable the whole matter to be viewed in proper perspective. Public concern may have been aroused by what was said during the Inquiry and it is important that groundless fears should be allayed.

133. I am advised that it has been the general experience that certain parts of the structure of aircraft develop cracks as the result of fluctuation of load, vibration or casual damage and that the external skin, whether in the wings, tail or fuselage is particularly vulnerable. Cracks which occur during manufacture do not differ materially, in their significance, from those which may develop subsequently save, of course, that their presence may indicate an unsatisfactory manufacturing process.

134. It is the ordinary practice to make careful inspection of the structure, both during manufacture and subsequently, particularly in regions known to be specially susceptible and, if cracks are found, to deal with each case on its merits in the light of a now very wide experience of the problem. Where frequent inspection shows that a particular crack is likely to spread, it is dealt with by a carefully considered repair scheme, either prepared by the designers or by the operators in collaboration with the designers. However, if after such repair the crack continues to spread, it is considered as a matter of major concern, possibly requiring a radical modification to the design to reduce the stress which gave rise to it.

135. For small cracks in regions not highly stressed the method of location is generally found to prevent further spread, provided that care is taken to ensure the inclusion of the end of the crack in the hole drilled. All witnesses who dealt with this matter in the Inquiry were agreed that location was a reasonable method of dealing with such cracks.

136. I am also advised that most aircraft experience cracks due to one or more of the causes mentioned above and that it would, indeed, be hardly practicable to insist on a standard of design and construction which would preclude completely the possibility of any crack in the skin.

137. The methods employed by de Havillands in dealing with manufacturing cracks were in no way different from those used to deal with other deviations from the strict requirements of the drawings to which the aircraft was being built. Defects whether discovered by the workman or the inspector would be dealt with by the procedure known as "Concession" procedure which varied according to whether the defect was classed as major or minor. Mr. Povey said that manufacturing cracks were required to be dealt with as major defects with the result that "Concession Notes" containing the proposals for dealing with them would have to go forward to the Chief Inspector and, if approved by him, would have to be submitted to the Design Department for final approval. In the case of Yoke Peter three cracks were discovered in the reinforcing plates of the A.D.F. windows. The action taken, which was approved by the Chief Inspector and the Design Department, was "splits have been located with a 1/16th dia. drill hole". According to the then current engineering practice this action would have been appropriate had the stresses been as low as de Havillands believed them to be, but was, in fact, inappropriate as the region concerned was one in which there were high stresses. However, as I have already stated in paragraphs 116 and 117 my opinion that de Havillands cannot be blamed for their ignorance of the true state of affairs, it follows that no responsibility attaches to them.

138. The evidence disclosed other cracks in Comet aircraft. Thus in the wreckage of Yoke Peter there was a crack in the skin at the starboard front corner of the rear A.D.F. window. This had been located at both ends. No Concession Note was available in relation to this crack

and it would appear that there had been a defect in the operation of the Concession procedure. Although this crack had spread during the life of the aircraft beyond one of the points at which it had been located, the actual fracture did not take place there nor was there any sign of fatigue. Other cracks were referred to in Yoke Uncle and Yoke Yoke but in no case was there any evidence that the crack had contributed to the failure of the aircraft.

139. I need not pursue further the question of manufacturing cracks of this type since the statement put in on behalf of de Havillands (see Appendix VIII) records that if in future a crack does occur at any time either in manufacture or subsequently during the life of an aircraft, no repair scheme for such a crack will be sanctioned unless it ensures that, after it has been carried out, the part of the aircraft concerned will be as strong and will have as long a life as it would have had, had there been no crack.

Part XV

FUTURE

(a) *Statements on behalf of the Attorney-General and de Havillands*

140. By s. 9 (12) of the Civil Aviation (Investigation of Accidents) Regulations 1951 the duty is imposed on me of making such recommendations as I think fit with a view to the preservation of life and the avoidance of similar accidents in future. I have been greatly assisted in that part of my task (*a*) by the statement as to future policy made by Sir Lionel Heald on the 12th November, 1954 on behalf of the Attorney-General after consultation with the Ministry of Transport and Civil Aviation and A.R.B.: (*b*) by the statement put in by Sir Hartley Shawcross on the 23rd November, 1954 recording the action which de Havillands now propose to take to deal with the problem of fatigue and with the other defects referred to in the Report of R.A.E. These statements are of such importance that I have attached them to this Report as Appendices VII and VIII. I respectfully agree with the course therein proposed to be adopted.

(b) *Further suggestions directed to guarding against fatigue*

141. The problem of securing an economically satisfactory safe life of the pressure cabin of an aircraft needs more study, both in design and by experiment, if the lightest possible safe structure is to be achieved. This is recognised by de Havillands in their policy in regard to the future of the Comet (Appendix VIII).

142. In Appendix IV para. 4 (iii), reference is made to the problem which arises owing to the variation among the lives, under a given loading cycle, of nominally identical parts, known as " scatter ". In the pressure cabins of aircraft there are probably a number of causes of scatter. Tests of a large number of specimens are however virtually impracticable and, in order to ensure a safe life well above the minimum that is economically acceptable to an operator, methods must be devised of ensuring that design, combined with a reasonable programme of tests, can guarantee that the pressure cabins of transport aircraft will be entirely safe.

143. The policy which de Havillands propose to adopt for the Comet is directed to achieving this end, primarily by reducing both the general level of stress and the local excesses, due to all known causes, above the general level of stress. The knowledge which has been acquired as a result of the investigation of the accident to Yoke Peter, and the tests made on Yoke Uncle at R.A.E., strongly suggests that steps should be taken to determine by calculation, by tests of typical parts of the cabin, and by tests on one or more complete cabins, both the distribution of stress throughout the structure in considerable detail, the influences which determine both the highest static load which it will sustain, and its life to failure under repeated loading. In the present state of knowledge, it is likely that two complete cabins will have to be tested, one under static loads and one under cycles of repeated loads.

144. From the evidence of Sir Arnold Hall and from advice I have received from my Assessors it became clear that there exist methods of calculating the stress distribution in the structure of a pressure cabin which could with advantage be employed more widely. Moreover the result of R.A.E.'s investigation satisfied me that in tests of pressure cabins or parts of them, the stress distribution should be determined by wide use of strain gauges. This procedure will enable the calculations used in the design to be verified or amended, and will lead to a fuller understanding of the problem.

145. When these measures have been applied and the tests completed, de Havillands will no doubt ask A.R.B. to recommend the grant of a Certificate of Airworthiness to the re-designed Comet aircraft. It would not be desirable for me to say anything which might in any way limit the discretion of A.R.B. but I may perhaps appropriately express the hope that this procedure will reassure the public as to the integrity of pressure cabins and will justify Sir Arnold

Hall's confidence that the Comet aircraft will fly again.

(c) *Use of available Government facilities*

146. In the course of the evidence there was some suggestion that prior to 1954 inadequate use was made in the development of the Comet of the unrivalled facilities available at R.A.E. to the civil aircraft industry. This may have been exaggerated. Be that as it may, in view of the importance of that industry to the national economy it is essential that in the future manufacturers should be aware of, and should make full use of, such facilities as the research establishments of the Ministry of Supply can offer. The Court was informed that in practice there had been close personal association between members of the staffs of A.R.B. and R.A.E. and that R.A.E. was represented on the Airworthiness Requirements Co-ordinating Committee of A.R.B. It is desirable, nonetheless, to strengthen the liaison between A.R.B. and all the research establishments of the Ministry of Supply and it might be worth considering whether, when the Council of A.R.B. is being strengthened in accordance with the statement made by Sir Lionel Heald (see Appendix VII), it should not also receive such additional reinforcement as will encourage the full use by manufacturers, operators and A.R.B. of all available facilities.

(d) *Avoidance of flight by unlicensed crew*

147. Reference has been made in paragraphs 35 and 36 to the fact that the Engineer Officer of Yoke Peter was not in possession of a valid licence at the time of the accident. I was informed by Counsel for B.O.A.C. that their system for ensuring the prompt renewal of licences had been overhauled and that adequate steps have been taken to prevent a recurrence of this lapse. It is clearly of the first importance to ensure that no aircraft flies save with a crew not only fully qualified in knowledge and experience but also properly licensed.

(e) *Suggested scientific and technical investigations*

148. There are certain scientific and technical matters on which, acting on the advice of my Assessors, I recommend that research can usefully be undertaken, in the interest of increasing knowledge of the problems of the design of pressure cabins. The first arises from the influence of the ductility of the aluminium alloy from which the skin of the cabin is made, on the manner in which the stress distribution in the skin is related to the difference between the internal and external pressure on the cabin. It is perhaps simplest to look at this problem in the light of the situation which develops as the pressure in the cabin is increased from the working pressure P up to the value somewhat below that at which it fails under a static test.

149. In the first place it is essential to appreciate that, although it would from many points of view be desirable that the stress in the skin should be the same everywhere, in practice considerable variations are unavoidable. There will, therefore, be points, generally near to the cutouts, where the stress is appreciably higher than the average, and it is on these points that the designer's attention is naturally focussed when considering the strength of the structure.

150. As the pressure difference in the cabin rises from P to, say, $1\frac{1}{2}$ P the stresses everywhere will rise in the same proportion. But as the pressure difference approaches, say, 2 P the stress in the more highly stressed regions will reach that at which the material is no longer elastic. Its extension will then be of a plastic nature, that is to say, one which does not disappear when the stress which caused it is removed. Over most of the skin the stress will remain within the range in which the material is still elastic and the removal of the pressure will restore this part of the skin to its original dimensions. But in areas where the stress was high, there will remain a permanent stretch. The pre-loaded cabin is therefore physically different from a new one, if the pre-load has exceeded a certain level.

151. Although the permanent extension of the material in the areas where it has stretched plastically, but without fracture, is small and undetectable by visual inspection, it may have a profound effect on the distribution of stress in the material when the working pressure is applied a second time. Without going into details, the general nature of this will be to reduce markedly the stress in the areas where it was previously greatest. The stress concentration in such areas is therefore relieved.

152. This is a process whose general nature is understood, and there are examples where it has been deliberately used in order to improve resistance to fatigue. It has indeed been suggested that it might be used in such structures as a pressure cabin. But there are obvious difficulties, not to say dangers, in applying it. Nevertheless, the subject should undoubtedly receive more study, if only to ensure that tests during design are not rendered unreliable by failure to appreciate its significance.

153. Though there can be no direct proof, there is no doubt that the phenomenon described above

provides at any rate a partial explanation of the apparent anomaly presented by the failure of the pressure cabin of Yoke Uncle at R.A.E. after 3,000 cycles, in spite of the survival of the test specimen of the forepart of the cabin to over 16,000 cycles when tested by de Havillands. The maximum pressure difference which had ever been applied to Yoke Uncle was $1\frac{1}{3}$ P, whereas the test specimen had been subjected to two applications of 2 P in addition to nearly twenty of between P and 2 P.

154. The second question which needs study may be put shortly as follows: what is the true static strength of the complete Comet cabin? Reasons have been given in paras. 120 and 122 why the tests made on sections of the cabin may have been somewhat misleading. A test conducted in the tank at R.A.E., with the most comprehensive exploration of the stress distribution, would be invaluable. Not only would it clear up such uncertainties as remain from our Inquiry, but, in conjunction with the repeated loading tests already made on Yoke Uncle, would provide an invaluable body of information for the basis of design of future pressure cabins.

155. The remaining question which requires study relates to the system used to operate the aircraft controls. Most of the evidence on this subject was concerned with the alleged excessive "break-out" force and indicated a difference of opinion, among pilots, as to whether the existing system was satisfactory in this respect, though none suggested that the alleged defect had in any way contributed to the accident. A different criticism was made by one of the Assessors to the Indian Court of Inquiry into the accident to G–ALYV and apparently prompted that Court's second recommendation, which was as follows: "That consideration should be given to the desirability of modifying the flying control system of the Comet aircraft in order to give the pilot a positive 'feel' of airloads exerted on the control surfaces." Only a passing reference was made to this before me. As advised by my Assessors, I am satisfied that the characteristics of the control system of the Comet should be reconsidered by de Havillands and by A.R.B. in the light of both the criticisms which have been made.

(f) *Observations on certain suggestions made in the course of the Inquiry*

156. I cannot conclude this part of my Report without mentioning two suggestions made during the Inquiry which, after full consideration, I feel unable to recommend.

157. The first of these arose out of some criticism which was made of the system whereby inspection of aircraft parts is delegated by A.R.B. to manufacturers. By this system, the operation of which is set out in an A.R.B. pamphlet on "The Approval of Inspection Organisations and the Maintenance of Airworthiness", manufacturers' own inspectors have the duty of supervising all the work done in building civil aircraft. This inspection organisation is supervised by A.R.B. through their own inspectors to ensure that it is adequate. A.R.B. inspectors do only such detailed inspection of work as is needed to assure themselves that the system is working satisfactorily. Evidence was given by Mr. Povey illustrating how this system worked at de Havillands.

158. The suggestion was made that the system for inspection would be more satisfactory if all the inspectors were responsible direct to A.R.B. and not to manufacturers, or alternatively that there should be a duplicate system of inspection whereby both manufacturers and A.R.B. would have inspectors. Reference was also made to the method of inspection of shipping by Lloyd's as an example of how such a system might work but no evidence was produced as to this method. I cannot, therefore, form any conclusion on the suggested analogy.

159. It is plain that there would be inherent dangers in duplication. Responsibility for the quality of his product must rest with the producer. It is, therefore, essential for the producer to have his own system of inspection. Any additional system would add to expense, but not, it was argued, to safety.

160. I have come to the conclusion that the present system of inspection by manufacturers approved and supervised by A.R.B., is essentially satisfactory. It is, of course, subject to human errors, but it has the beneficial effect of creating a sense of responsibility in manufacturers without which aircraft could not be designed and built to the requisite standard of reliability and safety.

161. The second suggestion arose out of some criticism which was levelled at A.R.B. on the ground that their flight testing organisation is relatively small compared with similar flight test teams at aircraft firms and at the Ministry of Supply Experimental Establishments. A suggestion was, therefore, put forward that A.R.B. flight testing and aircraft approval would be made more effective if an active pilot were appointed to their Council and if civil aircraft were sent to a Ministry of Supply test establishment where a much wider and more experienced opinion on flying qualities could be obtained from a larger organisation, instead of the somewhat restricted assessment at present available to A.R.B.

162. Although I am satisfied that there is no reason to criticise the flight testing of the Comet I as carried out by de Havillands and A.R.B., I think serious consideration should be given to the possibility of obtaining the best available opinion on the flight characteristics of future airliners particularly when they incorporate novel features in design which effect those characteristics. As I have mentioned in para. 146 of this Report, such facilities are available in Ministry of Supply Establishments, and the importance of the civil aircraft industry to the economy of this country seems to warrant making the fullest use of those facilities.

163. With reference to the suggested appointment of an active pilot to the Council of A.R.B., there are clearly difficulties in such an arrangement since the pilot would be unable to do his job as an airline pilot and at the same time be available to give his advice to the Council. I have no reason to believe that the present representation on the Council has been in any way lacking in the past and I hesitate to recommend any change. If an active pilot were to be appointed the post would have to be made a whole time paid employment and it would not be long before he ceased to possess the qualifications upon which those who advocated the appointment laid stress. On the whole I think it is better to rely on the Minister to secure that the person he nominates to the Council as possessing professional experience as a pilot of civil aircraft is always someone who is reasonably up-to-date.

PART XVI

QUESTIONS AND ANSWERS

My answers to the questions submitted on behalf of the Attorney-General are as follows:—

Question 1. What was the cause of the accident?

Answer. The cause of the accident was the structural failure of the pressure cabin brought about by fatigue. See para. 95.

Question 2. If several factors caused the accident what were such factors and to what extent was each contributory?

Answer. This does not arise.

Question 3. Was the accident due to the act or default or negligence of any party or of any person in the employment of that party?

Answer. The accident was not due to the wrongful act or default or to the negligence of any party or of any person in the employment of any party.

Question 4. At the time of the accident:

Question 4 (*a*). Had the aircraft been properly maintained in accordance with the current approved maintenance schedules? If not, did any defect in maintenance affect the safety of the aircraft or contribute to the accident?

Answer. Yes. The second part of the question does not arise.

Question 4 (*b*). Was the aircraft airworthy so far as could reasonably have been then ascertained?

Answer. Yes.

Question 4 (*c*). Was there a valid Certificate of Airworthiness in respect of the aircraft?

Answer. Yes.

Question 4 (*d*). Was there a valid Certificate of Maintenance in respect of the aircraft?

Answer. Yes.

Question 4 (*e*). Was the radio station of the aircraft serviceable and was there a valid Certificate of Serviceability in respect thereof?

Answer. Yes.

Question 4 (*f*). Was the aircraft properly loaded and trimmed within the limits specified in the Flight Manual?

Answer. Yes.

Question 4 (*g*). Were all members of the crew properly licensed and adequately experienced to make the flight? If not, did any defect in the licence of any member of the crew affect the safety of the aircraft or contribute to the accident?

Answer. All members of the crew were adequately experienced to make the flight but the flight engineer, Engineer Officer F. C. Macdonald was not properly licensed to make the flight (see paragraph 35). This defect did not affect the safety of the aircraft or contribute to the accident.

Question 5. Upon consideration of all facts disclosed by this Inquiry what steps should be taken to increase the safety of civil aircraft?

Answer. See Paragraphs 140-155 of this Report.

(Signed) COHEN.
W. S. FARREN.
W. J. DUNCAN.
A. H. WHEELER.

1st February, 1955.

APPENDIX I

LIST OF WITNESSES

ERIC NEWTON, Chief Investigating Officer, Accidents Branch, Ministry of Transport and Civil Aviation.

CECIL MONTIE MACK, Inspector, Grade I, employed by B.O.A.C.

MAURICE RUSSELL OVENDEN, Inspector, Grade I, employed by B.O.A.C.

ARCHIBALD AMOS ELLIOTT, Higher Executive Officer, Ministry of Transport and Civil Aviation.

ERNEST EDWARD RODLEY, Flight Captain, B.O.A.C. Comet II Fleet.

WALTER LANSDOWNE BENNETT, Fleet Engineer Officer, B.O.A.C. Comet Fleet.

ALBERT MEAGHER, Captain employed by B.O.A.C.

GEORGE GORDON STUART, Flight Engineer employed by B.O.A.C.

WILLIAM GEORGE THOMAS LATIMER, Station Officer employed by British European Airways Corporation (hereinafter called B.E.A.) at Ciampino Airport, Rome.

GERALD ARTHUR BULL, Licensed Aircraft Maintenance Engineer employed by B.O.A.C. at Ciampino.

BENJAMIN JESSE FOLLIARD, Assistant Inspector of Accidents employed by B.O.A.C.

PETER CLAUDE PINFIELD, Station Superintendent employed by B.E.A. at Ciampino.

LUCIANO LIPPERA, Operations Assistant employed by B.O.A.C. at Ciampino.

JOHN RICHARD JOHNSON, Captain employed by B.O.A.C.

CHARLES EVANS, Member of the staff of the Operations Controller, B.O.A.C. and formerly Fleet Navigation Officer, B.O.A.C. Comet Fleet.

PATRICK JOHN MEADE, Senior Meteorological Officer, London Airport.

JAN MARTHINUS BOTHA BOTES, Comet Line Captain, South African Airways.

CHARLES GERALD FORSBERG, Commander, Royal Navy.

ANTONIO FORNARI, Professor and Assistant to the Director of the Institute of Forensic Medicine, University of Pisa.

ROBERT DONALD TEARE, Doctor of Medicine, Assistant Pathologist and Lecturer in Forensic Medicine, St. George's Hospital, and Lecturer in Forensic Medicine, St. Bartholomew's Hospital.

SIR ARNOLD ALEXANDER HALL, Fellow of the Royal Society, Director of R.A.E.

PERCY BROOKSBANK WALKER, Doctor of Philosophy, Head of the Aircraft Structures Department, R.A.E.

GEOFFREY CORFIELD, Fleet Inspector, B.O.A.C. Comet Fleet.

PATRICK GRAEME TWEEDIE, Chief Inspector of Accidents, Ministry of Transport and Civil Aviation.

ERIC STANLEY MOULT, Doctor of Philosophy (Engineering), Chief Engineer, de Havilland Engine Company Limited.

DOUGLAS ERIC HOLLAND-MARTIN, Captain, Royal Navy.

BERNARDO RUSSO, Captain, Italian Air Force.

RICHARD HERBERT WILLIAM CLARKSON, Station Operations Officer employed by B.O.A.C. at Ciampino.

SIR FREDERICK WILLIAM BOWHILL, Air Chief Marshal, Royal Air Force (Retired), Chief Aeronautical Adviser to the Ministry of Transport and Civil Aviation and Chairman of A.S.B.

LEONARD EAST, Inspector, Grade I, employed by B.O.A.C.

LEWIS PHILIP BROMLEY BOWLES, Inspector, Grade I, employed by B.O.A.C.

DONALD WILLIAM FOOTE, Aircraft Maintenance Engineer employed by B.O.A.C. at Ciampino.

JOSEPH EDWARD COOK, Radio Maintenance Engineer employed by B.O.A.C. at Ciampino.

PETER ROSS WARDEN, Aircraft Maintenance Engineer employed by B.O.A.C. at Ciampino.

FILIPPO CUFFARO, Ground Engineer employed by B.O.A.C. at Ciampino.

CHARLES ABELL, Deputy Operations Director (Engineering), B.O.A.C.

ERIC LEWIS RIPLEY, Head of the Accidents Investigation Section, R.A.E.

THE RIGHT HONOURABLE LORD BRABAZON OF TARA, Chairman of A.R.B.

SIR VICTOR HUBERT TAIT, Air Marshal, Royal Air Force (Retired), Operations Director, B.O.A.C.

WALTER TYE, Chief Technical Officer of A.R.B.

BRUNO JABLONSKY, Aeronautical Engineer and Director of Jablo Plastics Industries Limited.

ALFRED JOHN MURPHY, Director of the Department of Metallurgy and Professor of Industrial Metallurgy, University of Birmingham.

ROBERT HENRY TRAVELL HARPER, Chief Structural Engineer, de Havillands.

RONALD ERIC BISHOP, Director and Chief Designer, de Havillands.

HARRY POVEY, Director in charge of production, de Havillands.

CHARLES TIMOTHY WILKINS, Chief Assistant Designer, de Havillands.

The evidence of the following was given by affidavit :—

RONALD FREDERICK YOUNG, Station Officer (Operations) employed by B.O.A.C. at Ciampino.

LIST OF WITNESSES—*cont.*

DONALD EDWARD HILL, Traffic/Operations Officer employed by B.O.A.C. at Ciampino.

ANTONIO DE TOMMASO, Clerk employed by B.E.A. in the Load Control Section at Ciampino.

ERNESTO ASTORINO, Station Assistant employed by B.E.A. at Ciampino.

NINUCCIO GERI, Sailor, of Capoliveri, Elba.

VASCO NOMELLINI, Farmer, of Portoferraio, Elba.

LEOPOLDO LORENZINI, Driver, of Castagneto Carducci, Leghorn.

UMBERTO DAMIANI, Resident of Portoferraio, Elba.

GIUSEPPE LOMBARDI, Lieutenant-Colonel and Officer Commanding the Harbour Authority, Portoferraio, Elba.

LUIGI PAPI, Fisherman, of Porto Azzurro, Elba.

ANTHONY ROBERT PIRIE, Translator.

GERT CORNELIS DRY, employed by the Government of the Union of South Africa in the Division of Civil Aviation of the Department of Transport.

IRENO CAFIERO, Load Control Supervisor employed by B.E.A. at Ciampino.

BRUNO BORGOGNINI, Traffic Clerk employed by B.E.A. at Ciampino.

BENJAMIN PERCIVAL LOUIS WELLMAN, Duty Officer employed by B.E.A. at Ciampino.

ORESTE MARINI, Freight Clerk employed by B.E.A. at Ciampino.

MARIO RUIA, Control Clerk employed by B.E.A. at Ciampino.

FEDERICO CONTE, Apron Controller employed by B.E.A. at Ciampino.

GIOVANNI MIRAGOLI, Control Clerk employed by B.E.A. at Ciampino.

FERDINANDO GIANNONTONI, Apron Control Supervisor employed by B.E.A. at Ciampino.

GIOSUE CARDUCCI, Traffic Clerk employed by B.E.A. at Ciampino.

COLIN REGINALD DRURY, Duty Officer employed by B.E.A. at Ciampino.

HENRY WYNDHAM FOLKARD, Operations Officer employed by B.O.A.C. at Ciampino.

CLIFFORD WILLIAM ROGERS, Licensed Aircraft Engineer employed by B.O.A.C. at Ciampino.

APPENDIX II

LIST OF REPRESENTATIONS

THE RIGHT HON. SIR LIONEL HEALD, Q.C., M.P., MR. J. P. GRAHAM, Q.C., and MR. P. J. STUART BEVAN (instructed by The Treasury Solicitor) appeared on behalf of H.M. Attorney-General.

THE RIGHT HON. SIR HARTLEY SHAWCROSS, Q.C., M.P., MR. RODGER WINN and MR. H. A. P. FISHER (instructed by Messrs. Linklaters & Paines) appeared on behalf of the de Havilland Aircraft Company Limited.

MR. E. J. RIMMER, Q.C., and MR. PATRICK BROWNE (instructed by Mr. K. H. Staple, O.B.E., and Mr. R. M. Forrest) appeared on behalf of British Overseas Airways Corporation; and (instructed by Mr. A. Conradie) appeared on behalf of South African Airways.

MR. L. G. SCARMAN, O.B.E., and MR. ANTHONY ALLEN (instructed by Messrs. Stanley & Co.) appeared on behalf of the Air Registration Board.

MR. M. A. L. CRIPPS (instructed by The Treasury Solicitor) appeared on behalf of the Ministry of Supply.

MR. D. A. GRANT, D.S.O. (instructed by The Treasury Solicitor) appeared on behalf of the Ministry of Transport and Civil Aviation.

MR. R. A. MACCRINDLE (instructed by Messrs. Evan Davies & Co.) appeared on behalf of the British Air Line Pilots Association: (instructed by Messrs. Heppenstall, Rustom & Rowbotham) appeared on behalf of the personal representatives of the late Captain A. Gibson; and (instructed by Messrs. Kingswell & Berney) appeared on behalf of the personal representatives of the late First Officer Bury.

MR. J. WHITFORD (instructed by Messrs. Waterhouse & Co.) appeared on behalf of Messrs. Aero-Research Ltd.

MR. G. D. EVERINGTON (instructed by Messrs. Barradale & Co.) appeared on behalf of Messrs. Normalair Ltd.

MR. J. M. SHAW, M.C. (instructed by Messrs. Janson, Cobb, Pearson & Co.) appeared on behalf of the personal representatives of the late Captain J. A. Collings, M.B.E.; (instructed by Messrs. Cardew-Smith & Ross) appeared on behalf of the personal representatives of the late Mr. and Mrs. Brooks; (instructed by Messrs. Ward, Bowie & Co.) appeared on behalf of the personal representatives of the late Miss D. M. Eady; (instructed by Mr. F. R. Howell) appeared on behalf of the personal representatives of the late Miss N. Young; (instructed by Messrs. Stikeman & Co.) appeared on behalf of the personal representatives of the late Mr. J. Rosenberg; (instructed by Messrs. Kenneth Brown, Baker, Baker) appeared on behalf of the personal representatives of the late Mr. F. H. Greenhaugh; and (instructed by Messrs. Charles Robinson & Son) appeared on behalf of the personal representatives of the late Mrs. E. S. D. MacLachlan.

MR. T. HUMPHREY TILLING (instructed by Messrs. Ingledew, Brown, Bennison & Garrett) appeared on behalf of the Navigators and Engineer Officers Union.

COLONEL R. MINIERO and SIGNOR R. ROVERI appeared as the Accredited Representatives of the Government of Italy.

LIEUTENANT-COLONEL L. E. LANG and MAJOR J. J. GRANZIER appeared as the Accredited Representatives of the Government of the Union of South Africa.

MR. R. G. LLOYD, C.B.E. (instructed by Mr. Stuart H. Lewis) appeared as an observer on behalf of Messrs. British Thomson-Houston Company Limited.

MAITRE LEOPOLD DOR (instructed by Messrs. Holman, Fenwick & Willan) appeared as an observer on behalf of Union Aeromaritime de Transport.

APPENDIX III

The Court sat at Church House, Westminster, as follows:—

19th October, 1954
20th ,, ,,
21st ,, ,,
22nd ,, ,,
25th ,, ,,
28th ,, ,,
29th ,, ,,
1st November, 1954
2nd ,, ,,
4th ,, ,,
5th ,, ,,
8th ,, ,,
9th ,, ,,
10th ,, ,,
11th ,, ,,
12th ,, ,,

The Court sat at the Institution of Civil Engineers, Great George Street, Westminster, as follows:—

17th November, 1954
18th ,, ,,
19th ,, ,,
22nd ,, ,,
23rd ,, ,,
24th ,, ,,

On the 26th October, 1954, the Court visited the Royal Aircraft Establishment at Farnborough.

APPENDIX IV

NOTE ON METAL FATIGUE BY THE ASSESSORS

(1) The fatigue of metals has been studied for upwards of 100 years, and there is a world wide literature about it. The name correctly suggests that metals (and indeed other materials) suffer from a type of weakness not unknown to human beings. They will break under a load which is repeatedly applied and then removed, though they can support a much larger steady load without distress.

(2) There is one generalisation which applies to all failures due to fatigue. The higher the intensity of the internal stress caused by the external load, relative to that which would just cause failure when applied once, the lower is the number of applications of that load under which failure by fatigue will occur. And for some materials (in particular steel, though not in general alloys of aluminium) there is an appreciable load below which fatigue is borne indefinitely.

(3) Enough is now known about the fundamental physics of fatigue for engineers to be aware that there is still much to be learnt. Research is continuous. But this relates more to discovering how to improve the resistance of materials to fatigue, than to any doubts about the principles which should govern the

design of engineering structures which must have a long life under loadings which vary. This is true both of mechanisms, such as engines, where the number of cycles of loading in an economic life runs into millions, or hundreds of millions, and of relatively static structures, such as bridges, or the wings or pressure cabins of aircraft.

(4) These principles have been arrived at by long experience, and are widely known and soundly founded. They are also simple. The highest stress to which the material will be subjected during a cycle must be limited by three considerations:—

(i) For a given " life ", expressed as the number of cycles of loading, there is for a given material an upper limit to the allowable stress. This can be determined only by experiment.

(ii) In the material of an engineering structure, or components of a mechanism, there exist inequalities of stress, some known and some unknown. For the former, which should be avoided as far as possible by design, allowance can be made. The latter arise for various reasons, such as unavoidable imperfections in workmanship, or the use of riveted joints. For these provision can be made only by adopting a conservative outlook based on laboratory experiments and on experience in service, and by meticulous inspection during manufacture.

(iii) When due allowance has been made for the points mentioned above, there remains a phenomenon known as " scatter "—the appreciable, in some cases large, variation among the lives, under a given loading cycle, of nominally identical parts. Tests of a number of specimens are necessary in order to assess it, and the " safe life " under service conditions must be determined by reference to them.

(5) In certain evidence and exhibits in the Inquiry the terms " high level " and " low level " fatigue were used in a way which may have suggested that two distinct kinds of fatigue are known to exist. The distinction was one of convenience only, and arose because of the contrast between the circumstances of two classes of *failure* due to fatigue, namely :—

(*a*) Failure under repeated loading when *the level of stress is high* in relation to the ultimate tensile stress of the material, and the life is accordingly short—a few thousand cycles of loading.

(*b*) Failure under repeated loading when *the level of stress is low*, and the life accordingly long—many thousands, or even millions, of cycles.

(6) The latter is the type of failure due to fatigue with which engineers are mostly concerned, and with whose visible symptoms they are most familiar. This is because most components whose design is governed largely by considerations of repeated loadings must have very long lives and ample margins of safety, since failure would be costly, if not calamitous. The very existence of multitudes of high speed mechanisms, engines, turbines, etc., testifies to the understanding of it which now exists. The appearance of the corresponding type of failure is characteristic of a process which has endured for some time.

(7) Failure due to fatigue at a relatively high level of stress is comparatively rare. Virtually no engineering components are designed to have a short life under alternating loads. Nor, owing to the influences mentioned above in para. 4, would it be easy so to design them satisfactorily. Not only are the symptoms of failure when it occurs after relatively few cycles therefore less familiar, but they are also less specific. The process has not endured long, and most of the symptoms of a disease which spreads gradually are absent.

(8) In the evidence given by Professor Murphy, Professor of Industrial Metallurgy at the University of Birmingham, are two remarks which summarise the situation as seen by an experienced metallurgist. He said:—" I am strongly impressed by the high general level of stress round these spots,* and I do not feel it necessary, or even relevant, to try to pursue the last final speck, as it were, which set off the fatigue failure. I think in various places, there was a readiness for fatigue failure, and it required only a mild stress raiser† to initiate failure."

" The prime consideration is, I think, to get the general stress level down so that you are not in jeopardy in this way. If you can get the general stress level down, you can tolerate the variations which are very liable to happen in practical manufacture. If you have a high stress level you are setting yourself the task of guarding against most minute variations from the ideal."

* The corners of the cabin windows

† Such as a rivet or bolt hole

Appendix V

DIARY—MAIN ITEMS—COMET G-ALYP

Item	*Date recovered*	*Date received R.A.E.*
Floating wreckage, Private Trawling (including one part of centre fuselage) ...	—	26.1.54 onwards
Pressure dome, parts of rear fuselage	22.2.54	18.3.54
Main items, wing centre section (engines about same time)	15.3.54	5.4.54
Front fuselage	3.4.54	15.4.54
Starboard outer wing (17–20) (other parts followed later)	7.5.54	22.5.54
Tail Unit	26.5.54	28.5.54
Centre fuselage—port side piece	16.6.54	21.6.54
Fin	9.6.54	30.6.54
Search re-orientated—6.7.54		
Centre fuselage—piece containing A.D.F. aerial windows	12.8.54	31.8.54
Outer portion, port tailplane	21.8.54	31.8.54

Appendix VI

Accident Note No. 270
September, 1954

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Report on Comet Accident Investigation

PART 1

OUTLINE OF THE INVESTIGATION

1. *Introduction*

This report gives an account of the investigation of the Comet 1 aircraft undertaken by the Royal Aircraft Establishment after accidents to Comet G–ALYP near Elba on 10th January, 1954, and to Comet G–ALYY near Naples on 8th April, 1954.

When this investigation was started, little of the wreckage of the aircraft which met disaster near Elba had been recovered, and it was not known how much of the wreckage would prove to be recoverable. A series of technical investigations of the properties of the aircraft were therefore initiated and proceeded simultaneously with the examination of the wreckage as it was received. Inevitably examinations were made of items which were subsequently shown, from the wreckage, to have played no part in the disaster at Elba although some may be relevant to the Naples accident, from which very little wreckage has been recovered. In Parts 2 to 11 of this report will be found accounts of all these investigations, but detailed reference will be made in this summary only to those shown to have possible relevance to the accidents near Elba and Naples.

The circumstances of the accidents and the results of the detailed examination of the wreckage of G–ALYP are set out in full in Part 2.

Details of investigations of the structural strength of the aircraft, including its resistance to metal fatigue, will be found in Parts 3, 4 and 5.

Arguments relating to the possibility of excessive pressures being built up in the fuel tanks and the cabin, covering explosion and pressure refuelling investigations, are outlined in Parts 6 and 7.

The possibility of loss of control due either to aerodynamic characteristics or to malfunctioning of the automatic pilot and power control systems, is examined in Part 8.

The results of tests on 1/36th scale dynamic models of the Comet are given in Part 9.

The results of flight trials of Comet aircraft G–ANAV are given in Part 10.

Relatively small miscellaneous investigations are contained in Part 11.

A note on the medical evidence, contributed by the Institute of Aviation Medicine, is contained in Part 12.

2. *Discussion of the accident at Elba*

The examination of wreckage shows that structural failure of the aircraft occurred in the following pattern. First, there was a violent disruption of the central part of the pressure cabin. Then the fuselage aft of the rear spar, the nose of the fuselage, and the outer portions of the wing fell away, all under the action of "downward" forces. Then the main part of the wing, now a separate entity, caught fire. The fuselage aft of the rear spar, complete with tail unit, fell into the sea in a single piece, falling in an "open end first, tail plane aft" attitude. The main part of the wing hit the sea in an inverted position. The full evidence on which the above outline is based is to be found in Part 2.

The flight plan which the aircraft was following would have brought it to an altitude of about 30,000 feet at the time of the accident. Supporting evidence showing that the break-up occurred at this height is as follows. Metallurgical examination of the burnt centre section shows that the fire was burning for about three minutes (Part 2) and calculations and model tests (Part 9) confirm that the time of descent of the centre section from 30,000 feet altitude would be of this order. Tests on models (Part 9) confirm that a "break up" of the kind outlined, at this altitude, would produce on the ground a pattern of wreckage similar to that found on the sea-bed near Elba, and that the motions of the larger parts would be of the type which would lead to impact with the sea in the directions which are thought to have occurred in the accident (Part 2).

The sequence of events outlined above appears to be consistent with the evidence obtained from examination of the bodies of the victims of the accident (Part 12).

To produce a violent disruption of the pressure cabin, there must either have been a structural failure under normal flight loads (including the internal pressure load), or the internal pressure must have been raised to an abnormally high value, or a failure must have been induced due to the development of abnormally high tail loads.

In Part 3 is an account of an investigation of the strength of the cabin in its ability to resist "fatigue". This work demonstrates beyond doubt that the fatigue life of the cabin is relatively short*. The failures produced on test originate at points of concentration of stress near the corners of "cut outs" in the structure of the cabin which accommodate windows and hatches. The general character of the concentration of stress is similar at each cut-out. Evidence from the wreckage suggests strongly that the initial failure in the accident occurred at one of these stress concentrations (Part 2) and was of the same nature as the fatigue failures produced on test at other similar points of concentration (Part 3). It is shown in Part 3 that, quite apart from the direct evidence from the wreckage, the test results can be interpreted as meaning that fatigue failure of the cabin, at the age of the aircraft involved in the Elba and Naples accidents, is possible. A failure of the type envisaged would cause the violent disruption of the centre fuselage which occurred in the accident.

* A structure with an ample reserve of strength in its early life may in the course of time fail "in fatigue" through repeated applications of load. The term "fatigue life" means the period required to produce failure under these conditions.

We notice in the wreckage (Part 2) that cracks had formed near a cut-out during manufacture of the Elba aeroplane, and their ends had been drilled to stop propagation. Their presence suggests that incipient cracks, undetected at the time, may have been induced in the material by the processes used in the manufacture of the aeroplane, and this may have brought about some acceleration of the onset of fatigue.

The possibility that the failure of the cabin might have been brought about by the development of abnormally high internal cabin pressure, due either to mis-operation of the ventilation and pressurisation system, or to explosion in the main cabin or in the equipment or luggage bays is dealt with in Part 7. No evidence can be found to suggest that such an event occurred, or is likely to occur in a form leading to disruption of the cabin, unless the cabin was already weakened, or unless an explosive were deliberately placed; no evidence has been found to suggest that the latter occurred.

Although the development of abnormally high tail loads might lead to the disruption of the cabin, it is unlikely that they would cause an initial break at the place at which it is thought (Part 2) the cabin first failed. Apart from this, however, the following evidence appears to be relevant. Strength tests on the tail-plane (Parts 4 and 5) showed it to be structurally sound. High tail loads might have developed if the automatic pilot or the power-operated-control system mis-operated in a serious way. No evidence has been found from the wreckage to suggest that this occurred, and examination of the system suggests that such mis-operation is unlikely (Part 8). High tail loads could also occur were the pilot to "over-control" the aircraft, perhaps subsequent to a violent disturbance of his flight path by a gust. A considerable sample of gust records made in previous flights of Comet aircraft have not suggested that gusts of such violence are likely to be encountered at the altitude of the disaster (Part 10). Opinions of test pilots who have handled the aircraft in the course of these investigations are that it is unlikely that they would be led into difficulties by the control system (Part 10), although they would prefer that the "break out" force associated with the elevator control were smaller. Experiments using a simulator which reproduced, in the laboratory, the characteristics of control and response of the Comet aircraft, and which are reported in Part 8, did not reveal any likelihood of such loss of control.

3. *Other technical matters*

In the course of these investigations, it was shown (Part 3) that the wing has a relatively low resistance to fatigue. This did not cause the Elba accident, for the wing did not fail in the "fatigue prone" region, but it may have a bearing on the Naples accident, from which there is no wreckage to examine. There are some reasons (Part 3) for supposing this to be unlikely in that particular case.

It has been shown (Part 10) that fuel from the fuel-tank venting system can enter the trailing edge area of the wing, near the jet pipe shrouds, and there is therefore some possibility of fire occurring in this region of the aircraft, in which there are no fire detectors or fire fighting units. Such a fire was not the cause of the Elba accident, as is shown by the wreckage.

Investigations into refuelling, which are discussed fully in Part 6, indicate that the outer wing tanks are liable to sustain internal damage during refuelling under conditions which, though abnormal, may sometimes have occurred in practice. An accident is unlikely to be caused by such damage, and, in particular, it did not cause the Elba accident, as is shown by the wreckage.

4. *Opinion*

We have formed the opinion that the accident at Elba was caused by structural failure of the pressure cabin, brought about by fatigue. We reach this opinion for the following reasons:—

(i) The low fatigue resistance of the cabin has been demonstrated by the test described in Part 3, and the test result is interpretable as meaning that there was, at the age of the Elba aeroplane, a definite risk of fatigue failure occurring (Part 3).

(ii) The cabin was the first part of the aeroplane to fail in the Elba acident (Part 2).

(iii) The wreckage indicates that the failure in the cabin was of the same basic type as that produced in the fatigue test (Parts 2 and 3).

(iv) This explanation seems to us to be consistent with all the circumstantial evidence.

(v) The only other defects found in the aeroplane (listed in Section 3) were not concerned at Elba, as demonstrated by the wreckage.

Owing to the absence of wreckage, we are unable to form a definite opinion on the cause of the accident near Naples, but we draw attention to the fact that the explanation offered above for the accident at Elba appears to be applicable to that at Naples.

5. *Acknowledgement*

We are grateful for the help which we have received in conducting this investigation from all authorities and organisations concerned in the construction and operation of Comet type aircraft, and from those responsible for the recovery of the wreckage.

APPENDIX VII

STATEMENT MADE TO THE COURT BY SIR LIONEL HEALD, Q.C., M.P., ON THE 12TH NOVEMBER, 1954

When I addressed the Court at the opening of this Inquiry I expressed the confident belief that everyone concerned would give willing co-operation, not only in ascertaining the cause of the Comet disasters, but also in the taking of constructive measures to improve the safety and efficiency of British aviation. I think the Court will agree that that is the spirit in which this Inquiry has been conducted. It certainly has enormously facilitated my task and I believe it has also lightened the labours of the Court.

I have been hopeful from the very beginning of this Inquiry that it might be possible for me, as representing the Crown in the interests of the public, to put before the Court some suggestions, however broad in outline, as to how the machinery for ensuring the safety of civil flying might be strengthened and improved, but it obviously would have been of no value to attempt to do this—indeed it might have seemed to be mere impertinence on my part—unless I could first be assured that any suggestions that I might make would have the support of all those most closely concerned with the matter. I have therefore consulted the Ministry of Civil Aviation and the Air Registration Board, and I am glad to be able to inform the Court of certain practical steps which the Air Registration Board propose to take, with the Minister's approval, as a result of the consideration that they have both been giving to this matter for several months past.

Since the Air Registration Board, as the Court is well aware, now represents all the main interests in aviation, and since the Minister represents the Government, I think that you will feel that this is an important matter.

In the first place the Board has already indicated its intention that complete cabins of pressurised aircraft shall be submitted to tank tests similar to those used at Farnborough, at any rate until knowledge of the fatigue problem has become much more exact. Before the certification of certain prototypes can be contemplated by the Board, therefore, provision will now be required for fatigue testing of entire components, and in the Board's view at least two airframes of each prototype will have to be made available, one for static testing and the other for fatigue testing.

Secondly, as you have heard in evidence, the whole of the country's technical resources can already be made available to the Board, but in view of the difficult problems facing aircraft designers and the Board at the present time, careful consideration has been given to the advantages which can be derived from the inclusion in the Council of the Board of one or more additional members specially selected for their eminence in the scientific field. It is proposed to take action on these lines.

Various other measures are under consideration but I do not think it would be of assistance to the Court to go into these in detail. I may, however, perhaps usefully mention two points. First, a purely practical matter, the value of test flights in the shape of extensive flying on proposed routes with fully instrumented aircraft, especially in relation to aircraft with engines of which there is no background of experience, for example, in the Royal Air Force. The second point is concerned with research. As you have heard in evidence, the Board has been concerned for some time about the structural integrity of modern high performance pressurised transport aircraft. The importance of research on fatigue in aircraft has also become increasingly apparent in recent years and much valuable work has been done on this by the Air Registration Board, in the Industry and in and the Ministry of Supply. In particular, research on the problem of fatigue in high grade light alloys has been sponsored for a long time by the Ministry of Supply and work on the programme has been intensified during the past two or three years. The subject is continually before the appropriate Committees of the Interservice Metallurgical Research Council. Although the subject is a difficult one and rapid results cannot be expected, it is fully recognised that the best brains and resources ought to be directed to it, and the Ministry of Supply has agreed to give the fullest co-operation in this work.

APPENDIX VIII

STATEMENT FOR SUBMISSION TO THE COURT ON PROPOSED FUTURE ACTION BY DE HAVILLANDS

1. Now that the danger of high level fatigue in pressure cabins has been generally appreciated, de Havillands will take adequate measures to deal with this problem. Naturally these measures will be taken in full consultation with A.R.B. To this end we propose to use thicker gauge materials in the pressure cabin area and to strengthen and re-design windows and cut-outs, and so lower the general stress to a level at which local stress concentrations either at rivets and bolt holes, or such as may occur by reason of cracks caused accidentally during manufacture or subsequently, will not constitute a danger. In addition de Havillands are already engaged on an extensive programme of detailed testing in order to establish a design technique which will minimise the effect of such local stress raisers as are necessarily inherent in the design. Further, de Havillands will carry out repeated loading tests on the lines indicated by Mr. Bishop.*

2. Every possible precaution will be taken by the use of appropriate design and manufacturing techniques and by stringent inspection procedure further to minimise the possibility of cracks occurring in manufacture. If a crack does occur at any time either in manufacture or subsequently during the life of an aircraft, no repair scheme for such a crack will be sanctioned by de Havillands unless it ensures that after it has been carried out the part of the aircraft concerned will be as strong and will have as long a fatigue life as it would have done had there been no crack.

3. *Wing Fatigue*

de Havillands are re-designing those parts of the wing structure which have been shown to be prone to fatigue in order to reduce the stress level. The measures to be taken will probably include an increase in the thickness of certain parts of the bottom skin and reinforcing the area aft of the wheel well.

4. *Fuel Venting*

Modifications have been devised which it is believed will prevent the venting of fuel during take-off and climb. These consist of Modification 755 and Modification 1404 (the siphon break). In addition the vent exit will be taken into the jettison pipe so as to ensure that any fuel which may be vented will be discharged clear of the aircraft.

5. *Refuelling*

de Havillands recognise the desirability of removing the possibility of damage from this source and are devising a method of doing this. As Mr. Wilkins stated it is not possible to particularise at present what the modification will be but de Havillands have no doubt that the risk of damage can be removed. In addition de Havillands will advise operators to incorporate a flow meter into the refuelling unit.

6. *Handling Characteristics*

de Havillands are considering a modification of the break out force to suit the convenience and comfort of the pilot. They are investigating the possibility of considerably reducing the break out force below the present figure of 18–20 lbs. A reduced break out force has already been incorporated in the design of the Comet III.

7. *Hydraulic Fluid*

de Havillands have carried out exhaustive investigations into the possibility of using non-inflammable hydraulic fluid. We shall continue to carry out further investigations and we hope that high priority will be given to the development of these fluids to make them suitable for use in modern commercial aircraft.

8. *Jet Buffet*

de Havillands have reduced jet buffet on the underside of the fuselage by slightly altering the angle of the jet engines in Comets II and III. The increase in the thickness of the fuselage skin (see Para. 1) will also serve further to minimise the risk of damage from this source.

9. *Accidental damage to doors and hatches*

Attention will be given to reinforcement of areas which are susceptible to damage from loading of passengers and freight.

* Mr. Bishop indicated that de Havillands would test specimen sections before testing the complete pressurised fuselage.

THE CIVIL AVIATION ACT, 1949

THE CIVIL AVIATION (INVESTIGATION OF ACCIDENTS) REGULATIONS 1951

Report of the Public Inquiry into the causes and circumstances of the accident which occurred on the 8th April, 1954, to Comet aircraft G-ALYY

AIRCRAFT: Comet G–ALYY ENGINES: Four de Havilland Ghost 50

REGISTERED OWNERS: British Overseas Airways Corporation

OPERATORS: South African Airways (under charter)

CREW: Senior Captain W. K. Mostert—Killed
First Officer B. J. Grove—Killed
Navigation Officer A. E. Sissing—Killed
Flight Engineer Officer A. R. Lagesen—Killed
Radio Officer B. E. Webbstock—Killed
Steward J. B. Kok—Killed
Air Hostess P. Reitz—Killed

PASSENGERS: 14—All Killed

PLACE OF ACCIDENT: Over the Mediterranean, S.E. of Naples.

TIME OF ACCIDENT: 8th April, 1954, at about 1910 G.M.T.

All times in this Report are G.M.T.

PART I

INTRODUCTORY

(a) *Matters in common with the Report on G–ALYP*

1. In my Report of today on the accident to Comet aircraft G–ALYP (sometimes called Yoke Peter) I gave a short explanation of the constitution and functions of the Air Registration Board (A.R.B.) and of the Air Safety Board (A.S.B.) which I need not repeat here. It is also unnecessary for me to repeat the account I gave in that Report of the origin and history of the Comet aircraft.

2. As the two Inquiries were conducted together, the evidence in the Inquiry into the loss of Yoke Peter is the evidence in the present Inquiry. I need not, therefore, append any lists of the witnesses or parties represented at the hearings or the dates of such hearings.

(b) *Arrangements with South African Airways*

3. South African Airways are the national operators of the Government of the Union of South Africa. Air communication between London and South Africa was carried on under arrangements made between British Overseas Airways Corporation (hereinafter called "B.O.A.C.") and South African Airways. I need not go in full into the history of the arrangements between the two operators. Suffice it to say that the arrangements were revised on the 3rd October, 1953 and it was agreed, amongst other things, that South African Airways should participate with B.O.A.C. in the operation of the standard class services between England and the Union of South Africa by operating Comet aircraft chartered from B.O.A.C. The Corporation trained the necessary South African Airways crews to carry out this arrangement. Amongst the aircraft so chartered to South African Airways was Comet G–ALYY (sometimes hereinafter called Yoke Yoke).

PART II

THE ACCIDENT

4. Yoke Yoke left Ciampino Airport, Rome, at 1832 hours on the 8th April, 1954 on a flight to Cairo. After taking off the aircraft from time to time gave its position by radio telephone to Rome Air Control at Ciampino and on the last

such occasion at about 1857 hours reported that it was abeam Naples and climbing to 35,000 ft. This position and those given earlier indicated that the flight was proceeding according to the B.O.A.C. flight plan. At 1905 hours Cairo received a signal from the aircraft reporting its departure from Rome and giving its estimated time of arrival at Cairo. Thereafter no message was received from Yoke Yoke and all attempts to make contact failed.

5. A chart, which is Figure 1 of my Report on Yoke Peter, was prepared by a Navigating Officer of B.O.A.C. from all the information available, and shows the probable flight track of the aircraft. It also indicates the position in which bodies and wreckage were found on the day following the accident. It is evident from the chart that something catastrophic happened to the aircraft at about 1910 hours when it must have been at or near the end of its climb to 35,000 ft.

PART III

THE AIRCRAFT

6. Yoke Yoke was the same in all relevant respects as Yoke Peter. Details of Yoke Peter are given in my Report thereon and I need not repeat them here.

7. Yoke Yoke was granted a Certificate of Registration No. R.3221/1 on the 18th September, 1951 in the name of B.O.A.C. as owners and first flew on the 10th September, 1952. On the 23rd September, 1952 it was certified and approved by A.R.B. for the issue of its Certificate of Airworthiness and this Certificate, No. A.3221, was issued by the Ministry of Civil Aviation on the 30th September, 1952. After approval by A.R.B. on the 21st September, 1953 the Certificate of Airworthiness was renewed on the 23rd September, 1953 and was valid at the time of the accident.

8. After the accident to Yoke Peter on the 10th January, 1954, special checks, in addition to the routine Check 4 in accordance with the Approved Maintenance Schedules, were carried out on Yoke Yoke and a number of modifications were made affecting the airframe, the controls and the fire detection and protection at the engines. On the 15th February, 1954, the fuselage was subjected to a proving test to 11 lb/sq. in. The aircraft was returned available for service on the 24th February, 1954.

9. On the 2nd April, 1954, following a Check 1 inspection in accordance with the Approved Maintenance Schedules, carried out at London Airport, a Certificate of Maintenance signed by duly licensed airframe and engine maintenance engineers and expressed to be valid for 75 flying hours, was issued. Further reference to this Certificate is made in paragraphs 21 and 22 of this Report. On the 7th April, 1954, an Aircraft Radio Station Certificate of Serviceability was issued and showed no items unserviceable.

10. At the time of the accident Yoke Yoke had had a total flying life of about 2,704 hours, including 841 since the renewal of its Certificate of Airworthiness and including less than 75 hours since the issue of the Certificate of Maintenance on the 2nd April, 1954.

11. From examination of the airframe and engine log books and maintenance records it appeared that all routine inspections of airframe and engines had been regularly carried out within the limits of time specified by the Approved Maintenance Schedules and that the flying life of each of the engines since its last complete overhaul was within, and in two cases very well within, the approved life between complete overhauls. Save as mentioned in paragraphs 21 and 22 of this Report the evidence disclosed no irregularity in connection with any such inspection.

PART IV

THE CREW

12. Senior Captain Willem Karel Mostert, who was in command of Yoke Yoke was born on the 27th April, 1916. Before joining South African Airways he had flown 2,812 hours in the South African Air Force and had served as a flying instructor. He joined South African Airways on the 10th June, 1946, was promoted Captain on the 1st November, 1946 and on the 15th June, 1949 became a Flying Instructor. On the 15th May, 1953, he became Senior Flying Instructor and on the same day was promoted to the rank of Senior Captain. In June, 1953, Captain Mostert was transferred to the Comet Line of South African Airways and became the Comet Line Instructor. In South African Airways, captains who are appointed Line Instructors have to spend two-thirds of their time on route flying and one-third on instruction within the line. During his service with South African Airways Captain Mostert flew a total of 8,159 hours of which about 51 hours by day and 35 hours by night were flown in Comets within the six months preceding the accident.

13. Captain Mostert's last "six monthly check" prior to the accident was carried out on the 19th December, 1953 and his report was: "Proficient. (Very well executed flight)". He had not been involved in any previous accident. Captain Mostert was the holder of a Union of

South Africa Air Line Transport Pilot's Licence No. 65A valid until the 11th June, 1954. A rating for Comet aircraft had been added to this licence by the British Ministry of Transport and Civil Aviation. I am satisfied that Captain Mostert was fully equipped to carry out his normal duties as a pilot and as a captain and to deal with emergencies.

14. The second pilot was First Officer Barent Jacobus Grove who was born on the 15th July, 1922. After service in the South African Air Force, in which he had flown a total of 1,640 hours, he joined South African Airways on the 29th January, 1953, as a First Officer and was posted to the Comet Line on the 26th February, 1953. While with South African Airways First Officer Grove flew for a total of 54 hours, including about 47 hours in Comets during the 90 days preceding the accident. There was no evidence of First Officer Grove having been involved in any previous accidents save as a result of enemy action. His last check took place on the 20th February, 1954, when he obtained a satisfactory pass. First Officer Grove was the holder of a Union of South Africa Senior Commercial Pilot's Licence No. 48 (S), valid until the 11th June, 1954, to which a Comet rating had been added on the 2nd March, 1954. I am satisfied that he was fully equipped to carry out his normal duties and to support his captain in emergencies.

15. Navigation Officer Albert Escourt Sissing was born on the 1st January, 1917. After training in the South African Air Force he joined South African Airways on the 16th October, 1946 and from then until his death had 4,840 hours flying experience including about 155 hours in Comets in 1953 and about 51 hours in Comets during 1954, all of the latter during the 90 days preceding the accident. At his last six monthly check, in March, 1954, he passed in Comet Refresher Flight Planning and Plotting. Navigation Officer Sissing was the holder of a Union of South Africa Navigator's Licence No. 17(N) valid until 1st December, 1954 and I am satisfied that he was a capable officer.

16. Radio Officer Bertram Ernest Webbstock was born on the 17th June, 1917. He joined South African Airways on the 23rd April, 1946 and after spending some time on the London service passed a Comet course on the 20th June, 1953 and thereafter flew only in Comets. His total flying hours were 4,373 of which about 98 hours were during the 90 days preceding the accident. He was passed as proficient in his Comet check on the 5th October, 1953. Radio Officer Webbstock was the holder of a Union of South Africa First Class Flight Radio Operator's Licence No. 348 valid until the 30th April, 1954 and I am satisfied that he was a capable officer.

17. Flight Engineer Officer August Ranwald Lagesen was born on the 22nd May, 1920. He had wide experience of several types of aircraft both during the war and after rejoining South African Airways on the 16th February, 1945. There was no positive evidence relating to his flying hours prior to the 11th May, 1950 but such records as were available suggested that up to that date he had flown a total of about 4,300 hours. After the 11th May, 1950 he had a total flying time of 2,290 hours 35 minutes. He had flown about 203 hours in Comets including about 141 hours during the 90 days preceding the accident and had completed a Comet Conversion Course on the 2nd September, 1953, a Comet Refresher Course on the 19th December, 1953 and a further refresher course and flight training programme on the 21st March, 1954. He was examined on the 19th December, 1953 and found proficient. Flight Engineer Officer Lagesen was the holder of a Union of South Africa Aircraft Maintenance Engineer's Licence No. 387, valid until the 26th February, 1955, and Flight Engineer's Licence No. 10 valid until the 22nd February, 1955. I am satisfied that he was a capable officer.

18. Air Hostess Pamela Reitz, who was born on the 16th February, 1932 and Steward Jacobus Bruwer Kok, who was born on the 18th December, 1918 had both flown extensively with South African Airways.

PART V

THE PASSENGERS AND CARGO

19. Yoke Yoke carried 14 passengers all of whom were killed in the accident. There was nothing in the cargo which could have been relevant to the cause of the accident and I am satisfied that, despite the off-loading of a small bag of aircraft spares at London after the Load Sheet had been completed, the aircraft was loaded and trimmed within the prescribed limits.

PART VI

PRE-FLIGHT INCIDENTS

20. Yoke Yoke, in common with the rest of the Comet fleet of B.O.A.C., had been grounded by B.O.A.C. after the accident to Yoke Peter. The circumstances in which Comet services were resumed are fully stated in paragraphs 54 to 57 of my Report on the accident to Yoke Peter and I need not repeat them here.

21. Yoke Yoke arrived at Ciampino on the 7th April from London and was due to depart

from Ciampino the same evening. However, on completion of refuelling it was discovered that the centre tank contents gauge showed no reading although the tank was full. The fault was eventually traced to a co-axial cable for which a replacement had to be flown from England and the departure of the aircraft was consequently delayed for about 24 hours. While the fault was being traced a number of bolts were found lying about in the port wing of the aircraft and further inspection revealed that an equal number of bolts were missing from the inspection panel providing access between the rear spar and the wheel-well wall and that the remainder of the bolts securing the panel, though in position, were not properly tightened. The missing bolts were replaced and all were properly tightened. The maintenance engineer who supervised this work was satisfied from visual examination and from the readiness with which the missing bolts were refitted that no distortion of the panel or adjacent structure had occurred during the absence of the bolts.

22. As has been stated in paragraph 9 a Check 1 inspection was carried out on Yoke Yoke before the issue of the Certificate of Maintenance on the 2nd April. It is quite clear that it must have been during that inspection that the panel was removed and incorrectly refitted and I was informed that disciplinary action had been taken against the inspectors concerned.

23. The arrangements for safeguarding the aircraft during its stay at Ciampino were the subject of a great deal of evidence. For the greater part of this period Yoke Yoke was under observation by B.O.A.C. officials whose duties, however, were not primarily concerned with security. For the rest of the time it was guarded by an Italian Finance Guard whose main duty was to prevent smuggling. In all the circumstances I consider it unlikely that any unauthorised person gained access to the aircraft.

24. Apart from the above-mentioned defects, the Refuel and Departure checks disclosed nothing unusual.

PART VII

WEATHER CONDITIONS AT THE TIME OF THE ACCIDENT

25. From the take-off at Rome at 1832 hours on the 8th April, 1954 until the time of the accident, which was approximately 1910 hours, Yoke Yoke climbed through three moderately thick layers of cloud. In the top layer there may have been slight to moderate icing conditions but these would have been insufficient to cause anxiety. It is unlikely that any severe turbulence was encountered either during the climb through the cloud layers or in the clear air above. It can, therefore, be assumed that the state of the weather was not a contributory cause of the accident.

PART VIII

ACTION TAKEN AFTER THE ACCIDENT

26. As in the case of the accident to Yoke Peter the assistance of the Royal Navy was invoked and on the 9th April, 1954, H.M.S. *Eagle* and H.M.S. *Daring* proceeded to search for Yoke Yoke. Avenger aircraft of H.M.S. *Eagle* were used to assist in the search as also were certain United States aircraft. A number of dead bodies as well as some aircraft seats and other wreckage were identified in the water and in due course recovered. The depth of water where the bodies and wreckage were found varied between approximately 520 fathoms and 580 fathoms and the evidence established that at that depth the prospect of further recovery was hopeless.

27. The six bodies recovered were not examined by Professor Fornari, who had examined the bodies recovered at Elba, but four of them were examined at Uxbridge on the 12th April, 1954 by Dr. Teare, one was not subjected to autopsy and the other was examined by the Italian authorities.

These examinations did not disclose anything inconsistent with the view that the accident to Yoke Yoke was attributable to the same cause as the accident to Yoke Peter.

28. As a result of the accident to Yoke Yoke the Royal Aircraft Establishment (hereinafter referred to as R.A.E.) were directed to conduct a full investigation into it and the accident to Yoke Peter. In the absence of any wreckage from Yoke Yoke R.A.E. could only proceed with their investigations in the light of *a priori* reasoning and experiments and of conclusions to be drawn from the wreckage of Yoke Peter. I have dealt at length with the R.A.E. investigations and Report in my Report on the accident to Yoke Peter.

PART IX

THE COURT'S CONCLUSION AS TO CAUSE OF ACCIDENT

29. R.A.E's conclusion as regards the cause of the accident to Yoke Yoke is expressed in the following paragraph:—" Owing to the absence of wreckage, we are unable to form a definite opinion on the cause of the accident near Naples, but we draw attention to the fact that the explanation offered for the accident at Elba

appears to be applicable to that at Naples ". I agree with this conclusion and have only to add that it is impossible in the case of the Naples accident to be dogmatic that defects of the kind considered in paras. 108–144 of my Report on Yoke Peter were not contributory causes to the Naples accident. I am therefore glad to note that the programme of future action outlined by the de Havilland Aircraft Company Limited and set forth in Appendix VIII to my Report on Yoke Peter includes measures to deal with those defects.

PART X

RESPONSIBILITY

30. I have dealt at length with this question in my Report on the accident to Yoke Peter. There is, however, one matter on which criticism was made which is applicable only to Yoke Yoke and that is the decision, after the accident to Yoke Peter, to allow the Comet passenger services to be resumed on the 23rd March, 1954. I have set out in paras. 52 and 53 of my Report on the accident to Yoke Peter the nature of the full investigation carried out by the Committee under the chairmanship of Mr. Abell, the Deputy Operations Director (Engineering) of B.O.A.C. and the modifications made on the recommendation of that Committee.

31. Before deciding to authorise the resumption of the Comet passenger services the Minister of Transport and Civil Aviation consulted A.R.B. and A.S.B. Both of these bodies recommended that consent should be given. When they did so, there had been only one accident to a Comet aircraft for which no explanation had been furnished. According to the evidence it was certainly not the practice either in the United Kingdom or elsewhere to ground all aircraft of a type because of an unexplained accident to one aircraft of that type. The evidence indicated that steps had been taken to deal with what the experts then considered to be all potentially dangerous features. In these circumstances I am of the opinion that no blame can be attached to any one for permitting the resumption of the services.

PART XI

FUTURE

32. I cannot usefully add anything to what I have said on this branch of the Inquiry in my Report on the accident to Yoke Peter.

PART XII

QUESTIONS AND ANSWERS

My answers to the questions submitted on behalf of the Attorney-General are as follows:—

Question 1. What was the cause of the accident?

Answer. Owing to the impossibility of salvaging any appreciable part of the wreckage of the aircraft no positive answer can be given to this question but the fact that this accident occurred in similar weather conditions, at approximately the same height and after approximately the same lapse of time after take-off from Rome as that to G-ALYP makes it at least possible that the cause was the same as in that case. The state of the bodies recovered was, as in the case of G-ALYP, consistent with the accident being due to failure of the cabin structure owing to metal fatigue.

Question 2. If several factors caused the accident what were such factors and to what extent was each contributory?

Answer. I cannot usefully add anything to my answer to Question 1.

Question 3. Was the accident due to the act or default or negligence of any party or of any person in the employment of that party?

Answer. There was no evidence on which I could attribute the accident to the wrongful act or default or negligence of any party or of any person in the employment of any party.

Question 4. At the time of the accident:

Question 4 (*a*). Had the aircraft been properly maintained in accordance with the current approved maintenance schedules? If not did any defect in maintenance affect the safety of the aircraft or contribute to the accident?

Answer. The aircraft had been properly maintained save that on arrival at Rome a number of bolts were found lying in the port wing of the aircraft and further inspection revealed that an equal number of bolts were missing from the inspection panel providing access between the rear spar and the wheel-well wall and that the remainder of the bolts securing the panel though in position were not properly tightened. The missing bolts were replaced and all were properly tightened and I am satisfied that this defect in maintenance did not affect the safety of the aircraft or contribute to the accident.

Question 4 (*b*). Was the aircraft airworthy so far as could reasonably have been then ascertained?

Answer. Yes.

Question 4 (*c*). Was there a valid Certificate of Airworthiness in respect of the aircraft?

Answer. *Semble* yes. I do not find it necessary to deal with the legal question whether the default in re-assembly referred to in paras. 21 and 22 of this Report had any effect on the validity of the Certificate of Airworthiness since I am satisfied that this default did not contribute to the accident.

Question 4 (*d*). Was there a valid Certificate of Maintenance in respect of the aircraft?

Answer. *Semble* yes. See my answer to Question 4 (*c*) on Certificate of Airworthiness.

Question 4 (*e*). Was the radio station of the aircraft serviceable and was there a valid Certificate of Serviceability in respect thereof?

Answer. Yes.

Question 4 (*f*). Was the aircraft properly loaded and trimmed within the limits specified in the Fight Manual?

Answer. Yes.

Question 4 (*g*). Were all members of the crew properly licensed and adequately experienced to make the flight? If not did any defect in the licence of any member of the crew affect the safety of the aircraft or contribute to the accident?

Answer. Yes. The second part of the question does not arise.

Question 5. Was the Minister of Transport and Civil Aviation properly advised in March, 1954 that Comet services should be resumed?

Answer. Yes. See paragraph 31 of this Report.

Question 6. Upon consideration of all facts disclosed by this Inquiry what steps should be taken to increase the safety of civil aircraft?

Answer. See paragraphs 140-155 of my Report on Yoke Peter.

(Signed) COHEN.
W. S. FARREN.
W. J. DUNCAN.
A. H. WHEELER.

1st February, 1955.

(81687) Wt. 4517— K12 2/55 D.L.

Printed and published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
P.O. Box 569, London S.E.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
Tower Lane, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast
or through any bookseller

Price 8*s*. 0*d*. net

Printed in Great Britain

S.O. Code No. 56-14*