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No. 36

Trans World Airlines, Lockheed Super Constellation 1649-A, N 7313C, accident in the vicinity of Olgiate Olona, Varese Province, Italy on 26 June 1959. This summary is based on the English translation of the final report of the Board of Inquiry, appointed on instructions from the Ministry of Defence, Republic of Italy, as released in November 1960 as a Civil Aeronautics Board (USA) Aircraft Accident Report, File No. 1-0045.

Circumstances

TWA's scheduled flight No. 891/26 took off from Malpensa Airport, Milan, at 1620 hours GMT for Orly Airport, Paris, with 8 regular crew, one extra member and 59 passengers on board. After 15 minutes of flight and while still climbing on the prescribed route (Malpensa - NDB Saronno - NDB Biella) disintegration of the aircraft occurred and it crashed to the ground, from an altitude of about 11 000 ft, near Olgiate Olona. All persons aboard were killed, and the aircraft was destroyed.

Investigation and Evidence

The Aircraft

As of 26 June it had flown a total of 6 671 hours; 895 hours since its last overhaul and approximately 72 hours since its last Upkeep and Line Inspection. It was considered to be airworthy on the day of the accident.

At the time of take-off from Malpensa, the aircraft's weight (120 175 lb) was well below the maximum authorized (160 000 lb) and the barycentre, at 21% of the mean aerodynamic chord, was within the limits allowed for the weight indicated.

The following are some of the aircraft's operational limits as taken from its Flight Manual:

Maximum permissible weight without fuel - 117 000 lb
- at take-off from Malpensa the aircraft's weight without fuel was 107 175 lb

Design diving speed (V_D)
336 kt (EAS)

Maximum permissible speed (V_{NE}) (up to 13 300 ft)
294 kt (EAS)

Normal operating limit speed (V_{NO}) (up to 18 800 ft)
261 kt (EAS)

Design manoeuvring speed (V_A)
195 kt (EAS)

Design (flap 80% extended) speed (take-off) (V_{FE})
185 kt (EAS)

Design (flap 100% extended) speed (landing) (V_{FE})
160 kt (EAS)

Optimum climbing airspeed (V)
156 kt (EAS)

Limit of acceleration: flap up, 2.5 g; flap down 2 g.

Maximum differential pressure in fuselage: 10.92" Hg. Also (from Lockheed's data on structural calculations):

Design speed for maximum gust intensity of 66 ft/sec (V_B)
175 kt (EAS)

The Crew

The captain held a CAA Airline Transport Rating Certificate for DC-3, DC-4 and Lockheed Constellation 049, 749-A, 1049 and 1649-A aircraft. He had his last CAA physical examination in April 1959, his last line check in September 1958 and his last instrument check in April 1959. He had flown a total of 25 514 hours, 682 of which were on 1649-A aircraft.

The co-pilot had been a TWA captain since June 1956 and held a CAA Airline Transport Rating Certificate for Martin and Lockheed Constellation aircraft. His last CAA physical examination was in May 1959, his last line check in June 1958 and his last instrument check in February 1959. He had a total of 12 150 flying hours to his credit, 76 of which were on Lockheed 1649-A's.

The first officer held a CAA Commercial and Instrument Rating Certificate and had flown a total of 3 500 hours, 382 of which had been on Lockheed 1649-A aircraft.

The two flight engineers held Airframe and Engines Mechanic Licences, and each had flown over 9 000 hours including more than 600 hours in Lockheed 1649-A aircraft. Their last line checks were carried out early in 1959.

All these crew members had had a rest period of 12 hours preceding the flight of 26 June.

Weather - General

At 1200 on 26 June, Western Europe was under the influence of a weak westerly influx of Atlantic air slightly cooler than the existing air, advancing from the West behind a relatively weak cold front which, upon reaching the Alps in the morning, settled against them, being held in check by the mountain chain and forming a wave motion along the Franco-Swiss side of the chain. Not until early afternoon did the front succeed in overcoming the obstacle and spreading over the Po Valley. Surface winds were very weak during the entire day over most of Europe. At an altitude of 10 000 ft (700 mb) there was noted a weak gradient wind of about 15 kt pushing the front forward.

It was very difficult to establish the exact surface position of the front in the Po Valley, but its existence was ascertained by an analysis of the general charts at various altitudes. The front was accompanied by vast and imposing formations of cumulus clouds, heavy showers and storm activity.

In view of the small rise in the surface temperature during the day because of dense clouds, the scattered storms hitting the Po Valley on the afternoon of 26 June seem to have been due to phenomena of forced updraft, caused by the infiltration of cold air from the Alps, and by the passage of the front rather than to thermoconvective phenomena.

The calculation of the available energy for the phenomena of forced updraft, as the maximum estimate of the rising vertical currents in the storm cell at the presumed height of the crash, i.e. between 10 000 and 11 000 ft, comes out to about 12 m/s, (approximately 39 ft/sec), a figure which may go up to 19 m/s, (approximately 62 ft/sec), if the thermic instability is also considered as being active.

Because of the aforesaid possible speeds of the rising currents, in contrast with the downward currents which, although weaker, were always present about the storm cell, the existence of turbulence with strong accelerations can be admitted.

Weather - At Time of Take-off from Malpensa

The weather bulletins showed that at 1620 hours, take-off time of the flight from Malpensa, the weather over the airport was not good but neither was it prohibitive, even though the rumble of thunder, already audible at 1600 hours, announced the approach of a storm. Storm activity of moderate intensity reached the airport at 1650 hours.

Weather - At the Site of the Accident

The aircraft crashed approximately 12.5 km from Malpensa Airport. The weather conditions may be presumed to have been similar to those reported by the weather stations at Malpensa and Linate. In fact, dense cloud formations covered the Milan area at altitudes of from 2 000 - 4 000 to 14 000 - 20 000 ft. At higher altitudes, towering cumulonimbus formations, in large cells, existed at up to 35 000 ft.

Below 2 000 - 4 000 ft the cloud ceiling may for short periods have dropped to 600 - 1 000 ft during the showers. More or less steady rain and shower activities existed over the Alps and in the Po Valley until the system moved on toward the Adriatic Sea, permitting the entry of northerly winds, after which the skies became clear.

Reasonably reliable witnesses stated that at the time of the crash, i.e. 1635 hours, it was raining slightly in the vicinity of Olgiate Olona and the ceiling was estimated at 600 - 700 m. Visibility was approximately 3 - 4 km. There had been a very heavy shower 5 to 10 minutes before the accident, and it rained very hard again, briefly, some time later. Some witnesses heard thunder and saw flashes of lightning just before and after the accident.

As there was no weather station in the vicinity of Saronno, no further data could be ascertained.

Conditions likely to cause disturbances, electric discharges and ice formations

Because of the frequency of strong upward and downward vertical air currents that accompany them, formations of storm clouds are always accompanied by disturbances, even of great violence, and the existence of strong electric charges with wide differences in potential and consequent discharges. Inside these formations, icing will occur at heights above the level of the thermic zero, which according to the soundings made by the Linate station at 1200 hours was in the neighbourhood of 11 500 ft. However, this altitude may vary inside the storm cloud; hence it is permissible to assume that in this case ice might have formed immediately above 10 000 ft.

Navigational Aids

There was no evidence that assistance was requested by the aircraft from the radio aids of the Terminal Area of Milan. From the authorizations issued by the Milan Area Control Centre and the communications exchanged between the aircraft and that control office, it appeared that the aircraft plotted its course by utilizing first the Saronno and then the Biella radio beams which were operating continuously during the flight.

Reconstruction of the Flight

Flight 891/26 began at Athens, Greece at 1015 hours on Lockheed 1649-A aircraft, N 8083H, which stopped at Rome at 1215 hours, where the flight was then resumed on N 7313C. The aircraft departed Rome at 1400 hours, arriving at Milan (Malpensa Airport) at 1536 hours after a normal flight. At Malpensa the captain went to the meteorological and operations offices for clearance regarding the flight to Paris.

The history of the flight from Malpensa Airport up to the time of the crash was reconstructed on the basis of the flight plan, the exchange of messages between the plane and the Malpensa tower, between the plane and Milan Control, and on the basis of the distribution of the wreckage on the ground, and testimony.

At 1617 hours the aircraft was cleared by Milan Control as follows:

> "Malpensa-Paris, via NDB Saronno and Biella. Over Saronno at 4 000 ft. Climb to 10 000 ft or more above Saronno following the waiting circuit. Approach Biella at 18 500 ft and maintain that altitude."

The aircraft then took off at 1620 hours and was asked to report on reaching 4 000 ft and Saronno. At 1623 it reported as being at 2 300 ft. One minute later contact was established between the aircraft and Milan Control (Linate), but the communication was interrupted because of power failure on the recorder. (The storm caused an interruption of the electric current.) By relating that communication with the authorization received and the previous conversations with the Malpensa Control Tower, it was assumed that the captain was reporting that he had reached the altitude of 4 000 ft and was proceeding toward Saronno. At 1626 the aircraft advised that it was on the Saronno circuit at 6 000 ft, then reported at 1632 that it was leaving Saronno NDB at 10 000 ft and proceeding toward Biella NDB. At 1633 the aircraft sent out its last radio signal to Milan Regional Control. The emergency conditions, which arose after this last contact, the disintegration of the aircraft and its crashing to the ground took place within about two minutes. It appears evident that the accident was of a sudden and violent nature and was due to unexpected conditions of abnormality.

Medical Aspects

In so far as the crew was concerned, the autopsies showed no evidence whatsoever of any intrinsic or extrinsic elements in the bodies, such as the presence of pre-existing organic changes, or the presence of carbon monoxide, or a sudden illness of the pilots followed by immediate death, or of the alcoholic factor (intoxication) with resulting erroneous handling of the aircraft etc., which might lead to the belief that there were other causes of death besides complex traumatism.

The Wreckage

The crash area was about 30 km to the northwest of Milan and included the towns of Olgiate Olona, Prospiano, Gorla Minore, Nizzolina, Marnate and Castellanza, all of which are to the northeast of Busto Arsizio in the Province of Varese.

Proceeding into the said area, in an east-west direction corresponding more or less to the aircraft's route, the scattering of the wreckage on the ground extended for about 3 km along a wide and irregular trail which began about 1 km to the northeast of Nizzolina and ended at the town of Olgiate Olona.

Along this path, the following principal parts and pieces of wreckage were found in the order listed below. All parts were brought to a central depot at Gallarate where a detailed examination of every piece was carried out.

1. The upper plate of a fuel tank cap (P.N. 750438-13). It was later ascertained that it belonged to tank No. 6 or No. 7.

2. The upper and lower panels, wing ribs, bulkheads, an inlet pipe (P.N. 478301) and other structural parts belonging to tank No. 6 and the right side of tank No. 7.

   The (right) wing structure from the outer bulkhead of tank No. 6 to the plane's centreline, including tank No. 6 and the right half of tank No. 7, disintegrated in flight into many pieces, which were found scattered over the wreckage trail, but at a distance up-course from the main wreckage and the rest of the right wing as described below in sub-para. 4.

In the area of tank No. 6, between the outer bulkhead and the bulkhead partition between tank No. 6 and tank No. 7, the upper wing structure and the front spar (constituting, with the rear spar and the two bulkhead partitions, tank No. 6) showed clear signs of having been bent outward, manifestly the result of strong pressures.

In particular, the wing panels on both the upper and lower sides, constituting the top and the bottom of tank No. 6, showed a curvature of about 25 cm.

As already stated, the structural pieces of the right side of tank No. 7 were found, together with those of tank No. 6, scattered over the wreckage trail, up-course from the main wreckage and right wing. The partitioning bulkhead between tanks 6 and 7 was found, in pieces of considerable size, at the beginning of the wreckage trail. The structural parts of the left side of tank No. 7 were, however, found in several pieces, damaged by the impact and by fire, under the fuselage at Olgiate Olona.

The intake pipe of tank No. 7 was split open by the obvious effect of great internal pressure. Examination of the ends of the pipe and of the corresponding connexion points on the partition bulkhead between tanks 6 and 7 and on the wing panel constituting the top of tank No. 6, disclosed that the pipe had been subject to outward stress and that, before that stress was exerted, both the partition bulkhead and the wing panel were at their proper places and in a normal position.

All these parts belonging to the area of tank No. 6 and the right side of tank No. 7 were found to be perfectly clean and free from traces or indications of fire. A careful examination did not disclose any trace of electrical discharges.

3. Engines No. 3 and 4 became detached from the right wing in flight, fell some 1 100 m to the southeast of the main wreckage and were considerably damaged. No failures, damage or fire occurred in these engines while the aircraft was still in the air. Subsequent checking (in the U.S.A.) of the calibrations shown by the governors of engines No. 3 and 4 revealed that they were set for the following speeds - 1 949 rev and 2 502 rev respectively, the latter indicative of a climbing speed.

4. The right wing, complete with its cowlings and landing gear assembly, was broken off at a point along the assembly housing. It fell 650 m to the southeast of where the main wreckage fell. Examination of all the areas of breakage showed no evidence of breakages due to stress or metal fatigue. The fire damage incurred took place after the wing had become separated for the aircraft.

5. The main wreckage included the fuselage, the left wing, the left landing gear assembly, the nose landing gear and engine No. 2. It struck the ground almost vertically, and was found with the nose pointing to the southeast in such a position that the axis of the fuselage formed with the north an angle of about 140°. It was badly damaged, twisted and broken

in many places. Engine No. 2 showed no signs of failures or damage in flight. As a result of severe fire damage it was not possible to ascertain whether it had caught fire in the air. As governor No. 2 had been destroyed by fire on the ground, it was not possible to determine its speed setting.

The inspection failed to disclose any concrete and significant evidence which might support the existence or the development during the plane's normal flight of abnormal conditions which would have been either the direct or the indirect cause of the accident.

6. The entire tail assembly became separated from the plane in flight at a point beyond the pressurization bulkhead and fell close by a fencing wall about 450 m south of the main wreckage, and was considerably damaged. Five pieces of the two elevators, the lower part of the left rudder and part of the terminal stern cone and fairing were found distant from the tail assembly, indicating that these parts broke off while the aircraft was still in the air.

   Examination of the breakage area of the tail assembly failed to disclose any trace of metal fatigue and showed that the assembly became separated from the end of the fuselage as a result of static overloads, directed to the left and downwards. Evidence showed that the assembly was structurally in its proper position when, during flight, a fire broke out on the front part of the aircraft and enveloped the tail assembly from its right side.

7. Engine No. 1, which became detached from the left wing in flight, fell about 250 m to the southwest of the main wreckage and was badly damaged. It had not had any failure, damage or fire while the aircraft was in the air. Later examination (in the U.S.A.) showed its governor was set for 2 611 rev, indicating a climbing speed.

Installations and Equipment of the Aircraft

Various factors made the examination of these parts quite difficult. Some conclusions were not so much the result of concrete and specific physical evidence as they were of careful and logical interpretation and of indirect but relevant indications. Some parts were subjected to bench tests and partially or totallv disassembled.

The results of the various examinations follow. The term "abnormality" used means any failure or breakdown which, having occurred before or at the time of the accident, might have been the direct or indirect cause of it.

Air conditioning system

No abnormalities were found in pressurization, heating, refrigeration or air circulation.

Automatic pilot system

No abnormality. It was not possible to determine whether the automatic pilot was on at the time of the accident; however, it was not believed to be the case.

The Air Data Sensor's calibration showed the following data:

Altitude: between 2 685 and 7 000 ft

Speed: between 145 and 195 mph.

Communications and navigation

No abnormality. The weather radar was operating.

Fire fighting equipment

No abnormality. It had not been used.

Flight controls

It was concluded that the various controls were in normal operating condition at the time of the accident. The flap controls were in the "retracted" position.

Fuel system

In view of evidence that tanks No. 6 and 7 had disintegrated in flight, this system was examined with extreme care.

With the exception of tank No. 6 and the right side of tank No. 7, all tanks showed signs of damage from fire. All tank caps were recovered. It was established that one of them, of which only the upper plate remained, belonged either to tank No. 6 or No. 7.

The level-indicating rods for tanks No. 1 and 6 were not found. It was believed that they had been removed from the crash site by unauthorized visitors.

All the metallic mesh filters, with which the fuel intake ports on the top surface of the wings were equipped, were found, with the exception of the one belonging to tank No. 5.

The fuel dumping controls were found in the closed position.

The right side vent outlet of the fuel tanks was in place on the right wing; the left side one was found in the main wreckage, crushed and detached from the left wing. These outlets were later subjected to a series of tests intended to ascertain any possible traces of lightning.

The seven submerged pumps of the seven tanks were recovered, identified, and checked by testing and disassembling. They were all in proper working order.

No other parts of the system showed any signs of abnormal conditions.

Hydraulic system

Nothing abnormal was found with the exception of minute bronze residues in the flange and the angle joint of the return pipe of hydraulic pump No. 1. It was disclosed that the residues came from pistons No. 3 and 8; however, the pump was found to be in working condition.

It was deduced from examination of individual parts and kinematic motion tests thereon that the two sides of the landing gear and the nose wheel assembly were in the retracted position when the aircraft disintegrated. The fact that the left portion of the landing gear was found in an extended position, and the right portion in a partly extended position, was ascribed to the inertia forces generated by the breaking off of the right wing and by the impact of the right wing, the fuselage and the left wing with the ground.

About 80% of the accessories of the front compartment of the hydraulic system were recovered. From examination of these parts it could not be established whether fire broke out in this compartment while the aircraft was in flight, however, if there actually was such a fire, it could only have been a small one.

Lubricating oil, oxygen and electrical systems

No abnormalities were found.

Instruments and controls

The Commission could not arrive at any reliable factual deductions from examination of the various flight instruments and installations recovered.

Practically all the instruments were broken, twisted and damaged as a result of the disintegration of the aircraft in flight, the impact of the wreckage with the ground and the fire. The same was true of the engine controls.

It was possible, however, to deduce that the aircraft at the time of the accident was proceeding toward Biella within the prescribed limits of speed, altitude and route and that it did not make use of any emergency measures.

Damage from lightning

No traces or signs of structural damage of any significance due to lightning were found. In particular, the structures of tanks No. 6 and 7 showed no signs of damage of this kind.

No signs of lightning strikes were found on the static dischargers or the areas near them. Likewise, no evidence of lightning strikes was found on the collectors of the fuel tank vent outlets.

Maintenance records of the aircraft and engines

The records were examined to determine whether pre-existing conditions of abnormality might have had a direct or indirect relation to the causes of the accident. It was ascertained that previously the aircraft had made five landings in an overloaded condition and one landing which had been classified as a "hard" landing; however, inspections made after such landings had disclosed nothing abnormal. It was also disclosed that the automatic control of the pressurization system had, in the past, given continuous trouble and was still doing so at the time of the last flight; however, the system's manual control was in good working order. The records also showed a series of minor difficulties, which were taken into account in the examination of the wreckage. Included in these were some leaks in the fuel tanks, which had been promptly repaired as soon as discovered.

Supplementary Inquiries

Along with the afore-mentioned inquiries, a series of other tests was carried out on various accessories, material and parts in the plants of the Alfa Romeo, Secondo Mona and other industrial firms.

The results briefly were as follows:

1. Inspection of the seat of cap P.N. 700438-13 on the wing top of tank No. 6, to ascertain whether a burn mark found had been due to lightning -

   - the mark had been caused by welding during repair work.

2. Tests on samples of metal taken from the wing frame and inspection of the "fracture areas" to ascertain the characteristics of the metal and the type of fractures -

   - the metal conformed to the specifications, and the fractures showed the characteristics of impact fractures.

3. Microscopic examination of the fuel tank vent outlets to ascertain whether traces of blackening and heating found on one of the vents could be ascribed to electric discharges -

   - the traces were due to heat of the fire, and the two vents bore no evidence of lightning strikes.

4. Examination of and bench tests on the submerged pumps of tanks No. 4, 5 and 7 and parts of same to ascertain whether the pumps were in good working order -

   - they were.

5. Examination of a roll of paper found along the wreckage trail

   - the paper was a special wrapping paper having no properties capable of starting or feeding any process of spontaneous combustion.

6. Examination of the technical data supplied by Lockheed Aircraft Corporation pertaining to the plans of the Super Constellation, 1649-A

   - the results of this examination are presented in study No. 1 of the section which follows dealing with principal inquiries in the United States of America.

Principal Inquiries in the United States of America

Other studies were made in the United States of America at industrial plants, maintenance shops, special institutions and laboratories under the direct supervision of the Civil Aeronautics Board.

1. Analysis of the breakage points of the individual pieces of wreckage to ascertain, on the basis of the construction calculations, the results of the breakage tests made on the prototype, and the breaks that occurred in N 7313C, whether disintegration of that aircraft in flight was due to aerodynamic stresses of any kind or to other causes -

   - disintegration of the aircraft was due to explosive forces originating in tank No. 7.

2. Study of the trajectory of fall of some significant parts of the aircraft which became separated in flight from the aircraft after its disintegration to ascertain the height at which the plane disintegrated, by comparing the actual distribution on the ground of som of the significant parts which became detached in flight with the position obtained by calculation:

   - within the framework of the assumptions on which the study was based, the results showed, with the same degr of probability, the following three combinations of altitud and speed (with wind):

560 kt IAS at an altitude of 5 000 ft
290 kt IAS at an altitude of 10 000 ft
125 kt IAS at an altitude of 15 000 ft

Because of the uncertainty existing in the evaluation of certain parameters entering into the calculations, the results of the study must be taken as indicative and not conclusive.

3. Pressure tests on fuel tank caps P.N. 0750438-13 to ascertain whether pressure, and if so how much, could cause the fuel tank cap to separate into its componen parts so that one of those parts, namely the upper plate, could appear in the same condition as the one that was found, i.e. clean and undamaged.

   The tests, made on new caps, revealed that the caps in question

   a) can be ejected from the seat onto which they are screwed, following fracture of their lower portion, by pressures ranging between 110 and 136 ps or thereabouts, namely, a pres sure much higher than that which will, in fact, cause the tank structure to collapse and the fuel intake pipe to crack;

   b) cannot be damaged, by stresses deriving from pressures of various strength, in such a way as to cause a breaking down of the various component parts resulting in the separation of the upper plate only and no other damage.

On the basis of these tests, it was definitely agreed that the cap to which the plate belonged could not have been ejected from its seat, in the upper surface of the wing, as a result of explosive forces.

4. Tests on the vent outlets for the escape of gasoline vapours from the fuel tanks of the Super Constellation, 1649-A to ascertain whether the gasoline vapours, assumed to be flammable, emerging from the vents, can be ignited electrically, and if so, whether the resulting fire, through the outlets, will spread to the interior of the tanks -

   - under the conditions in which the tests were made, it was established that the gasoline vapours will ignite under certain conditions, but the flames will not spread to the tanks.

5. Inspection of the inner surfaces of some pieces of pipe of the vent outlets for the escape of gasoline vapours, belonging to N 7313C to ascertain whether the condition of the surfaces gave physical evidence of the spreading of flames through these pipes -

   - the result was negative.

6. Study of the possibility of sabotage to ascertain whether it is possible to introduce, through the fuelling ports and into the fuel tanks, suitable compounds, properly prepared, which will later ignite the gasoline vapours existing in the tanks and cause them to explode, without leaving any physical evidence -

   - it was concluded that such a possibility existed as some such cases have been known to occur.

7. Inspections and bench tests, made on the premises of specialized firms, on various parts, accessories and equipment belonging to N 7313C -

   - no evidence of abnormal conditions was found.

8. Static tests on fuel tank caps P.N. 750438-13

   - revealed that the breakage of the individual component parts of the caps occurs under loads corresponding to pressures ranging between 126 and 141 psi, namely, pressures far greater than those required to cause the tank structure to give way and the fuel intake pipe of tank No. 7 to burst.

9. Statistical inquiry into the trouble encountered in the practical use of submerged pumps in the fuel tanks to examine the typical defects encountered in pumps of this type and to ascertain whether such defects, if found present in the submerged pumps of N 7313C, might have directly or indirectly caused the gasoline vapours in the tanks to ignite and explode -

   - it was established that the pumps of N 7313C had no such defects.

10. Tests on the highest temperature that the body casing of a submerged pump can attain when the pump is, by mistake, kept operating for a long time in a practically empty tank to ascertain whether, under the conditions in question, the result would be an explosion of the gasoline vapours contained in the tanks -

    - the tests showed that the highest temperature reached under the conditions cited would be about 120° C.

11. Statistical inquiry into the replacing of P.N. 750438-13 caps and P.N. 481742-1 dipsticks on TWA planes at some past time to ascertain from existing records, whether any cases of loss of these accessories in flight had ever occurred in the past -

    - no evidence was found of any cases of this kind.

12. Statistical inquiry into the damage suffered by 193 planes which were struck by lightning in 1958-1959 to obtain factual elements for an evaluation, on the basis of and in accordance with past experience, of the importance to be given to damage caused by lightning to the structure of N 7313C -

    - such damage was no greater than that usually suffered by other planes struck by lightning. Also, it showed that there were no cases on record of vent outlets being struck by lightning.

13. Inspection of all the technical records on former use of N 7313C from the date it was built to the date of the accident to ascertain whether the trouble, the malfunctioning, the stresses from abnormal landings etc., which had occurred during the practical use of the aircraft might have been directly or indirectly related to the causes of the accident -

    - the results of the inquiry were considered during the technical examination of the wreckage.

14. Inquiries as to the origin of a roll of paper found along the wreckage path -

    - it was not possible to ascertain the origin of the paper nor as to whether it was aboard N 7313C.

15. Chemical analyses of the roll of paper -

    - they disclosed only that the roll was a special type of wrapping paper having no particular characteristics of flammability, and that it contained no substance that would aid combustion.

16. Inspection of the vent outlets of N 7313C to ascertain whether the vents showed traces of lightning strikes or of static electric discharges (steamer corona) such as might cause gasoline vapours to ignite -

    - the vents showed no evidence of electric discharges; however, it was decided that this did not exclude the possibility that static discharges had occurred in the vents that could have ignited the gasoline vapours issuing from them.

17. Microspectrographic examination of the metallic mesh filter of tank No. 7 to ascertain whether the filter might have been, in some way, the starting point of the explosion in that tank and whether it showed anything abnormal -

- the result was negative.

18. Tests on the ignition of gasoline vapours issuing from the vent outlets of Super Constellation, 1649-A, by means of static electrical discharges (streamer corona) -

- they revealed that:

a) On an L-1649-A plane static discharges should occur at the vent outlets if the aircraft is struck anywhere by lightning, or, if it is not struck, when it flies through clouds that are charged with electricity;

b) Static discharges of an intensity comparable to those likely to occur in flight, generated in calm air in a receptacle containing flammable fuel vapours, will ignite these vapours;

c) While the above-mentioned tests, in the present state of knowledge, do not show that static discharges, generated at the vent outlets of an aircraft in flight, will necessarily cause the flammable fuel vapours issuing from these outlets to ignite, they indicate that this hazard cannot be excluded;

d) The tests and observations mentioned in the two preceding paragraphs definitely indicate that adequate precautionary measures should be developed and adopted, particularly the application of anti-flame screens to the vent outlets and the design and construction of these outlets so as to reduce the possibility of the formation of electrical static discharges;

e) Static discharges can, and generally should, develop without leaving on typical aircraft metals, and therefore on the vent outlets, any normally visible evidence.

Discussion

Explosion in fuel tanks No. 6 and 7

Central tank No. 7 is subdivided into two symmetrical parts by a central bulkhead having an ample opening through which the two sections communicate with each other. In the hermetically sealed right bulkhead of tank No. 7, which separates this tank from tank No. 6, there are three holes. The fuel intake pipe (P.N. 478301), which runs through tank No. 6, connects hermetically the said three holes with the fuel intake port recessed below the top surface of the wing at a point where that top surface constitutes the ceiling of tank No. 6. Said fuel intake port is hermetically closed by cap P.N. 750438-13.

The following main accessories are installed in the left section of tank No. 7: submerged booster pumps and respective wiring, electric level-indicator (probe unit), vent valve, and 3-way selector cross-feed valve.

The following main accessories are installed in the right section of tank No. 7: electric level-indicator, vent valve, and 3-way selector cross-feed valve.

Therefore, unlike the other six tanks, which have only one vent valve each, tank No. 7 has two vent valves for the escape of gasoline vapours.

The two vents are symmetrical. They begin at the right and left bulkheads of tank No. 7 and end at two vent outlets situated one on the trailing edge of the right wing and the other on the trailing edge of the left wing, behind engines No. 1 and 4, respectively. To these vent outlets are connected also the vent pipes of tanks No. 3, 4 and 6 (outlet to the right) and of tanks No. 1, 2 and 5 (outlet to the left). The outlets are not equipped with anti-flame wire gauze.

From the description of the damage of the right wing area and taking into account the structural features of tanks No. 6 and 7 described above, it is deduced that:

a) an explosion took place in the right section of tank No. 7;

b) the explosion caused the fuel intake pipe of tank No. 7, which runs through tank No. 6, to split;

c) the splitting of this fuel intake pipe immediately caused an overpressure, or another explosion, in tank No. 6.

Nature of the explosion

The plane took off from Malpensa Airport with the following fuel supply:

Tanks 1, 2, 3 and 4 (capacity of each tank 1 343 - 1 386 gallons)	625 gallons each
Central tank No. 7 (total capacity 1 644 gallons)	22 gallons, excluding the non-usable residual quantity (11 gallons)
Tanks No. 5 and 6 (capacity 1 370 gallons each)	0 gallons each, excluding the non-usable residual quantity (5 gallons)

At the time of the accident the fuel supply conditions had changed as follows:

Tanks No. 1, 2, 3 and 4	550 gallons each

Conditions in central tank No. 7 and tanks No. 5 and 6 had remained the same.

An inspection of the plane's refuelling records showed that:

1) the non-usable residual quantity of gasoline in tanks 5 and 6 had been in the tanks for about 10 hour

2) the residual quantity of gasoline (22 usable and 11 non-usable gallons) in tank No. 7 had been in the tank for about 30 hours;

3) under these conditions, tanks No. ! 6 and 7, at the time of the accident contained gasoline vapours issuing from the residual fuel;

4) the igniting of those vapours in tanl No. 7, whatever its cause, resulte in the explosion of tank No. 7, and that in turn immediately either pro duced an excess of pressure or another explosion in tank No. 6.

Position and altitude at which the disintegration occurred

On the basis of various considerations and taking into account also testimony believed to be reliable, it was estimated that the aircraft disintegrated in the air space above the area bounded by Ravello, Rescaldina and Nizzolina.

With regard to the altitude at which the disintegration took place, it was not possible to arrive at any conclusive and definite findings.

The study of the descent paths of some of the main wreckage parts disclosed that their actual distribution on the ground was in agreement with that obtained from the calculations for three different combinations of speed and altitude (see Inquiries in the U.S.A., No. 2).

Considering that -

a) at 1633, the time of the last radio signal, the aircraft should have been at an altitude slightly below 11 000 ft;

b) the accident occurred suddenly and was over in 2 minutes;

c) the operational procedures, subsequent to the last radio signal, gave as most probable for the aircraft a speed of 170 kt IAS along its flight path and a climbing speed of 800 - 1 000 ft/m;

the afore-mentioned study of the descent paths showed that its results were not completely in conflict with a possible disintegration of the aircraft at a height of 11 000 - 12 000 ft and a speed of about 170 kt IAS. However, other combinations of speed and height are just as possible.

Hypotheses regarding the causes of the explosion

I Structural failure due to aerodynamic stresses of any kind (turbulence, excessive manoeuvre loads, etc.) ensuing explosion of the fuel tanks and, finally, disintegration of the aircraft;

Explosion of the fuel tanks, caused directly or indirectly by:

II Faulty operation and fire in the engines;

III Fires of a different nature;

IV Breakdowns and malfunctioning of the flight instruments and controls in general;

V Foreign bodies of any kind striking the aircraft;

VI Sabotage;

VII Electric discharges from the atmosphere, and consequent disintegration of the aircraft.

I Structural failures due to stresses, ensuing explosion in the fuel tanks and final disintegration of the aircraft

On the strength of technical data supplied by Lockheed, a study was made of the various conditions which might substantiate structural failure as the primary cause of the accident. The inquiry was limited to the wing, because it was believed that its breaking away preceded all other breakages.

The considerations and deductions set forth hereunder are based on the assumption that at the beginning of its last flight, the aircraft was in a normal condition as regards maintenance and structural soundness.

Metal fatigue

The possibility of a collapse of the wing structure as a result of metal fatigue appeared unlikely for the following reasons:

1. no evidence of breakage from this cause was found;

2. the resistance of the main structures to fatigue was positively evidenced by the results of tests made by Lockheed and by the results of the practical use of the L-1649-A aircraft;

3. the wing structure met the U.S.A.'s Fail Safe Requirements; therefore, even in the case of breakdown of a structural element, no collapse of the entire wing structure should have occurred.

Excessive Manoeuvre Stress or Gust

Under the conditions of weight and the position of the aircraft's centre of gravity at the time of the accident and in the presumed climbing trim, with the speed of 170 kt or less indicated on the flight path, neither intentional manoeuvre nor positive, or negative, gust of any intensity could have caused the breakdown of the wing, because, before the forces necessary to cause the collapse of the structure had appeared, the wing would have gone into a stall.

At speeds higher than that indicated above, the wing could not have broken away except under one of the following conditions:

1. Manoeuvre: Exceeding the positive load factor 4.5 g. This condition appears to be unlikely, because the value 4.5 is very high (180% of the prescribed manoeuvre limit factor) and to reach it would have required a sharp manoeuvre at a very high speed, such as after a prolonged dive, which does not seem likely to have happened in view of the suddenness of the accident, but above all, because the breaking of the wing should have occurred in the outer part and not in the inner part, as actually happened.

2. Gust: At the typical design cruising speed (V_C) and design speed for maximum gust intensity (V_B), that is to say at the plane's speed of 261 and 326 kt (EAS), the wing was capable of standing, without breaking, vertical gust speeds not in excess, respectively, of 100 ft per second (30.5 m/sec) and 75 ft per second (22.7 m/sec).

These figures are very high and give a convincing demonstration of the structure's margin of safety with respect to stresses due to gusts, even if the calculations concerning this inquiry were developed exclusively from the static aspect, without taking into consideration the dynamic effect of the gusts.

However, a further investigation for the evaluation of the dynamic effect of gusts on the wing of the model 1649-A aircraft disclosed that the increase factor of the bending moment on the wing, due to said dynamic effect, is not very great, ranging as it does between 1.06 and 1.2, and that in any case it is no greater than that calculated for the previous models 749 and 1049-C, both of which have been tested extensively. In as much as it is shown by the foregoing that the breakdown of the wing by overstress from gust requires the concomitance of high flight speeds (not admissible in a highly turbulent atmosphere) and gusts of extreme intensity, and in as much as in this case also the breaking of the wing should have occurred, in all probability, in the outer part of the wing as explained above, the hypothesis of the breaking of the wing by stress from gusts is believed to be wholly improbable.

Excessive diving speed

Breakdown from excessive diving speed was considered in the event, which cannot be excluded a priori, that the plane, having gone out of control in rough air exceeded its design diving speed (V_D) = 326 kt EAS.

1. Static overload - Under this condition, the structure that undergoes the greatest stress is not the wing but the fuselage (on the rear area) because of the depressive force exerted on the horizontal tail surface (downward flexion). Actually, the breaking up of the fuselage and separation of the complete tail assembly occurred in flight. However, as the examination of the wreckage disclosed, the separation occurred after and not before the wing broke away. Proof of this is the consideration that, had the tail assembly become separated before, the plane would have dived abruptly, with the result that the wing would have broken off by inverse flexion, which did not happen.

2. Dynamic overload

i) Wing flutter

Data supplied by Lockheed regarding the plans of the 1649-A aircraft showed that the wing is free from self-induced vibration up to the speed of 1.2 V_D (391 kt) and under any condition of fuel load.

Since the worst condition exists when the wing has a fuel load of 7 650 gallons, it follows that with the fuel load the aircraft was carrying at the time of the accident (2 200 gallons), the possibility of flutter was very remote. Flutter would have caused the maximum bending stresses in the area of the nacelles of the outer engines and the maximum torsion stresses in the area between the outer and inner nacelles. Examination revealed no breakage from stresses of this type. Self-induced flutter vibrations would very likely have caused the lead masses fitted on the leading edges of both wing tips to break away during flight - instead, they were recovered very close to their respective wing portions.

ii) Tail flutter

As in the case of the wing, the absence of flutter up to the speed of 1.2 V_D = 391 kt EAS was ascertained also with respect to the tail assembly. Also it was shown that separation of the tail took place after the events causing the accident.

Thus, wing and tail flutter could not be considered primary causes of the accident.

Excessive rolling or excessive yawing

A violent rolling manoeuvre or an excessive rolling speed would have caused signs of torsion on the wing covering in the area of the outer nacelles - such signs were not found - or aileron breakages of a type different to those observed on examination of the wreckage.

As for yawing manoeuvres, the most critical structures are the back portion of the fuselage and the vertical tail surface. Actually, there was evidence that the plane was yawing at a high angle of drift, with strong side stresses, but the traces of fire on the tail assembly and the symmetrical nature of the breakage on the tail indicated that a breakdown from excess of unsymmetrical loads while yawing must likewise be excluded as the primary cause of the accident.

Explosion of the tanks and subsequent disintegration of the plane

II Explosion set off by malfunctioning of, or fire in, the engines

The technical inquiries made into the power plants excluded the possibility that the engines may have broken down or been on fire prior to the explosion and, therefore, may have been the determining cause of the explosion.

This was confirmed by the fact that:

1. neither the flow of air cooling the generators nor the flow of gasoline and oil to the four engines was interrupted;
2. the fire extinguishers of the four engines were not turned on;
3. none of the propellers was feathered.

III Explosion set off by other fires

A fire may have broken out on the plane in flight and set off the explosion, however, such a possibility appeared to be remote and wholly improbable.

Fire damage on the wreckage of the aircraft, however it occurred as a result of the explosion, would hardly have been such as to prevent recognition of any evidence of fire occurring during normal flight. Because of the suddenness of the accident, such a fire would have left very characteristic and easily identifiable marks. No such evidence was found.

IV Malfunctioning of the flight instruments and controls in general

No physical evidence of breakdowns or abnormalities as the direct or indirect cause of the explosion of the tanks was found, which was not attributable to the consequences of the explosion itself.

No evidence of electrical discharges was found in the interior of tanks No. 6 and 7.

As to the upper plate of cap P.N. 750438-13, three hypotheses were considered:

1. The cap, to which said plate belonged, was removed, at the crash site, from the wing panel to which it was attached by some unauthorized person who, after having disassembled the cap into its component parts, kept one or more of them and threw away the others, including the plate.

   This hypothesis was subject to doubt in view of the following -

   i) the plate was found at a distance from the wing panel in the middle of a field about 100 m away from the nearest road;

   ii) not one of the remaining parts of the cap was found in said field and immediate vicinity;

   iii) the plate was found exactly at the beginning of the wreckage trail, where it probably would have fallen if, for any reason whatever, it had become detached from its cap and from the wing as a consequence of the explosion, or just before it.

2. The cap became detached from the wing and then broke up into its component parts as a consequence of the explosion.

Considering the results of tests, this might be explained, for instance, as the result of some hidden fault in the thread of the central stem onto which the check nut is screwed.

In fact, if the central stem should break off in that area, the cap would automatically separate into its component parts. In as much as the link chain of the cap was not found in its place on the wing panel, it must either have become detached as a consequence of the explosion or it was removed by unauthorized persons who detached it from the panel.

Against this hypothesis was the fact that the P.N. 750438-13 caps were subject to periodical inspection and tests.

3. Hidden fault etc. as mentioned, with the variation that the final breaking of the thread of the central stem occurred immediately before the explosion as a consequence of the pre-stress exercised by the check nut, the repeated opening and closing of the cap for refuelling, etc. - that is to say, in the course of the practical use of the P.N. 750438-13 cap.

Of these three hypotheses, the third one, regarding the loss in flight of one of the fuel tank caps, is by far the least probable. There was no record that loss in flight of P.N. 750438-13 caps had ever occurred in the past. However, since such a hypothesis is the only one of the three which is pertinent in so far as the search for the causes of the explosion of tank No. 7 was concerned, it was nevertheless taken into consideration.

V Explosion set off by bodies striking the plane's outer surface, whether such bodies were extraneous to the plane or were parts of the plane which had become detached from it

There were no traces of such an eventuality.

VI <u>Explosion set off by explosive devices as the result of sabotage</u>

No evidence of such a possibility was found.

In view of -

1. the results of investigations regarding the roll of paper;

2. the fact that, after the loss of the right wing and the tail assembly, the fuselage was still a closed body; and

3. the fact that the plane's cargo was found with the main piece of wreckage;

it was considered that even if the roll of paper had been aboard the aircraft, the chemical analyses carried out regarding it excluded the possibility of its having characteristics such as would set off explosions or start fires.

VII <u>Explosions set off by atmospheric electric discharges</u>

In as much as -

1. examination of the structural parts of tanks No. 6 and 7 disclosed no evidence of internal electrical discharges within said tanks;

2. tank No. 7 has two vent outlets;

3. the two vents were not equipped with anti-flame screens;

4. no physical evidence of lightning strikes was found on the two vent outlets; a study was made of the possibility that the explosion might have been set off by ignition of the gasoline vapours issuing from the vent outlets, caused by discharges of static electricity (streamer corona). In fact, discharges of this type would leave no visible traces on the outlets.

This possibility assumes the coexistence of the three following conditions -

a) that the gasoline vapours contained in tank No. 7 formed with the air a mixture that came within the ignition limits;

b) that the flammable vapours issuing from the vent outlets could be ignited by an electric discharge;

c) that after the vapours had been ignited at the vent outlets, the flames could spread to tank No. 7 through the vent pipes.

For each of the three conditions mentioned above, the following observations are made:

a) Taking into account what emerges indirectly from the six hypotheses set forth above, the fact that there was an explosion of the vapours contained in tank No. 7 would in itself indicate that the vapours were capable of being ignited. This may be ascribed to -

   i) an aging process of the gasoline residue contained in tank No. 7;

   ii) a penetration of air in tank No. 7 through one of the two vent outlets, the conditions for such a circumstance having, in some way, been produced by the existence of the two outlets;

   iii) by the possible loss, in flight, of the P.N. 750438-13 cap, taken possibly as a circumstance in conjunction with the two preceding ones.

b) As previously mentioned, the possibility that static and non-static electrical discharges might ignite flammable gasoline vapours issuing from the vent outlets was studied in the United States of America, with positive results.

Tests conducted at a specialized institution confirm that:

In the present state of knowledge, it cannot be stated that static electrical discharges generated at the vent outlets of an aircraft in flight will invariably ignite flammable gasoline vapours issuing from the outlets; the tests, however, indicate that this hazard cannot be ruled out.

The weather conditions at the time of the crash were most appropriate for creating, on the vent outlets of the Super Constellation N 7313C, electrical discharges fully capable of igniting flammable gasoline vapours in the test conditions described.

Other tests were made in a tunnel as follows:

On only one of the original outlets, placed on the trailing edge of an airfoil, from whose four outlet pipes issued vapours containing a mixture that was within the limits of flammability in the case of tanks No. 6 and 7, and not within those limits in the case of tanks No. 3 and 4;

at a pressure corresponding to an altitude of 1 700 ft;

at an air flow speed of 170 kt IAS;

for an outgoing speed of the vapours, for each individual outlet pipe, corresponding to climbing speeds of 900, 600 and zero feet per minute.

They disclosed that in the presence of non-static electrical discharges of sufficient intensity, said vapours ignite only if the plane is climbing, and that flames will not spread to the interior of the tanks.

In conclusion, if the tests mentioned do not make it possible to state definitely that static electrical discharges occurring at the vent outlets of a Super Constellation in flight can ignite flammable gasoline vapours issuing from these vent outlets, the tests nevertheless indicate that this hazard cannot be excluded and that the vapours would actually ignite if the electrical discharges were non-static and sufficiently intense.

c) With regard to the possibility that, once the gasoline vapours had ignited at the vent outlets, the fire may have spread to tank No. 7 through the pipes, it is observed that the tunnel tests during which such spreading did not take place -

i) did not reproduce the real vent outlet system of tank No. 7 (existence of two outlet pipes and, therefore, two vent outlets;

ii) did not bring about the true conditions in which the plane must have found itself at the time of the accident.

In particular, the tests did not take into account the effects generated by the turbulence, by sudden variations in flight trim, etc; such conditions, in concurrence with the existence of two vent outlets in tank No. 7, may have made it possible for the flames to spread to the interior of tank No. 7, causing it to explode.

Similarly, in said tests, no consideration was given to the possibility, however improbable it might be, of the loss in flight of cap P.N. 750438-13, supposedly belonging to tank No. 7, located on the upper surface of the wing. This circumstance may in fact have caused the fire to spread to tank No. 7.

Lastly, the fact that the inspection of the inner surfaces of some sections of the outlet pipes taken from N 7313C showed no traces of the passage of flames does not appear to be sufficient proof that such a circumstance did not actually take place. If flames had actually passed through the outlet pipes, their speed would have been too great to leave any traces on the inner walls of the pipes.

The likelihood of hypothesis VII requires the assumption that in the past, in spite of the continuous operation of Super Constellation 1649-A aircraft, none of this type aircraft was ever involved in that set of circumstances and conditions which, having occurred in the case of N 7313C, caused its destruction.

Such an assumption, although only a possibility, must be regarded as a matter for consideration. In fact, no Super Constellations, Model 1649-A, were equipped, at least up to some time after the N 7313C accident, with an anti-flame screen at the vent outlets and, at least on short or medium-length flights, they flew with tanks 5, 6 and 7 empty.

Therefore, also because of the considerations mentioned above,the hypothesis in question, although based on some factual elements, can be proved only by a suitable series of tests on the ground and in flight.

It can be pointed out that the said hypothesis appears to be, indirectly, in agreement with almost all the statements made by witnesses, regardless of the relative value at which such statements are taken; in fact, in the statements, the crash of the aircraft was closely associated with a lightning strike, with the following succession of events:

1) lightning strike (and, therefore, subsequent formation of static electricity discharges);

2) sound of the explosion, or explosions;

3) fall of the plane's burning wreckage.

Probable Cause

In examining the seven hypotheses dealt with in the report and in determining the degree of probability (plausibility) of these hypotheses, the Commission followed a process of elimination whereby the first six were discussed and discarded, whereas the last was discussed and deemed probable.

The breaking up in flight of the aircraft was due to the explosion of the fuel vapours in tank No. 7, followed immediately by either an excess of pressure or a further explosion in tank No. 6.

In the absence of further significant and concrete evidence, taking into account the stormy weather conditions, with frequent and severe electric discharges, existing in the area at the time of the accident, it may be assumed that the explosion of the fuel vapours contained in tank No. 7 was set off, through the outlet pipes, by the igniting of the gasoline vapours issuing from these pipes as a consequence of static electricity discharges (streamer corona) which developed on the vent outlets.

Recommendations

1. In view of the hypothesis advanced, it was recommended that the manufacturers and organizations concerned undertake a programme of research and tests intended to give deeper insight into the phenomena relating to the possibility of fuel tank explosions caused by electrical discharges.

2. It was suggested that pilots be instructed to avoid, whenever possible, crossing meteorological areas where flying conditions are particularly dangerous.

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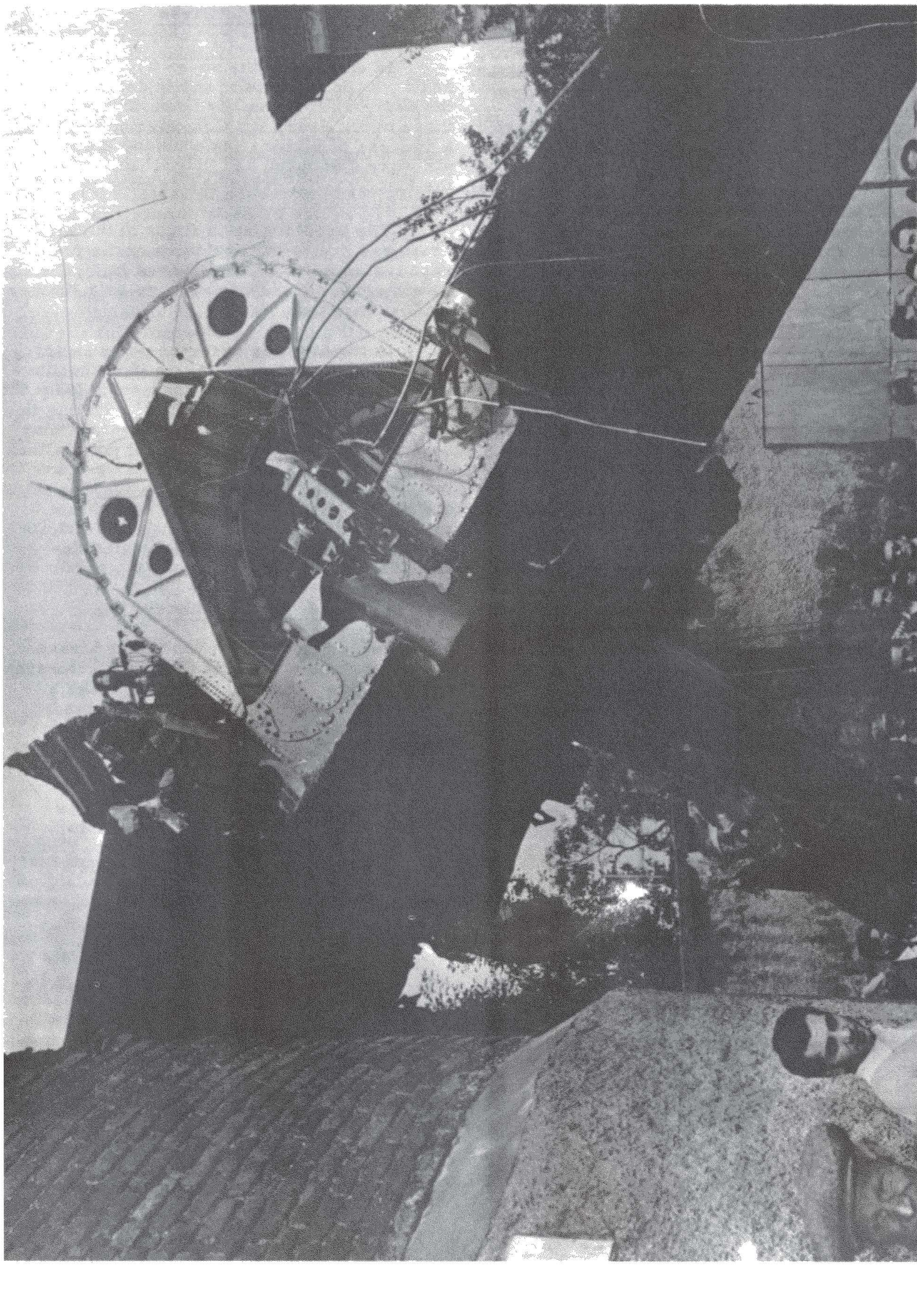

FIGURE 7 Tail assembly of Trans World Airline's, Super Constellation, N 7313C which crashed in Varese Province, Italy, on 26 June 1959.