No. 7

SABENA, Boeing 703-329, OO-SJB, accident at Berg, 2 km northeast of the threshold of runway 20 at Brussels National Airport, Belgium on 15 February 1961. Report released by the Minister of Communications, Belgium.

Circumstances

The accident occurred at the conclusion of a normal scheduled non-stop flight from New York to Brussels. The aircraft was on long final approach to runway 20 and had been cleared to land. When near the runway threshold, instead of landing, the pilot increased power and retracted the undercarriage. The aircraft gained height and made several circles in a left turn. During these turns the bank angle, while decreasing several times for short periods, increased more and more until finally the aircraft was in a near vertical bank. It then crashed and fire broke out on impact. All 11 crew members and the 61 passengers aboard were fatally injured in the accident, and the aircraft was completely destroyed. One person on the ground was killed and another seriously injured. The accident happened at 0905 hours GMT.

Investigation and Evidence

The Crew

The aircraft's crew consisted of a captain, co-pilot, navigator, flight engineer, 5 stewards and 2 stewardesses.

The captain held an airline transport pilot's licence valid until 30 July 1961. His licence was endorsed for the Boeing 707 instrument and night flight, and he had a restricted radiotelephony licence. As of February 1961 he had a total of 15 384 hours flying time. His experience on the Boeing 707 was:-

- simulator training: 6 hr
- flight training: 13 hr 51 min day
  1 hr 15 min night

He was declared proficient on Boeing aircraft on 27 February 1960 and had a proficiency check on 17 October 1960. He was fully qualified on the route New York - Brussels.

The co-pilot was also the holder of a valid airline transport pilot's licence which was endorsed for DC-6, DC-7 and Boeing 707 aircraft. As of February 1961 he had a total of 16 231 hours flying time to his credit, and was also fully qualified on the route New York - Brussels. He had the following experience:

- simulator training: 6 hr
- flight training: 14 hr - min day
  - 45 min night

Examination of the personal files of the crew members showed them to have received a thorough indoctrination and training on this type of aircraft and their qualifications and experience were established. From the medical point of view, they had undergone the required medical examinations, and the results had always been favourable. The minimum required rest periods were observed and even exceeded, while the total flying times were within the limits authorized.

Nothing in the post mortem examination indicated any reduction in the physical capabilities of the crew.

The Aircraft

The airframe had 3 038 hours of flying time. Between a type II overhaul (11/1/61 to 9/2/61) and the accident, the airframe had accumulated 37 hours of flying time.

The aircraft held a certificate of airworthiness valid until 8 August 1961 which was revalidated on 9 February 1961 at the conclusion of a test flight in which a delegate of the technical services of the "Administration de l'Aéronautique" participated.

The aircraft was maintained by the technical services of Sabena. These operations are supervised by the control services of that company. The maintenance programme is laid down by the technical services of the "Administration de l'Aéronautique" which also approves the Sabena controllers and makes its own supplementary independent checks.

As the maintenance and work cards concerning the aircraft did not show any abnormalities, the Commission felt that OO-SJB had been correctly maintained in accordance with the approved programme.

At the time of take-off from New York the aircraft's all-up weight was 119 500 kg of which 50 000 kg were JP. 1 fuel. The centre of gravity was 26% MAC. According to the flight plan the aircraft's estimated all-up weight on arrival was to be 79 230 kg.

At the time of the accident the aircraft was at an all-up weight of 77 500 kg, and the centre of gravity was 25.5% MAC.

Trouble reports

It was found that OO-SJB, as well as other Sabena Boeing 707s, had been affected by blockings or hard spots in the aileron control. Examination showed that the reason for these difficulties was jamming, at low temperatures, in the aileron trim mechanism. The two trim assemblies of OO-SJB, left and right, were removed and replaced during the overhaul carried out on 11 January 1961. They were examined and tested by the Boeing Company. It was possible to reproduce complete jamming of one of the mechanisms by cooling to a low temperature. A considerable force, equivalent to 90 lb at the wheel, was necessary to unjam the mechanism.

No other significant remark was noted in the trouble reports of OO-SJB. However, two difficulties were found which affected the flight controls after overhaul.

1) The pilot noted that during the first test flight on 9 February 1961 the trim button had to be pushed *harder than normal. A second* test flight was made to confirm the fault, after which the pilot noted "abnormal response of the stabilizer particularly after trimming nose down; slight nose up impulses give no result."

The corrective action taken by maintenance consisted of replacement of the stabilizer trim motor. A ground test gave normal responses in both directions.

2) The second incident was observed during the same flight. The pilot noted: "At the beginning of the flight there was a strong tendency of the aircraft to roll to the right. In level flight, the two left wing spoilers are 1 inch out."

"After descent, speed brakes out, at the moment of their retraction there was a marked roll to the right - it did not recur afterwards."

"At the end of the flight, the tend*ency to roll to the right was con*siderably diminished."

An inspection on the ground did not reveal anything abnormal. This fault did not recur during subsequent flights.

Examination of the trouble report, already signed by the captain, for the flight during which the accident occurred, and a message to the company at 0848 hours established clearly that there was no malfunctioning of the aircraft during this flight, and the crew considered it was airworthy for a subsequent flight.

Weather conditions at Brussels National Airport

They were as follows: visibility: 3 500 m; cloud: 7/8 at 6 000 m; wind: 190°/2 kt; dry bulb temperature: +7.4°C; dewpoint: +4.6°C; relative humidity: 82%.

The weather conditions were good and had no bearing on the accident.

Reconstruction of the trajectory

1. According to ATC information and radio communications

Figure 2 shows this trajectory from the point of entry into Belgian territory until the break in radio communications.

2. According to the testimony of witnesses

The trajectory was also reconstructed from the turn onto a long final approach until impact. The trace of this trajectory figures as Points A, B, C, D and I on Figure 3. These witnesses included persons spaced along the trajectory, Air Force personnel stationed at the airport, personnel of the Air Traffic Control Services and aircrew and technical personnel of Sabena.

The witness located at Point B saw the undercarriage in the "down" position. Point C is the last point at which the aircraft reported its position (Hofstade). Up until Point D, all witnesses saw the aircraft flying normally. It then started its "overshoot". It overflew the runway threshold at an approximate height of 300 ft, climbed whilst turning to the left along an apparently steep trajectory. Traces of smoke were observed coming from the four engines. At an estimated height of approximately 1 500 ft it levelled off, reducing power. The aircraft then described three 360° left turns relative to the approach direction. During this trajectory it started first a descent, then several climbs followed by small descents; power was reapplied and cut several times. The left bank angle, while considerably reduced during short periods, increased more and more. The last 90° of turn were accomplished at slow speed, engines idle, with a large bank angle (close to 90° according to certain witnesses). The aircraft then nosed down and crashed. Fire broke out on impact.

3. According to the indications of the flight recorder

The trajectory is shown as Points E, F and G on Figure 3. It is based on information extracted every 12 or 15 seconds on the time scale of a graph. It is to be noted that the flight recorder was an experimental model and, moreover, it was found in an area where the fire was particularly intense. For this reason, the value of the information furnished by the graph during the last 4 or 5 minutes of flight is uncertain or worthless. The recorder does not give points of the trajectory directly. It provides for the airspeed and heading of the aircraft at each instant. From these observations and supposing that the speed vector has the same direction as the heading, a series of tangents can be traced for which the envelope constitutes the trajectory. There is no correlation between the times of the testimonies and the times of the recorder, however, one may attempt to place the curve established according to the witnesses' testimony over the curve established according to the elements of the flight recorder by displacing the latter and by taking into account its orientation, which is determined by the indications of successive headings.

By doing so, as the two trajectories nearly superimpose, the time scale can be deduced and Point D can be located 4 minutes prior to the impact time.

Examination of the wreckage

The wreckage was minutely examined.

The assistance of experts from the Civil Aeronautics Board, the Federal Aviation Agency and the Boeing Airplane Company was obtained for different phases of the technical investigation.

Structure

The aircraft's structure was nearly completely destroyed by impact and the subsequent fire. A major part of the wings was burned, but it was possible to rebuild the essential part of the controls. The breaks, in the different parts of the airframe, revealed nothing abnormal.

The debris found at the site of the accident confirmed that the aircraft's structure was intact before impact. The cockpit debris, projected outside the fire zone, presented no trace of fire.

Although two witnesses believed they had seen some objects become detached from the aircraft at different times, an extensive search in the particular areas did not reveal anything.

Controls

Inboard ailerons

Nothing on the surfaces, the structure, the hinge supports, the control tabs, the snubbers, nor on the balance panels indicated any defect prior to impact. The pressure seals on the passage of the control cables into the fuselage were found burned in their lodgings. Examination of the markings observed on the structure determined that at the moment of impact the inboard ailerons were in a position for a right turn. The left-hand inboard aileron was in a 10° down position, while the right-hand inboard aileron was in a 14° up position. The control pulleys, located below the captain's control column, were found in position for a left turn while those below the co-pilot's control column were found in position for a right turn. These pulleys control the displacement of the aileron control tabs but not the ailerons directly. They are interconnected by a cable which was found broken.

Aileron trim

The positions of the aileron trim control drums showed that the aileron trim was in the neutral position on impact.

Outboard ailerons

It was not possible to determine with certainty the position of the outboard ailerons on impact. However, the measurement of the extension of the control rods of the lock-out mechanism showed that they must have functioned and that the ailerons should normally have been in the neutral position. The control system of the left-hand outboard aileron was intact with the exception of the quadrant which was broken. The quadrant is a casting which permits the control of the outboard ailerons through a cable link with the inboard ailerons.

Apart from deformations, due to impact, nothing abnormal was found amongst the remaining parts of the structure, the balance panels, and the hinges of the left aileron. The right-hand aileron control system was badly damaged.

In the case of jamming of an outboard aileron

a) flaps down: the inboard ailerons will also be blocked;

b) flaps retracted: the inboard aileron adjacent to the jammed outboard aileron will be forced in the same direction as the position of the jammed aileron until such moment as the inboard aileron reaches its full displacement. For example, the inboard aileron will be forced upwards if the outboard aileron is jammed in an "up" position, and vice versa. When the inboard aileron reaches its stop the jamming of the outboard aileron has to give sufficiently or one of the parts in the mechanism will be deformed or broken. If the outboard aileron is jammed in the neutral position the inboard aileron will, after a momentary "up" displacement, return to neutral.

Tests were made in order to clarify the reasons for the fracture of the steel extremity of the outboard aileron control rod under the possible action of flap retraction, ailerons jammed in the down position.

These tests showed that the weakest component in the mechanism is the attachment bolt of the upper outboard part fixing the bell crank driven by the actuator. This bolt breaks by shearing. The blocking torque of the aileron at the moment of rupture is of the order of 250 Kgm.

None of the four bolts, left and right-hand, were found sheared, and it was, therefore, presumed that the breaking of the aileron control rod was due to the impact force.

Spoilers

The position of the spoilers on impact was difficult to determine. The spoilers were all found retracted. However, according to the marks on the structure and rods, it seems that the position on impact might have been as follows:

left-hand outboard spoiler	: undetermined
left-hand inboard spoiler	: probably : retracted
right-hand inboard spoiler	: out (approxi- : mately 40°)
right-hand outboard spoiler	: undetermined.

The position of the spoilers could, therefore, correspond to a right turn control demand.

The "speed brake" control lever was in the neutral position at the moment of impact.

There was no visible indication on what remained of the structure, controls, spoiler actuators and control valves that could lead to the conclusion of a failure prior to impact.

However, it was noted that all shear rivets on the control follow-up mechanism were sheared.

The three by-pass valves of the system were found in the normal position (hydraulic pressure "on").

The by-pass valves of the left and right-hand outboard spoilers were contaminated by fire. The inboard spoilers' by-pass valve was intact.

Bench tests of these valves gave the following results:

inboard valve	: functioned normally
right-hand outboard valve	: functioned normally after reconditioning (replaced seals and springs).
left-hand outboard valve	: functioned abnormally, even after reconditioning. The valve remained stuck in the "open" position.

The overhead panel on which the control switches of the spoiler by-pass valves are located was considerably damaged by impact. The cover of the inboard spoilers' by-pass valve switch was intact and in the normal (down) position but imprisoning part of the panel normally situated outside the switch cover. The cover of the outboard spoilers' switch was in the "up" position but with one of its corners broken off.

Flaps

The flaps were in the retracted position on impact. The selector lever was in the 0° position.

Apart from multiple breaks due to the impact forces, nothing abnormal was found in the structure or control systems.

Rudder and vertical fin

They were not damaged by fire and were relatively intact. Traces on the

structure showed that there was a 20° right rudder position on impact. The traces left on the quadrants controlled by the rudder pedals also showed a 20° right rudder position on impact. No abnormality was found on the structure, hinges, balance panels, tabs, snubbers, or in the power-assisted control system, and the whole control rod system was correctly assembled and safety wired.

The trim was found with a one unit right setting.

The split pins of the centring spring mechanism of the rudder trim were incorrectly installed. Also, the cable which slackens on right rudder application was outside of its lodging. For large rudder movements these split pins, when incorrectly installed, will hit the central support arm of the pulleys of the rudder centring mechanism, and the corresponding cable will slacken and may jump out of its lodging on the drum. When the rudder returns to the neutral position or beyond, this cable may then roll up in the neighbouring lodging. This will result in a displacement of the neutral position of the rudder which, when measured on the ground, has been found to be of the order of 3°. This displacement will remain constant as long as the rudder is not displaced beyond the angle where split pins will again hit the support arm.

Elevator

There were no indications of failure prior to impact on the structure, hinges, balance panels, control tabs, stabilizer actuated tabs or snubbers. At impact the elevators were in the "up" position.

Stabilizer

It was in a position corresponding to 10 - 10.5 units nose up trim, close to the maximum of 11 units. The marks left by the index on the pedestal indicated 8 - 8.5 units nose up trim, but the cable connecting the front drum and the indicating mechanism was broken.

The stabilizer control mechanism was examined for electrical and mechanical failure. The only significant discrepancies were:

a) A relatively important quantity of water condensation was found in the lower housing and in the input shaft well for the electric actuator;

b) The locking nut of the input shaft of the electric trim actuator was excessively tightened and the locking washer was sheared;

c) A piece of fibre was jammed between the rear drum and the cable. The cable had rubbed considerably on the protective covering.

The remains of the electrical parts of the control were strip examined and revealed nothing.

Tests were made to determine the influence of certain faults and to ensure the correct operation of the trim mechanism taking into account the stabilizer's position. Low temperature tests indicated that water in sufficient quantity in the input shaft well of the electric actuator may cause the jamming of the electric trim motor control. While the motor continues turning, water can also cause excessive tightening of the locking nut and shearing of the locking washer.

Other low temperature tests were made to determine the influence of contamination while the mechanism is in operation.

This contamination is a result, partly, of the humidity in the atmosphere which infiltrates during each flight when the mechanism is no longer airtight, and partly because grease on the screw is sucked inside the topcasing during the movements of the screw. The contamination of the lower casing could result from the grease packed inside the mechanism's roller bearings.

The screw is reversible and when operating normally, this reversibility is prevented by two brakes: the primary brake (containing brake plates) and a secondary brake (shoe brake). Tests were made to ascertain whether or not the brakes would slip due to contamination by humidity, ice, grease, or a combination thereof. The possibility of slipping, especially in the case of the secondary brake, was established. However, conditions of prolonged slipping were not apparent. The fibre found between the rear drum and the cable wound upon it could have caused the disconnect clutch to operate due to the friction of this cable on the protective cover, rendering the electrical trim inoperative. The tests made at ambiant temperature, with the squashed fibre and a new assembly, did not operate the disconnect clutch mechanism.

Power plants and systems

Nothing abnormal was found in the power plants, electrical and hydraulic systems, mach-trim, radio or autopilot.

Discussion of the data established during the investigation

Results of the examination of communications exchanged between the aircraft and ground stations during the flight and also from flight recorder tape analysis showed nothing abnormal until 0859:30 hours when approach control cleared the flight to land at Brussels and requested that the tower be contacted on frequency 118.6 Mc/s. The aircraft replied: "All right 118.6 JB". At that moment it was at 1 500 ft, near Hofstade, 5.5 NM from the threshold of runway 20 on which it was to land.

It did not contact the tower. After appearing close to the runway threshold at an altitude and in an attitude which seemed normal, it began a series of abnormal manoeuvres and crashed at 0905 hours, 2 km northeast of the runway threshold.

The flight recorder indicated that 0859:30 hours the aircraft was at a speed of about 220 kt, a magnetic heading of 185° and a pressure altitude of 1 400 ft which corresponds to an altitude of 1 560 ft(QFE). It also indicated a loss of altitude of 1 000 ft/min with a reduction in airspeed from 215 kt to 145 kt between 0900 and 0901 hours. To obtain this loss of altitude and speed reduction the pilot probably took the following action in quick succession:

1) power reduction
2) lowered flaps to 30°
3) lowered landing gear
4) lowered flaps to 40°
5) lowered flaps to 50°

It the aircraft was trimmed longitudinally at the beginning of this manoeuvring and if the pilot continued to maintain his longitudinal trim during the reduction in speed and altitude, the number of units of trim would have passed from one unit nose up to 5 units nose up, which represents approximately 8 seconds of trim motor action. The aircraft would, therefore, have been in the landing configuration and at a height of 560 ft above the airport elevation, which would have made it possible to continue and land normally on the runway. Contrary to all expectations, the aircraft started a manoeuvre which, in the beginning, resembled an overshoot. This changed almost immediately into "an abnormal sequence of evolutions", characterized by left-hand banks and sharp left turns.

The investigation was limited to a technical failure which showed up clearly between the end of communications with approach control and the beginning of the overshoot. This covered a period of 1 min 30 sec during which the flight recorder registered a rapid decrease in speed and altitude, which could only be explained if the crew took the actions stated above over a one minute period.

As the evolutions observed thereafter showed clearly that it was not possible to control the attitude of the aircraft, the Commission looked for the causes of the accident in a failure or combination of technical failures and tried to establish a

correlation between the appearance of this or these failures with one of the manoeuvres made by the crew during the minute preceding these evolutions.

The engine thrust produces a certain effect on the aircraft's attitude, determines the speed and is, therefore, closely related to the use of the flying controls. Therefore, the possibilities and conditions of operation of the engines immediately prior to the accident were examined.

Stripping of the engines showed no abnormal conditions, and all four of them were running at impact but probably at reduced thrust. The reverser shells were in the normal in-flight condition, which excludes the possibility of untimely reversing of one or more of the engines. The reverse thrust controls were in the forward position. All four engines were idling and each was developing from 1 000 to 1 500 lb of thrust. It was concluded that the engines did not prevent controlling the aircraft's attitude, and the examination of possible causes of the accident was therefore limited to a flight controls failure.

Rudder, Elevator and Horizontal Stabilizer

The possibility of rudder, elevator or elevator control being causal factors in the accident due to failure or jamming was carefully examined and rejected as highly improbable.

The horizontal stabilizer was then considered. It was in a 10 unit nose up position. In the landing configuration and at the reference speed (V ref = 1.3Vs, Vs = stall speed) the position of the stabilizer should have been 5.9 units nose up with the engines at take-off thrust.

The position of the horizontal stabilizer increasing linearly with the lift coefficient should reach approximately 8 units nose up at 105 kt in level flight and landing configuration (lift coefficient at Vs = 1.7 times the lift coefficient at 1.3 Vs).

It was, therefore, concluded that the stabilizer's position was abnormal for the approach.

If the protective coverings of the spoiler by-pass switches were lifted before the crash, it indicates that the pilot wished to by-pass one of the two spoiler systems either to eliminate a defective spoiler system or to obtain a nose down pitch movement in order to compensate for the exaggerated nose up stabilizer position.

The stabilizer position can only be explained if:

1) one of the control systems of the stabilizer ran away;

2) there was an untimely slipping of the horizontal stabilizer due to unbalanced aerodynamic loads upon it; or

3) failure of one of the other flight controls required increased action of the stabilizer.

Assumptions - 1st hypothesis

"The position was the consequence of a failure in the control system of the stabilizer."

The stabilizer can be controlled by the autopilot, by the mach trim system and by the electric motor of the manual system.

The autopilot was disconnected on impact. The servo motor was recovered completely destroyed but the mach trim may be eliminated as the switch inside the KIFIS was intact and in the open position. (It is normally open below 0.83 Mach.) A short circuit or a faulty toggle switch might have caused a continuous displacement of the stabilizer.

This is, however, anticipated in the emergency procedures, by operating the cut-out switch on the pedestal to cut off the

electrical supply to the motor and the clutches. The switch and the relay were recovered damaged, but nothing indicated that they did not function correctly before impact. Furthermore, the Commission considered it difficult to believe that during the 8 to 10 seconds that the runaway would have lasted, the pilots did not have an opportunity to operate the cut-out switch.

2nd hypothesis

"The position was the consequence of a slipping stabilizer."

The uncontrolled slipping of the horizontal stabilizer under the influence of unbalanced aerodynamic loads is prevented by two friction brakes. Tests were made on these. The tests showed that in certain conditions, which may be encountered in normal operations, one of these brakes slips at high speed and is, therefore, inefficient, whereas the other brake slips but at a slow rate. Therefore, some doubt as to the efficiency under all circumstances of the braking device remains. This would be a possible explanation of the accident. Once the stabilizer is out of trim, the aerodynamic loads which act upon it have an unfavourable influence which increases with the slipping.

The Commission felt, however, that it was difficult to admit this explanation because it would then have been necessary for -

1) the two brakes to become inoperative;

2) the slipping of the primary brake to be rapid, when the tests under conditions of severe contamination produced only a slow creep.

Finally, a rapid slipping due to aerodynamic loads would most probably have brought the screw nut in contact with the mechanical stop, whilst in actual fact, it was found one to two turns away from this stop. It was admitted that the crew could have partly returned the stabilizer, but no certain indication whatsoever of the use of the manual trim could be found.

3rd hypothesis

"The position was necessary to compensate for the failure of one of the other flight controls."

The efficiency of the elevator decreases during turns. The pitching component of the angular rotation speed causes a relative air flow which tends to create a nose down movement. This is due to the distance existing between the stabilizer and the centre of gravity.

Under these conditions the nose up tendency of the stabilizer must be increased. A 10 unit nose up position could be necessary to trim the aircraft for a coordinated turn at speeds between 120 and 155 kt (40° to 60° bank, flaps down).

The requirement is less in the flaps up configuration (the maximum lift coefficient is reduced). It should not be more than 7 units for a turn at 60° of bank and at the buffet speed. The effect of the elevator being equal to 5.5 units of trim, it follows that, in the final configuration, the equilibrium of the aircraft was only possible within tight limits of speed and bank angle.

No figures are available for speed lower than the buffet speed but if a linear variation of the coefficient of aerodynamic pitching moment as a function of the lift coefficient is admitted, then a setting in the order of 10 units nose up is found.

The Commission concluded that the probable cause of the accident could hardly be attributed to a malfunctioning of the stabilizer as it could have been used for a steep turn close to stalling speed.

Lateral controls

Inboard ailerons

In normal flight, i.e. flaps retracted, the outboard ailerons are inoperative, and only the inboard ailerons are used.

Numerous cases of in-flight jamming of the inboard ailerons were found in the trouble reports. Wreckage examination disclosed that the inboard ailerons were deflected in such a direction as to produce a right bank. However, it was not possible to determine whether the position was such before impact or had been caused by it.

The aileron trim cartridge showed a point where jamming had occurred. This jamming was due to corrosion combined with insufficient clearance.

The cartridge corrosion deposit analysis conducted by Boeing indicated that the corrosion was due to the effects of the fire which followed the crash.

This point was so located as to permit a full displacement of the control for a left bank but only allowed a very limited displacement past neutral for a right bank. Assuming that the pilot decided to overshoot and started a turn to the left, the Commission found it difficult to understand why he did not maintain the wings level by using later on whatever remained of lateral control and with the help of the rudder. Moreover, there are shear rivets on the connecting rod between the jammed aileron trim cartridge and the aileron tab control mechanism. Once these rivets are sheared, the aileron control is free. The theoretical shear force to be applied on the control wheel is 105 lb. A test made on the recovered part produced a shear force of 152 lb. Notwithstanding the 50% increase over the theoretical force, such a force could have been applied, especially by two pilots. These rivets were actually intact.

The Commission, therefore, concluded that this point of jamming in the aileron trim cartridge could not explain the accident.

Outboard ailerons

If the outboard ailerons are jammed in a position near neutral but not exactly neutral, the extension of the flaps will create a temporary displacement of the control wheel; displacement which could be unnoticed by the pilot or to which he may attach no importance. The entire aileron system, both inboard and outboard, will be jammed if flaps are lowered partially or fully under those conditions.

The kinematics of the system are such that, if the pilot then decides to raise the flaps, the inboard ailerons will be carried along in an opposite movement of an amplitude corresponding to several times the amount of offset from neutral of the outboard ailerons. This operation could set up large internal stresses within the control system, stresses which could cause permanent distortion or breaking of some of the control elements.

However, the inboard ailerons can be freed if there is no permanent distortion during this manoeuvre and if the flaps are fully retracted.

Due to the construction of the linking mechanism between the outboard and inboard ailerons and the flaps, several possibilities of bringing the inboard ailerons to full deflection exist if the outboard ailerons were jammed before or after flap extension. This could have been a possible explanation of the accident, however,

1) as far as is known by the Commission, no case of jamming of the outboard ailerons has ever been reported;

2) there was nothing in the examination of the debris to support this hypothesis;

3) the inboard ailerons were in a position for a right bank which, due to the presence of the snubbers, can hardly be attributed to impact forces.

Spoilers

Examination of the spoilers and their control mechanism showed that the shear rivets on the follow-up mechanism between

the spoilers and the hydraulic valves were sheared on all four pairs of spoilers. Also, the hydraulic by-pass valve of the left-hand outboard spoilers was deficient; it remained locked in the 'open' position.

If the rivets on certain spoilers were sheared before impact, this means that if these spoilers were used they could have gone to the fully extended position. Furthermore, if the lateral controls were then moved, the spoilers could either remain fully extended or could retract depending upon the friction existing in the system.

As the friction between the axis and the differential of the sheared follow-up mechanism is modified during the relative displacement of the two parts, a progressive loss of alignment of the follow-up mechanism of the corresponding hydraulic valve can ensue, bringing differences in the extension of the corresponding spoilers.

However, in the most unfavourable case they will retract for a rotation of the control wheel exceeding 17° to 20° in the opposite direction.

A pair of outside spoilers completely extended causes a torque which will result in a roll rate of 13°/sec at 150 kt.

To counterbalance this torque a displacement of the control wheel far superior to 20° in the opposite direction is necessary. When the amount of control wheel exceeds this value, the spoilers will retract and the control wheel movement will produce a roll rate in the opposite direction of approximately 4°/sec with flaps up and spoilers extended and of the order of 2°/sec with flaps up and no spoilers.

The spoilers can normally be put out of action by activating the corresponding spoiler by-pass valve switches.

The spoilers cannot be put out of action if the corresponding by-pass valve remains jammed in the open position. As the left-hand outboard spoilers' by-pass valve was deficient, it follows that, if the shear rivets on the follow-up mechanism were sheared on these same spoilers, the pilot could not overcome the defect in the lateral control system by the action foreseen. The only possible solution in this case would be to cut out the hydraulic utility system.

The Commission expressed the opinion that such critical flight conditions would quickly lead to an accident.

Interpretation of the investigation results

Examination of the wreckage showed that the positions of the control surfaces at impact were:

- stabilizer: up to 10.5 units nose up
- elevator: up
- rudder: 20° right
- ailerons: inboard - set for a right turn; outboard - probably neutral
- spoilers: left-hand outboard - undetermined; left-hand inboard - probably retracted; right-hand inboard - extended (40°); right-hand outboard - position undetermined
- flaps: up

Analysis of these observations showed that the pilot must have had normal use of the elevator, rudder and aileron controls. It was established that the aircraft, during its abnormal manoeuvres made only left-hand turns with variable bank up to 60°. Without being able to confirm that the positions in which the various controls were found corresponded necessarily to their position in flight, they all indicated an attempt to turn or bank to the right. At the same time, the elevator was pointing upwards when the stabilizer was already 10 - 10.5 units nose up.

It was concluded that an important abnormality, in spite of the use of the

flying controls and engines, forced the aircraft to the left and prevented the pilot from re-establishing level flight and manoeuvring with a view to landing.

Consequently, in order to establish a sequence of events compatible with the facts, all factors which could influence the lateral stability were examined. As no evidence of engine failure was found, attention was drawn to the fact that all shear rivets on the entire follow-up system were sheared and that during tests the left-hand outboard spoiler valve remained jammed in the 'open' position several times.

Observations made as to the position of the safety covers of the switches operating the spoiler by-pass valves led to the assumption that the pilot had envisaged their use in connexion with the lateral control difficulties he encountered.

The use of these switches is only justified in two instances:

1) abnormal functioning of the stabilizer;

2) abnormal functioning of the spoilers.

As malfunctioning of the stabilizer was eliminated, the Commission assumed that the pilot wanted to correct a spoiler malfunction. This assumption is supported by the fact that at that time other cases of shearing of rivets on the spoiler follow-up system were found. Shearing of these rivets results in abnormal and erratic behaviour of the spoilers. While it has been proved that a spoiler, following its separation from its follow-up system, may go to the fully extended (60°) position even for a relatively small aileron control wheel movement (3 to 5°) it has also been proved:

1) that it is necessary, in case of the most unfavourable displacement of the spoiler control valve, to apply 17 to 20° of wheel in the opposite direction to retract the spoiler completely;

2) that it is impossible for the pilot to bring back all lateral control surfaces to neutral simultaneously and that, therefore, he is confronted with a lateral control system modified in such a way that it is no longer possible to find a position of the controls where the roll torque can be cancelled.

Having admitted the foregoing, and if the pilot arrived at the conclusion that his difficulties came from the spoiler system, the fact of by-passing them could only aggravate the situation in the present case, as the left-hand outboard by-pass valve was not functioning.

The pilot would then be in a situation where the aircraft had lost all lateral stability. The use of rudder to remedy such a situation would result in a violent dutch roll, difficult to stop because of the abnormal functioning of the lateral controls and also because of the tendency of the nose to drop. In addition to this the possibility of a displaced neutral position of the rudder, which could have occurred precisely at this phase, would thereby have created a further difficulty for the pilot.

Considering the foregoing, the Commission tried to reconstruct the sequence of events which led to the accident.

The flight recorder indicated that the approach appeared normal until 0900:30 hours. At that time the trace showed a rapid variation of 15° to the left immediately followed by an equal variation to the right. Unfortunately, the trace stopped immediately after 0901 hours.

These variations in reading may coincide with the beginning of the difficulties of OO-SJB, which were such as to prevent the co-pilot from establishing communications for which he normally is responsible. This would explain the aircraft's silence on frequency 118.6 Mc/s.

At 0901 hours, as the aircraft was not aligned with the runway, the pilot started his overshoot.

If it is admitted that the cause of the trouble was the shearing of the rivets in the follow-up system of the left-hand outboard spoilers, the difficulties could then only increase.

Confronted by a lateral control problem the pilot had only one possibility, that was to by-pass the spoilers. The use of the by-pass switches seems confirmed by the position of their covers as found in the wreckage. Whatever they were used for, the situation became worse as the left-hand outboard spoiler was not working properly.

Under certain conditions, this would result in severe lateral instability. If this was the situation in OO-SJB it is most probable that it led to the final loss of the aircraft.

The Commission admitted that the above account, while very plausible and based on certain material elements and observations, had not a character of certainty. It felt, however, that it could not be excluded.

The Commission had no indication as to when the flaps were retracted or the reasons which led the pilot to retract them completely. It noted that although the flaps and landing gear were found in the retracted position, that fact was not connected in any way with the accident sequence as here presented. The lateral instability of the aircraft with the modulated extension of the spoilers is always a fact no matter what the configuration may be.

Supposing an erratic functioning of the spoilers, the Commission considered:

1) What actions could the pilot have taken to correct it?

The only possibility was to suppress the hydraulic pressure activating the spoilers. In order to accomplish this, the pressure in the utility system could have been dropped by activating the pressure control switches of the hydraulic pumps.

2) Why did the crew not take this action?

The Commission was of the opinion that, if the sequence of events as explained previously was admitted, it was impossible in the time available, and under the circumstances in which the crew found itself, to identify with certainty the failures with which it was confronted. Moreover, the identification of such failure is complicated by the fact that it is nearly impossible to observe the spoilers from the cockpit.

Probable Cause

Having carried out all possible reasonable investigations, the Commission concluded that the cause of the accident had to be looked for in the material failure of the flying controls.

However, while it was possible to advance certain hypotheses regarding the possible causes, they could not be considered as entirely satisfactory. Only the material failure of two systems could lead to a complete explanation, but left the way open to an arbitrary choice because there was not sufficient evidence to corroborate it.

Recommendations

With regard to modifications that the Commission could recommend, it noted that the following Service Bulletins sent out by Boeing and by Sabena cover the suggestions that could have been made:

No. 1117 Spoiler follow-up crank shear joint modification (18 January 1961)

No. 1336 Outboard spoiler shut off valve consolidation (18 September 1961)

No. 1344 Inboard aileron centring spring cartridge modification (27 July 1961)

No. 1410 Control wheel stabilizer trim switch replacement (5 September 1961)

No. 1484 Hydraulic system solenoid valve replacement spoiler system (15 December 1961)

No. 1635 Stabilizer trim electrical limit revision (15 June 1962)

No. 1680 Rudder control centring spring cable guard installation (25 May 1962)

No. 114 Sabena Bulletin - Installation of a supplementary brake for stabilizer trim actuator (7 May 1962)

Moreover, the introduction of a spoilers' position indicator would facilitate the detection of any abnormality in their operation and would permit adequate corrective action to be taken.

Comments of the State of Manufacture (United States of America)

The Administrator of the FAA (Federal Aviation Agency) has sent the following comments to the Director General of Civil Aviation, Belgium.

"Several possible causal factors for this accident are mentioned in the report."

"With respect to the spoiler malfunction hypothesis, we cannot agree that such a malfunction as described in the report would have been responsible for the flight path described by witnesses. Flight test data in our file indicate that the Boeing 707 aircraft is readily controllable with an outboard spoiler blocked in the fully open (60 degrees) position and the flaps positioned to 30 degrees or to zero degrees."

"Of the several hypotheses evolving from findings in the accident report, we believe the most plausible to be that concerned with a malfunction of the stabilizer adjusting mechanism permitting the stabilizer to run to the 10.5-degree aircraft nose up position. If such a malfunction occurred and the split flaps and spoilers procedure (inboard spoilers and outboard flaps extended) not employed, the only means to prevent the aircraft from pitching up into a stall would be to apply full forward column and enter a turn in either direction."

"It is apparent from the recorded impact positions of the controls that the split flaps and spoilers technique was not used. The wing flaps were found in the up position and had the inboard spoilers been extended both would have been up at impact and the speed brake handle would not have been in the neutral position as found."

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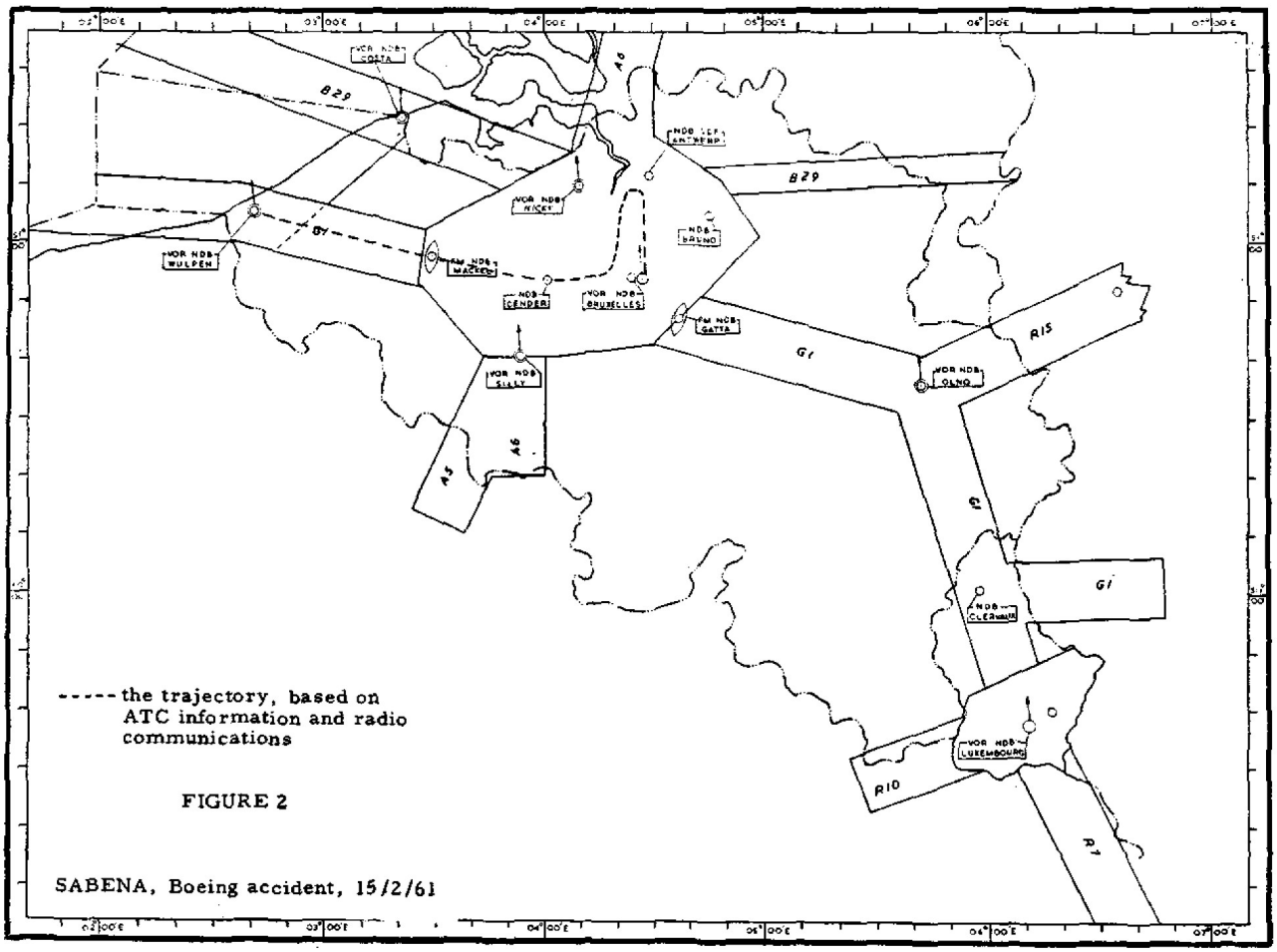

----- the trajectory, based on ATC information and radio communications

FIGURE 2

SABENA, Boeing accident, 15/2/61

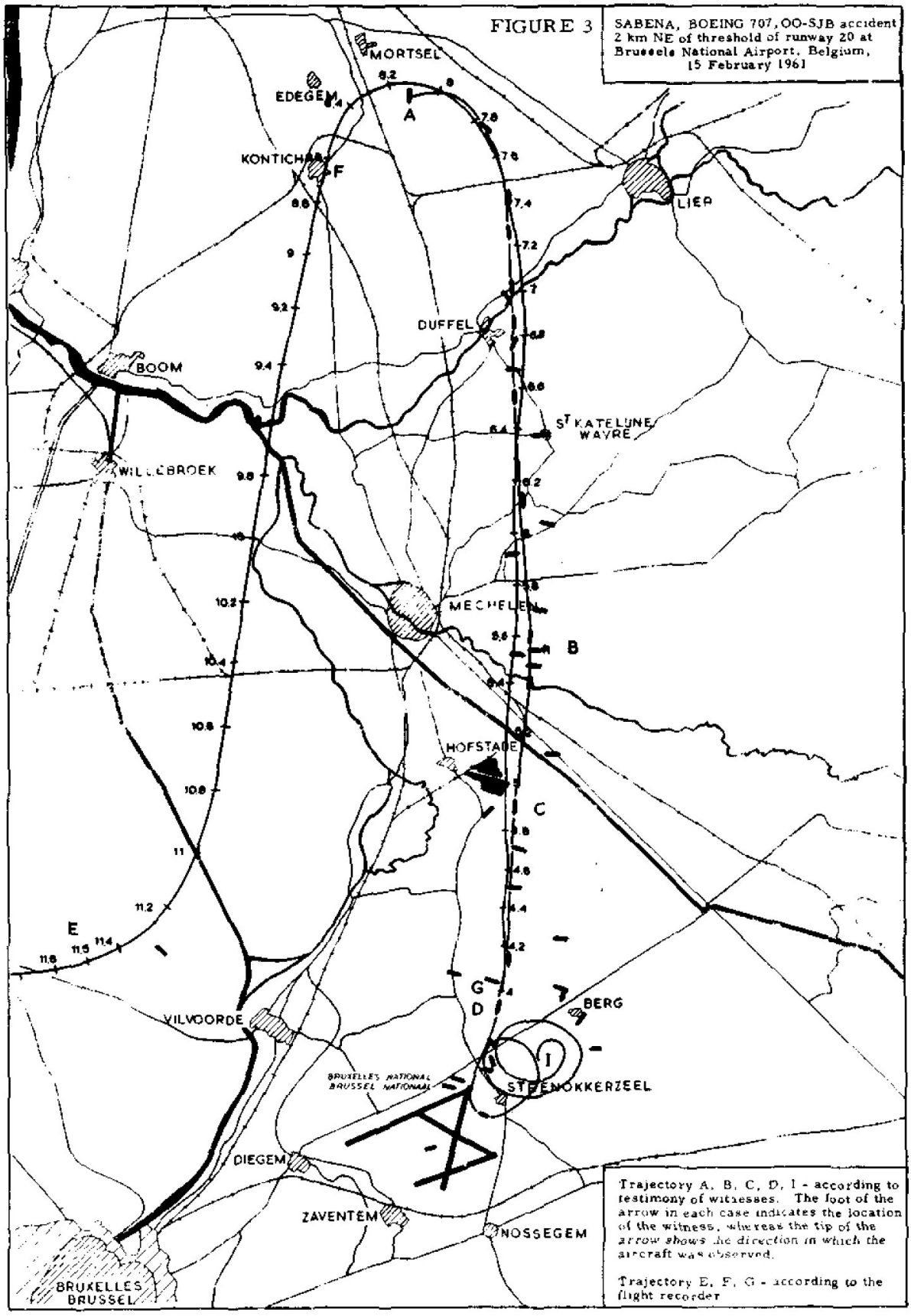
FIGURE 3
SABENA, BOEING 707, OO-SJB accident 2 km NE of threshold of runway 20 at Bruessels National Airport, Belgium, 15 February 1961
MORTSEL
EDEGEM
KONTICH
LIER
DUFFEL
BOOM
ST KATELINE WAVRE
WILLEBROEK
MECHELEN
HOFSTADE
BERG
VILVOORDE
BRUXELLES NATIONAL
BRUSSEL NATIONAAL
STEENOKKERZEEL
DIEGEM
ZAVENTEM
NOSSEGEM
BRUXELLES
BRUSSEL
A
B
C
D
E
F
G
I
Trajectory A, B, C, D, I - according to testimony of witnesses. The foot of the arrow in each case indicates the location of the witness, whereas the tip of the arrow shows the direction in which the aircraft was observed.
Trajectory E, F, G - according to the flight recorder