

Accident to Itavia DC-9 near Ustica, 27 June 1980

Wreckage and Impact Information & Analysis

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Background to paper

On 27 June 1980 the DC9 aircraft I-TIGI owned by ITAVIA crashed into The Tyrrhenian Sea near the island of Ustica at approximately 1900 hrs GMT while flying from Bologna to Palermo, most of the wreckage sinking to a depth of some 3500 metres. Floating debris and some bodies were recovered during the following few days. Quite soon there were suggestions that the DC9 had been shot down by a missile and this view has been held firmly by many people ever since.

Newspaper reports in the USA and the UK as well as in Italy have regularly implicated the Italian Air Force, the US Navy, the Libyans, the Israelis, the Russians, just about everybody. There have been several TV programmes, at least one film and some books, most, it is believed 'proving' a missile theory (but not the same one!). There has been a fair amount of misinformation circulated and accusations of 'cover-up'. In Italy 'Ustica' is a cause célèbre and has been so since 1980.

Since the evidence available during the first few years after the accident was not conclusive various commissions failed to agree and in 1990, despite the recovery of a fair amount of wreckage from the sea bed during 1987-1988, the 'Blasi Commission' split and was unable to decide whether the 'cause' was a missile or an internal explosion. As a result a further Technical Commission, under the Tribunale di Roma was established in September 1990, this for the first time being 'international' with two from the UK including the author, two from Sweden and one from Germany joining five from Italy. A second German with specialist knowledge of missiles was added in 1993. As is apparently usual with Italian investigations the majority of the members had relatively little prior experience of accident investigation although all were 'experts' in their own field.

One of this Commission's first decisions was to call for the recovery of more wreckage. Using the trajectory program described in the 1989 ISASI Seminar the likely position of the wreckage was predicted and, after a number of problems, much of it was located, recovered, identified and reassembled. Note that the DC9 was flying almost due south at about 24,000 feet and there was a strong westerly wind at high altitude veering to a north-westerly at sea level.

In July 1992 the author was asked to submit a report on the aircraft wreckage recovered. The initial version of this was submitted in September 1992 since when it was progressively up-dated. This ISASI paper is based closely on that submitted to the Tribunale in June 1994 and although the views expressed are the author's own they were almost totally supported by the majority of the Commission members (not by all the other parties), thus most of the following may be found in the Commission's report handed to Judge Priore on 23 July 1994. However due to the 'legal' nature of the investigation and the need to answer the points made by the representatives of the various parties involved in the legal proceedings, the Commission's 1280 page report does not conform to the ICAO format, thus the author's contribution has been somewhat fragmented and,

since certain deductions and the conclusions presented here could not be proved, toned down. In fact this fragmentation and consequent lack of a clearly logical and sequential report has perhaps been instrumental to the report not being fully accepted by all parties, thus near the end of 1994 the matter is still not closed.

It is acknowledged that major contributions to the thinking behind this paper were made by two members of the Commission in particular and by others associated with the investigation. In addition the work by the 'radar group' in relating radar returns to the trajectories of falling debris is thought to be totally original, it is hoped that this work will be described in a paper to the 1995 ISASI Seminar.

The Commission's report describes and comments upon a great variety of evidence relevant to the wreckage in addition to that following in this paper, most notable being small fragments with signs of 'rolled edges' and 'hot gas wash' and some minute traces of explosive. These are not dealt with here since it is felt that the main wreckage stands on its own and tells its own story. Furthermore, in a climate seemingly full of intrigue, the main wreckage alone remains totally above suspicion in that it could not have been tampered with.

An important point to bear in mind is that both the FDR and the CVR stopped abruptly during normal flight as a result of electrical power failure, no really useful information was forthcoming from either except of course the most important fact that power failure did occur as part of the initial event and with no prior warning.

Each piece of wreckage was allocated three reference numbers, related to its discovery, recovery and position (whether identified or not). The latter two numbers appear throughout the text without in this case the full list of pieces or the relevant diagrams, these numbers have been left in so that reference may be made to the Commission's full report when it becomes more readily available. Thus E77/AZ461 was the 77th piece recovered from Zone E and the 461st examined by Alitalia engineers to ascertain its position on the aircraft.

Fuselage station numbers are expressed in inches from the nose and the stringer numbers start at 1 along the top with 18 being at floor level.

Introduction

Reference will be made to the wreckage trail and to where pieces of wreckage were found. An important point is that study of the wreckage itself provides a great deal of information regarding the sequence of break-up. Totally independent of this, the position within the wreckage trail also provides information regarding the sequence of break-up. Looked at together the two methods provide very powerful evidence. A further independent source is provided by the break down of the electrical supply, this and other features must all be consistent with the chosen hypothesis, however to prevent this paper from being even longer not all supporting evidence is discussed.

Factual Information

Wreckage and Impact Information

The wreckage of the DC9 was found to be distributed along an essentially west to east trail approximately 1.5km wide and at least 16km long. Due to pressure of time the eastward search

and recovery was stopped just over 16km downwind of what was subsequently determined to be the initial point of break-up. For the purposes of search and recovery this trail was divided into a number of zones. Not all the wreckage has been recovered and that to the far east, beyond Zone E, has not been searched for. This section considers the main groups of wreckage starting from that at the western end of the trail, Zone B, through Zones C, A, F and E.

The engines

Both engines, their cowlings, associated components, forward mountings and much of their pylons were found in two areas close to each other, in Zone B, but separate from all other parts. Debris was spread into roughly south to north bands with lighter pieces in general being further north. The two engines suffered similar, almost identical, damage. Each has considerable crushing damage to cowlings, and to roughly a third of turbine, fan and compressor blades approximately opposite the pylon. The remaining two thirds of the blades, opposed to these, are intact with no damage of a rotational nature.

The port engine cowlings have no other significant damage.

The starboard engine cowlings have a variety of dents, cuts, holes, scratches and paint marks on the left side, that is on the parts adjacent to the fuselage side. These are centred on about station 810. Approximately in line with piece AZ567 (F88), a section of frame and floor beam attachment at station 801, there is quite severe damage to the lower cowling. Although the majority of the holes have metal bent or petalled into the cowling there are also a few in the reverse sense. The majority of the dents, holes and scratches are below the pylon. Above the pylon there are several dents and a considerable number of red deposits (assumed to be red paint from the fuselage skin). Much of the red deposit is in the recessed 'grooves' of the damage, not only on the 'peaks'.

The intake of the port engine is dented and has red and white deposits over a considerable area. The red colouring has been found to be identical to the red paint used on the DC9 fuselage side. The starboard engine intake has no such deposit.

The engines were stripped and some material was found inside.

Damage to and within the starboard engine pylon is described under 'upper rear fuselage' and 'rear toilet area'.

The wings

The wings, apart from the outer 5.2m of the port wing, were found in an area to the north east of the engines in Zone C but again with debris mostly in a south to north band. The port outer wing, AZ683 (F83), was found over 3km further downwind in Zone F.

The port wing

The inboard half of the port wing is in one piece and virtually undamaged, the outer half, has broken into a few large sections. The outboard tip upper skin is pressed downwards over the internal structure. The fracture line with the inner part shows a tensile failure at the top skin and a compression bending failure at the bottom skin.

The leading edge root region is crushed back and a length of fuselage skin attached to the wing top surface is bent outboard.

Near the inboard end of the main flap the trailing edge is crushed but with no adjacent scratching or scoring.

The starboard wing

The starboard wing is extensively broken up into spanwise planks. The skin aft of the front spar is rolled downward along the whole length of the wing. The leading edge skin has been crushed but has no other damage.

The centre wing section

The wing centre section is extensively broken although little of the bottom skin has been identified. The top skin is broken into spanwise planks and the ribs, running fore and aft, are buckled. Behind this centre wing box, which also forms the centre fuel tank, the main undercarriage is retracted. All four wheels and tyres are intact.

Wing trailing edge flaps

A detailed examination of the flaps, including by X-ray, has been made. Nothing of significance was found.

The fuselage

The forward fuselage, centre section and rear fuselage below the cabin floor were also found in Zone C intermingled with the wing pieces. The extreme rear of the fuselage, with the fin and much of the tail plane (horizontal stabiliser) attached and the elevators were found in Zone A approximately 2.5 kilometres to the east of the forward fuselage. The rudder has not been found. The remainder of the fuselage, that is the upper part of the rear fuselage aft of station 642 together with rear pressure bulkhead parts, was found in Zones F and E, the long west to east band downwind of Zone A. The various parts of the fuselage will be described separately.

The forward fuselage and cockpit

The whole fuselage ahead of the wings is crushed, buckled and fragmented. The upper part of the cockpit windscreen frames are bent inwards. The predominant feature of the starboard side of the fuselage is severe longitudinal buckling with fracture into small pieces. The port side although also showing severe buckling has broken into very much larger pieces.

Centre fuselage

The degree of buckling and fragmentation decreases rapidly from front to rear of the centre section with the rearmost skin panels and frames being almost undistorted.

The rearmost skin panel on the port side, AZ435, from station 630 to 660 at stringer 6, is scratched laterally adjacent to some 22 rivet holes to a distance of from 80 to 30 millimetres. A few of these scratches then continue rearwards at an angle of approximately 30° to the aircraft centre line, to the rear edge of the panel at station 660.

Close to this on the same panel, is an area of skin displaying 'quilting', that is localised bulging of the skin between frames and stringers, just above the window belt on the port side. Slight upwards curvature of the skins is also evident in this area and there is slight kinking of the skins in this same area at the points where the stringers are attached to the frames.

Lower rear fuselage and rear cargo bay

This section is on the whole only slightly damaged except for considerable distortion just forward of the rear pressure bulkhead. At the rear the APU was detached and found with its casing crushed against its more solid core. The CVR is believed to have become detached from its mounting and to have been found some distance away within Zone C. The cargo bay door had been partly pushed inside its frame and its outer skin rolled down from the top, forward corner. Both the door and its frame are bent longitudinally approximately half way down, the frame being bent slightly more than the door. There are scratches across the door and across the nearby skin to the rear, however these are not continuous and are at different angles to the horizontal. A section of floor beam at station 817 beneath the toilet, is crushed and buckled and also bent downwards with respect to the fuselage frame, which itself shows evidence of downwards movement with respect to the central portion. The end 60cm of the floor beam under the toilet at station 801 is missing, the adjacent 30cm is twisted down to the rear and the port section is bent upwards just outboard of the port supporting strut .

Rear pressure bulkhead

The rear pressure bulkhead, found in Zone F, is complete above floor level except for the part to the rear of the toilet. The part found is attached to a large section of fuselage skin and to the rear part of the port engine pylon fairing. The parts on the starboard side of the ventral door, found at various distances downwind in Zones E and F, all bulge away from the toilet, the lower parts bearing the imprint of the rear and side of the ventral door. Only the lower part of the door itself has been found also in Zone F remote from the adjacent parts, this has diagonal buckle creases across one forward facing panel. The frame to the ventral door is torn down at the top starboard side and there is buckling of the supporting structure on the lower port side. All stiffeners are present on the port side while on the starboard that immediately above the missing skin is itself missing and the one above the door frame is bent upwards but with no apparent point of contact.

Tail section including fin, tail planes and extreme aft fuselage

This section was in one piece except for the outer half of the left tail plane and the whole of the port tail plane leading edge section which had separated and broken into several pieces. All pieces were found in Zone A.

Fin

The 'D' box at the leading edge of the fin is fractured along the 'L' section fitting which attaches the leading edge skins to the front spar and the complete 'D' section has been pushed over to starboard, exposing the spar. A large buckle in the torsion box starboard skin extends diagonally from the rear spar at the bottom to the front spar at the top.

Lighter damage in the form of denting and bruising is evident on the leading edge, extending from the root right to the top, just below the junction with the tail planes. A small area of red

smearing is visible on the port side of the leading edge near the base of the fin. Lighter coloured smearing is also present on the leading edge.

There is no damage to the rear of the fin but the rudder mountings are broken and bent.

Left tail plane

The leading edge is quite severely dented particularly at about mid span. Some red deposits are also present.

Right tail plane

This has not been examined closely but does not appear to carry any significant evidence.

Extreme rear fuselage

Only a very small section of the fuselage is attached to the base of the fin . The skins on the starboard side are intact and essentially undamaged but with considerable scratching beside the fin root. The skins on the port side are torn off exposing the frames and stringers and leaving a narrow strip of skin alongside the base of the fin. The free edge of this strip has the shape of a slightly undulating wave.

The fuselage frame on the port side is bent rearwards. The FDR rack is in place and undamaged, the FDR was found to the eastern side of Zone C, with the forward (as mounted) of the larger faces moulded into and over its internal structure.

Upper rear fuselage

A considerable portion of the skin above the window belt has not been found, however the parts that have been recovered are unbuckled, largely undamaged and larger than those from further forward.

The starboard window belt, AZ461 (E77), with parts of the frames and stringers and six windows (5 complete with transparencies), the rearmost part of which fits behind the starboard engine inlet, has no damage in that area but has smears at its front end at station 642, smears that do not continue across the adjacent skin of the centre section. A certain amount of 'quilting' is present below the window belt. The section of skin behind and below the engine has not been found.

The port window belt is in two pieces, the front four windows, AZ529 (F46), and the rearmost two, AZ522 (F13). There is a mark under the third and fourth windows and curving up and across the fifth window. This is continuous across the break between the fourth and fifth windows which are just ahead of the engine intake. There is also a diagonal fold across the top rear corner of the fourth and sixth windows. The front lower corner of the forward piece has a slightly depressed area with diagonal scraping marks across it.

Generally the edges of the pieces of skin display a lop-sided, wavy failure line between the rivets but the forward 2m or so of the port window belt top edge displays a straight even failure line between the rivets.

The frame AZ528 (F9), at station 786 on the starboard side, adjacent to the forward engine mount and forward wall of the rear toilet, is bent outwards and forwards. The frame AZ506 (E120), at station 801 is only a little distorted above the pylon with a considerable number of rivets remaining, all quite straight and with the heads missing, higher up it is bent forward. The frame AZ496 (E118) at station 817 is twisted rearwards.

The skin AZ418 (E51), at and immediately behind the rear pressure bulkhead is bent violently upwards and backwards on the starboard side. The damage, i.e. distortion to skins, frames, floor beam etc. in the region of the rear toilet is consistently curved or bent **away** from the toilet itself.

This and other pieces of skin and/or frames and stringers are generally unbuckled and only slightly distorted, with no indication of fatigue at the fracture edges. Many fractures have been examined in detail. Many of the stringers forward of the rear pressure bulkhead are bent or broken some 20-30cm forward of the bulkhead. The hot air ducts connected to those in the starboard pylon, and positioned immediately behind the missing portion of bulkhead, are caved in on the forward face and undistorted to the rear.

Internal cabin material

Cabin material, principally seat cushions and similar low density items, and bodies, were found floating in an area roughly 30km to the east and 30km to the south of where the main fuselage and engines were subsequently found. The position of each item was recorded but because of the various boats involved these positions could not be verified with any certainty.

Many pieces of cabin trim and unbent window internal frames were found in Zones E and F but their exact position in the aircraft has not been established. The two triangular shaped support pieces, AZ532 (F21) and AZ533 (F47) from the roof of the cabin ahead of the rear pressure bulkhead, show severe distortion to the starboard piece above the toilet wall but little damage to the port piece.

Rear toilet area

Parts of the rear toilet, on the starboard side between stations 786 and 817, have been recovered from Zones E and F. The toilet seat and cover, assumed to be from the aircraft, appear undamaged apart from splitting at the edges but other parts show considerable damage and distortion. The cleaning spray pipe, AZ453 (E12), from within the toilet waste tank is partly missing and partly flattened. The 90cm within the forward part of the tank is relatively undamaged, the 68cm long portion to the rear, closest to the fuselage skin and rear pressure bulkhead is missing and the remaining 38cm, the rear part closest to the washbasin, is almost totally flattened. The hand wash basin, AZ558 (F30) is pressed from stainless steel. Its edges although severely buckled are still shiny, the forward folded edge has been almost totally straightened before being buckled, the centre bowl is severely buckled, torn and badly corroded. The waste pipe, with its approximately 300° loop, and other fittings have not been found. Other stainless steel fittings are also buckled and corroded. The recessed box, for tissues, AZ511 (E183), in the outer wall is almost completely flattened.

The hinge AZ537 (F2), to the toilet door has been opened out through 180 degrees along the door's full height prior to being bent in several places. The lower part of the bottom half of the door jamb AZ639 (E147), is deformed inwards relative to the toilet, it also shows signs of relative movement between it and its restraining screws. The top half has not been found.

Very little of the outer wall of the toilet has been recovered, those pieces that were found, in Zone E, were about the size of a hand, that is very much smaller than most other pieces of skin. The exact position of the piece of aluminium alloy skin, AZ644 (E180), found at the northern edge of the wreckage trail has not been established. One of the similarly damaged pieces of titanium skin, AZ498 (E121), has on it the imprint of two fasteners from the lower panel of the engine pylon and is curved so as to fit around a hot air duct within the pylon. The hot air duct itself is partially flattened and bears the imprint of a second duct that runs parallel to it within the pylon but closer to the engine. The damaged ducts connecting to these which run behind the rear pressure bulkhead have already been described.

There is one hole in the lower skin of the pylon which appears to be from outside in. Within the pylon there is a second titanium sheet acting as a further fire wall to protect the fuselage from an engine fire. On the port side this is intact, as is most of the pylon and its contents, on the starboard side most of this is missing. One piece, AZ499 (E142) again roughly the size of a hand, is curved so as to fit around the hot air duct first mentioned above. The piece of internal fire wall that lay between the fuselage skin AZ 498 (E121) and the duct has not been found.

Still attached to the starboard main pylon structure are other parts of this titanium fire wall with several dents and holes. These are again in the vicinity of station 817, close to the rear pressure bulkhead. The outer wall of the pylon, closest to the engine is partly missing but the area just aft of station 786 is bent forwards and outwards, that remaining in the centre at about station 800 is bent straight out, while that to the rear is bent rearwards.

Analysis

Wreckage and Impact Information

The large area of floating wreckage with light pieces such as seat cushions found many kilometres east of the main wreckage clearly indicate a mid-air break-up. Furthermore the curved 'hockey stick' shape of the wreckage trail is entirely consistent with in-flight break-up at a point at or just to the south of the last radar return, taking account of the aircraft height and velocity and the wind velocity and profile. It is also consistent with the radar data showing a drift of debris downwind to the east.

The north to south spread of wreckage across the trail gives a good indication of the sequence of break up with items to the north generally having departed the aircraft before those further south. An analysis of this is to be found later.

The distribution of individual groups of wreckage into the various Zones shows the nature of the initial break up. Thus the four main areas, Zones B, C, A and F & E together were occupied by the engines, the forward fuselage (and lower rear fuselage) and wings, the tail section, and the upper rear fuselage respectively. This distribution can only have occurred as a result of a major break up which caused the engines and tail section to detach and fall separately leaving the entire forward fuselage, wings and aft cargo bay to fall in one piece. The only part of the aircraft fuselage to be distributed downwind is the upper rear fuselage and rear pressure bulkhead area, confirming that this was the only section to fragment extensively in the air.

This pattern is independently confirmed by examination of individual parts.

The engines

All engine debris was found in Zone B, the crushing damage was entirely consistent with each engine unit comprising the engine, its cowlings and the pylon attachment fairing, impacting the sea in a roughly level attitude, slightly front end high with the pylon fairing uppermost.

The dents, scratches, red marks and the majority of the holes on the side of the starboard engine cowlings facing the fuselage are consistent with them being struck by fragments of fuselage skin. The damage at about station 801 on the lower cowling appears to have been caused by a piece of frame from station 801, AZ567 (F88). This piece was close to the northern edge of the trail and thus was one of the first pieces to leave the aircraft. The few holes that appear to have been made from **inside** the cowlings may have been made by pieces passing through the pylon and ricocheting off the more solid engine casing. Some may have been caused by the cowling being pressed against hard objects inside either during the in-flight break-up or on impact with the water.

The impact damage and lack of rotational damage to the rotating assembly show that the engines were probably not even windmilling on impact with the sea.

Having established that the two engines fell free at altitude it may also be concluded that the red and white paint marks on the port engine intake were caused by a section of fuselage window belt moving out and hitting the engine **before** it fell free. The lack of similar damage and marking on the starboard side show that the starboard window belt was still intact when the engine came off. However the red marks on the top cowling and the dents and holes in the bottom cowling show that adjacent skin, the outer wall of the toilet, come off **before** the starboard engine detached.

Thus either the initial event or failure was on the port side, above and ahead of the port engine, or it was on the other side roughly level with the starboard engine. Subsequent sections will show how the extensive internal damage around the rear toilet and the starboard engine pylon confirms that the latter is the case.

The damage to the engine mountings is not inconsistent with the impact with the sea being as described, the weight of the mounting, pylon and possibly a small part of the fuselage skin and inner support, under high 'g', being sufficient to produce the observed fractures.

The finding of debris inside the engine is consistent with water impact, casing damage and subsequent contamination.

The south to north distribution of engine debris, with the denser parts to the south, directly below where impact with the sea occurred, and with progressively less dense pieces further north, shows that there was a very slight water current from the south.

The wings

The port wing

All the damage to the inner part of the port wing appears to have occurred during impact with the sea with the wing essentially complete and intact at the time. Damage near the root suggests that the wing moved upwards and forwards relative to the fuselage during impact with the sea.

However the outer wing section, found to the east, came off in flight due to downward bending. This is consistent with a violent pitch down occurring which suggests a prior failure of the rear fuselage or tail plane.

The trailing edge damage to the rear flap appears to have been caused by contact with an extremely rigid object, probably part of the recovery ship.

The starboard wing

The overall pattern of damage is consistent with the starboard wing having impacted the sea at high speed while pitched down beyond the vertical with the leading edge approximately parallel with the water surface. The wing appears to have been intact and undamaged prior to impact with the sea and in particular the leading edge shows no signs of penetration.

The centre wing section

Damage here is consistent with the above, although it is not clear why no section of the bottom skin has yet been identified.

The fuselage

Forward fuselage

The damage to the nose, cockpit and forward fuselage was undoubtedly produced by impact with the sea. The crushing of the cockpit roof and the more severe damage to the starboard side of the fuselage show this to have been slightly past the vertical and yawed to port. Thus the fuselage damage is entirely consistent with that to the wings and shows that they were still together at the moment of impact with the sea.

Final confirmation that these were together but separate from the engines is given by the debris pattern on the sea bed. The debris of wings and fuselage are intermingled and distributed for the most part along a south to north band, similar to and parallel to, but not intermingled with, the engine debris.

Although there are still some gaps remaining in the reconstruction of the forward fuselage there are no gaps or damage that suggest that any parts were missing on impact with the sea. Furthermore there are still many pieces of fuselage skin, adding up to a considerable area, whose position on the reconstruction has not been established, thus it is certain that many gaps could eventually be filled.

Centre fuselage

The lack of buckling towards the rear of the centre section shows that at the moment of impact with the sea no structure was present behind this upper skin. The discovery later of adjoining skin several kilometres downwind to the east confirmed this point.

Of particular significance is the lateral and diagonal scratching of the upper port rear centre section skin panel AZ435 from station 630 to 660. These scratches show that the adjacent panel below it hinged up, at stringer 6 port, and over at considerable speed, travelling almost directly **across** the aircraft for several centimetres before moving across and backwards. The angle of

these secondary diagonal scratches show that the panel was moving across the aircraft at over half the speed that the aircraft was moving forwards. It is believed that movement at this speed could only be caused by internal overpressure, it follows that this was amongst the first pieces of skin to leave the aircraft, probably coincident with the loss of most of the top skin (which has not been recovered).

The nearby 'quilting' and skin curvature are consistent with internal overpressure.

Lower rear fuselage and rear cargo bay

The damage to the APU is consistent with it having fallen free and hit the water detached from the aircraft.

The similar nature of the curvature of the aft cargo door and its frame suggests that the door was closed on impact with the water and that it moved inwards as a result of this impact. The scratching on the starboard lower skin and across the aft cargo door, since they are at different angles and are not continuous, probably occurred during recovery. The rolling back of the cargo door skin is most likely, therefore, to have been caused by overpressure in the rear cargo bay.

The considerable distortion to the skin immediately forward of the rear pressure bulkhead and below the toilet is indicative of a severe overpressure in this area. This damage appears to be more violent than elsewhere.

Tail section

The extreme tail section, fin and tail plane probably drifted downwind in one piece, or at most two or three pieces, and partially broke up on impact with the water. There is little doubt that the heavy damage to the fin was produced by the water impact. The damage to the rudder attachments and the lack of impact damage to the rear of the fin, ahead of the rudder, together with the fact that the rudder was not found, suggest that the rudder detached in flight. It is probable that the object reported to have been seen floating the day after the accident was the rudder, however the position recorded is unlikely to be correct.

The lighter damage to the leading edge of the fin is consistent with it having been struck by pieces of aircraft structure prior to impact with the sea and therefore prior to the separation of the tail section.

Although the red smears have not been analysed it is reasonable to conclude that these were caused by a piece of the port window belt hitting the fin.

Similarly the damage to the leading edge of the port tail plane together with the red marks suggest that pieces of fuselage hit it before separation.

The FDR casing damage, consistent with water impact, in conjunction with the lack of equivalent damage to the FDR mounting, show conclusively that the FDR fell free from the aircraft. This is further confirmed by its position on the sea bed to the east of the rear fuselage but to the west of the tail section.

Upper rear fuselage

The distribution of wreckage over a length of many kilometres shows that the rear fuselage broke up into many pieces as part of and/or immediately following the initial event. The lack of appropriate damage to, or marks on, the starboard 'six window' piece AZ461 (E77), or on the adjacent engine intake show that the starboard engine had come off before this window belt panel came off. However the facts that smears are present at the forward end of the panel, including the edge normally hidden behind the adjacent centre section skin, also that these are not continued across the centre section skin, show that this window panel was in contact with other structures after it had moved rearwards relative to the centre section, however the cause of these has not been identified.

The marks made by the port engine intake on the adjacent window belt, AZ523 (F46) and AZ522 (F13), show that this folded down in one piece and only broke into two after hitting the intake.

The alternative sequence of the engine swinging in and hitting the fuselage is not consistent with the symmetrical engine mounting damage, the relatively light damage to the window belt and the outward and downward failure mode of the window belt top edge.

While many of the skin pieces in this area show evidence of peeling backwards, certain parts lack the curved, asymmetrical fracture line between rivets that usually denotes rearward movement. These, like the one part in the centre section, were straight but still displaying evidence of tensile failure, not fatigue. It is concluded that these parts which initially moved outwards were amongst the first to fail, due to an explosive overpressure. Having thus opened up the fuselage all other pieces were torn back by the airflow, progressively weakening the structure.

A detailed examination of the remains of rivets in the fuselage frames and stringers can show where the skin split and where it tore off. If the rivet heads are intact the skin split, if the heads are missing the skin tore off. From the remains of the rivets it can often be deduced whether the skin came straight off or peeled back.

The toilet area

The breaking of many stringers some 20-30cm forward of the rear pressure bulkhead suggests that the skin tore violently off the rear pressure bulkhead frame kinking or fracturing the stringers roughly half way between adjacent frames. The damage to the frame AZ496 (E118), supporting the rear pressure bulkhead at station 817 and the skin behind it, AZ418 (E51), is particularly violent suggesting an explosive force below it in the rear toilet.

The loss of the rear pressure bulkhead above floor level behind the toilet and the damage to the forward face of the duct behind it, the outward and forward distortion of the fuselage frame AZ528 (F9) and fracture of the forward engine mounting struts at station 786, the downward bending and severe buckling of the floor beam AZ539 (F44), at station 817, together with the bending at floor level and general bulging of the lower part of the bulkhead AZ495 (E163), at station 786 and of the centre door diaphragm AZ497 (F76) and pillar AZ534 (F40) at station 817, together with the tearing down and across to the port side of the whole door frame and the upward bending of the frame and skin in the roof at station 817, all indicate an explosive overpressure in the rear (starboard) toilet. A flattened box or tissue holder, AZ511 (E183), on

the toilet wall and a flattened spray pipe AZ453 (E12) from within and to the rear of the toilet waste tank suggest that an explosion occurred in this area probably in or just above the waste tank or somewhere to the rear of the toilet and close to the fuselage skin and rear pressure bulkhead. It is firmly believed that no initial event other than an explosion can explain this extensive, violent and consistent movement outwards and away from the toilet.

The wash basin AZ558 (F30), from the rear toilet shows clear evidence of being violently distorted by an explosion, however the actual direction has not been established since it was not practicable to test all possible positions for the charge. This is amongst the most violent distortion found and suggests that the explosion was fairly close to the basin. Beneath the basin is a cupboard which contains the waste paper bin; a chute leads to this from behind the wash basin. More significantly, access to this whole area may be obtained directly through the cupboard door. This door also provides access, through an easily removable flap, probably not even present in 1980, to the area above the toilet waste tank, an area unlikely to be inspected and indeed very difficult to inspect. Access to the space between the aircraft skin and the toilet outer wall is given via the tissue holder, just forward of frame 801, in the wall above the toilet and possibly, in 1980, via other routes also. The flexibility of the inner plastic wall allows, in most but not all of the aircraft checked, access to the area behind frame 801 as well as to that surrounding the holder itself.

It was originally hoped that the damage to the washbasin would pinpoint the location of the explosion. However explosive trials initiated before much of the detailed evidence in the region had been recorded, though producing similar damage, including the stretching out of the folded front edge, produced significant changes to the metal grain structure while no such changes were found on the DC9's washbasin. Although the closest match was found with the charge slightly higher than the basin it could be concluded only that while an explosion was the only likely cause of the damage our limited trials had failed to reproduce the charge size and position used.

The deformations to the toilet door hinge AZ537 (F2) and jamb AZ639 (E147) are consistent with the wall aft of the door being folded outwards and forwards with the door pivoting about the door jamb. It should be noted that while the outer part of the forward wall of the toilet is supported by the bulkhead and engine mount at station 786, that part close to the door jamb is unsupported, allowing it to move forwards relatively easily. It must be recognised that the damage to the door jamb may, in isolation, be interpreted in a variety of other ways since it only shows evidence of relative movement between parts. Considered alongside other evidence however it is certain that there is no inconsistency.

The lack of penetration or pitting of surrounding metallic structure suggests that the explosive was not in a hard container but only in, for example, a plastic wrapping. Such a charge leaves evidence of pitting and high temperature only over a very small area close to the charge, it is unfortunate but should not be considered surprising that we appear not to have recovered pieces from this small area.

Evidence from the deformations

In the absence of such so called 'forensic' evidence it is necessary to look more closely at the pattern of damage and distortion within and around the toilet in order to determine the most likely position of the explosion.

The floor

The twisting and deformation of the floor beams at stations 801 and 817 suggests a centre of pressure behind station 801, forward of station 817 and close to the fuselage side. In particular beam 801 shows evidence of being bent downwards and forwards with sufficient force for it to be broken as a result of pivoting about the port support strut. However it is not easy to assess the effect of the toilet waste tank on these parts.

The inboard structure

The evidence from the ventral door frame and adjoining panel suggests that the pressure wave was close to floor level and, less precisely, to the rear of the toilet. However in view of the complexity of the structure in this area, in particular the effect of tunnels and the curvature of the rear pressure bulkhead and the 'fickleness' of explosions in general, this does not rule out the source being rather higher and slightly further forward.

The outer wall and engine pylon

The deformation to the pylon, including the upward bowing of the lower skin, favours an explosion below the pylon, i.e. below stringer 16.

Little of the titanium skin from forward of station 817 has been found, however piece AZ498 (E121) at station 798 to 804 appears to have been torn violently and moved more or less straight out but with some forward rotation. The one hole found in the lower skin of the pylon could have been made by a piece of skin travelling outwards and upwards. The pylon inner fire wall suggests that the centre of pressure was between 786 and 817, with piece AZ499 (E142), at station 808 to 814 wrapped around the hot air duct in the pylon in such a way as to confirm rearward movement. This also suggests that the explosion was more or less level with the pylon. The deformation of the fuselage frames suggests a centre of pressure not far from station 801. The flattening of the hot air ducts within the pylon is further evidence of the violent nature of the event but adds little to the determination of the position.

Piece AZ519 (E139), the frame at station 801 between stringers 14 and 16 shows, with a straight outwards separation, deformation suggesting a centre of pressure slightly behind it. The cut-off at or by the top and bottom of the pylon is further evidence that the explosion was between stringers 14 and 16.

The engine forward mounting

This suggests that the explosion was close to the skin, the more so since it appears that the charge was small, however it does not help establish the height.

The engine cowlings

Damage to the cowlings appears to be centred on a point just behind the main tear to the upper cowling, that is between stations 801 and 817. Although both upper and lower cowlings are damaged there is significantly more to the lower, suggesting that the centre was around the level of the lower skin of the pylon, say at about stringer 16.

The toilet cleaning spray pipe

This pipe AZ453 (E12), is missing close to the outer skin but flattened either side of station 817, this supports the idea of an explosion close to the skin but does not really help locate it. It may be noted that explosive trials with charges further back and inboard did not flatten the pipe.

The wash basin

The evidence from the explosive trials favours a position outboard and slightly above the wash basin, however this position did not reproduce other damage. It is therefore not possible to rule out a position lower down.

The tissue holder

The flattening by opening out of this piece tends to rule out an explosion away from the wall since this might be expected to buckle it; this therefore strongly suggests that the explosion was between the fuselage skin and the inner lining and level or a little below the tissue holder.

Discussion

Although there is no single, clear conclusion from the above the common factor seems to be a centre of pressure between stations 801 and 817, and at a level just above the lower skin of the pylon. This coincides, inside the cabin, with a position forward of the toilet cupboard and above the tank cover. It seems that the cupboard itself is too far aft, the front wall being just forward of station 817, also the top of the toilet waste tank appears too low with respect to the pylon. It would be possible to tape a packet of explosive onto the cupboard wall at the appropriate height and this would of course make it very difficult to detect. However the most likely position appears to be between the aircraft skin and the toilet wall at about station 804 or 806, this would be virtually impossible to detect by any but a most extensive search.

The most likely access to this area is through the forward tissue holder. This gives access directly into the gap and, providing the inner wall is sufficiently flexible as it is in many cases, to an area to the side and below as well. Alternatively there may in 1980 have been access through another drawer or recess in the front wall of the cupboard.

Order of break-up

Setting out the wreckage in its order across the wreckage trail and parallel to the original aircraft track gives a good idea of the sequence of break-up. All pieces recovered from Zones E and F have been listed including the distances down track that they were found. Based on a speed of 240m/s this indicates the time they were released from the main wreckage.

From this list, when looked at in conjunction with the wreckage itself, the approximate sequence can be deduced. It may be noted that so far as can be seen no internal pieces have departed the aircraft 'before' an adjacent external piece. For example the air ducts in the roof clearly came out after (**soon** after) the top skin, of which only piece F33 has been found. Similarly the duct F16 further forward and the piece of frame E40 came out after the missing piece of skin that left its scratch marks on skin piece AZ435. Also the pieces from inside the rear toilet were allowed out because frames F54, F8, E118 at stations 801 and 817 and nearby skin F10 had already gone.

There is also confirmation of the sequence predicted and/or deduced earlier concerning the engines and the window belt pieces. The damage and missing pieces adjacent to the right engine are consistent with the starboard engine coming off early. On the port side piece F46 which struck the engine intake clearly came off before piece F13 which is adjacent to the engine. This in turn came off before the large skin and rear pressure bulkhead piece F93.

It is believed that the detachment of F93, which includes most of the rear pressure bulkhead, signifies the final break-up of the rear fuselage with the tail section coming off at about the same time. This event would have caused or aggravated the pitch down of the forward fuselage which in turn caused the left outer wing F83 to fail in download.

Summary of break-up sequence

Although no sequence of events is likely to be proven without doubt the following appears to fit all the known facts, is logical and, so far as can be seen, there is no evidence that conflicts directly with it.

1. An explosion occurred in the rear toilet outer wall just behind Station 801 and just above Stringer 16, i.e. just above the lower skin of the starboard engine pylon. The explosion was of a relatively small quantity of explosive probably wrapped only in plastic sheet.
2. The explosion caused local damage and, as a result of both the elevated pressure and shock waves, blew the toilet walls outwards in all directions. The first 'contact' was of pieces of fuselage skin from above and below the pylon hitting the starboard engine cowlings.
3. The principal local structural damage was to the outside skin, the rear pressure bulkhead, the forward starboard engine mounting at station 786, the roof and the floor.
4. In addition there was immediate damage to the air ducts and electrical cables in the pylon, below the floor and behind the rear pressure bulkhead and to the oxygen pipe in the roof.
5. The damage to cables caused the FDR and CVR to stop recording and that to the oxygen pipe prevented the system from pressurising and thus deploying the masks.
6. As a result of the inner wall of the toilet and the toilet door blowing into the cabin a shock wave was felt by the upper skin on the port side, this, possibly in conjunction with the already failing top skin, caused skin on either side of station 642 to fold rapidly upwards at about stringer 6L leaving the distinctive scratch marks.
7. Within about 2 seconds most of the top skin above the window belts and between station 642 and, on the starboard side, station 897 had come off, together with internal parts, including the wash basin, toilet door hinge and jamb, cushions, passengers, etc.
8. Also within this period the starboard engine came off and the download on the tailplane, plus the additional aerodynamic drag caused by the open-topped rear fuselage, started to overload the window belt at station 642.
9. During the third and fourth second the port window belt came away at station 642 and hit the engine intake before breaking at station 718. This was followed by the remaining

starboard side frames at stations 786 and 801 together with a large piece of port side skin F3 bridging both the rear pressure bulkhead and the floor. Further internal pieces including air ducts and trolley rack parts were released about the same time.

10. Sometime, probably towards the end of this period, the port engine came away together with the remaining piece of port window belt, F13, from station 718 to 817. This left virtually no structure above floor level to the rear of station 642 and significant damage at and below floor level at station 817.
11. The break-up was effectively completed during the next second, the fifth since the explosion. The remaining pieces of frame 786 above floor level broke away followed by the final failure at the rear pressure bulkhead, station 817. This allowed the tail fuselage, fin and tailplane to break away and separate, releasing a large number of trapped pieces and the bulk of the rear, ventral stairs.
12. The last major parts to break away were the starboard window belt E77 and, as a result of the sudden pitch down associated with the loss of the tailplane, the port outer wing.
13. Pieces continued to come away from the aircraft remains during its subsequent near vertical dive into the sea. Such pieces would have formed a second, more southerly trail leading away from Zones B and C. This would tend to be progressively less well defined since the lower the break-up, the less effect the high altitude westerly winds would have, leaving the north westerly surface winds to produce the major movement.
14. There is no doubt that much wreckage remains on the sea bed in Zone F and to the east, further downwind of Zone E as well as to the south of Zones E and F.

Alternative hypotheses

It should be noted that although slightly different break-up sequences can be postulated no sequence of break-up nor failure mode can explain the violent damage and distortion in and around the rear toilet. Therefore this damage and distortion definitely preceded the break-up and was not the result of it.

During the investigation various hypotheses were put forward to explain the accident, because of the nature of the investigation it was necessary to examine each one in detail, the principal hypotheses and the conclusions reached are noted below.

Structural failure whether due to fatigue, corrosion or overload is ruled out both by lack of evidence and because this could not have produced the actual damage present.

The possibility of a missile penetrating the fuselage close to the engine exhaust and exploding inside is ruled out because of the lack of penetration of nearby structure by pieces of metal casing.

The original hypothesis of a missile exploding close to the aircraft, although tenable when little wreckage was available for examination, is now irrevocably ruled out due to the total lack of appropriate damage to the almost complete aircraft skin now available and, primarily because this cannot explain the damage around the toilet.

The hypothesis of a near collision causing the port wing to fail may also explain certain features of the break-up sequence but cannot explain the damage in and around the toilet, thus this too is ruled out.

The only explanation that fits the facts and does explain the damage in and around the rear toilet is an internal explosion.

Conclusions

- 1) It is concluded that the accident was brought about by in-flight break-up resulting from extensive structural damage caused by the detonation of an explosive charge in the rear (starboard) toilet.
- 2) The charge was probably located in the outer wall of the toilet although other nearby positions cannot be ruled out.
- 3) For the preferred position the charge would most probably have been inserted via the tissue holder just forward of station 801 and pushed rearwards to lie to the rear of the frame at station 801 and at a height at or just above the lower skin of the adjacent engine pylon.
- 4) Other possible and accessible positions include either inside the toilet waste tank, via the waste hole, or on top of it, via the cupboard under the wash basin.

Postscript

The author's original proposed conclusions were more strongly in favour of Conclusions 2) and 3), however only the substance of Conclusion 1) of the above was adopted by the Technical Commission as it was agreed that the position suggested, although likely, could not be proved. It was also concluded that the size and nature of the explosive charge could not be ascertained.

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