# A case history involving wreckage analysis

**The following paper was presented by invitation to a conference in Rome during October 1998 but now includes pictures from the presentation and a few additional explanatory notes. The conference and paper had two main objectives, to clarify issues relating to the Ustica DC9 accident and to reiterate the point that Italy should have an independent air accident investigation authority as called for by ICAO & the EU (which it now has).**

# Lessons from the Ustica investigations

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## 1 Introduction

This is an account by an outsider who for many years knew of the accident but not of the controversy surrounding it. The background information picked up after becoming involved, as presented below, is no doubt incomplete and may in some cases be incorrect but is included to give an idea of what an open minded investigator has felt to be of interest. However it is not the background that is really important, it is the lessons to be learned from the wreckage. Since even a 'domestic' accident has international implications this account has been written with a wider audience in mind, which should explain the lengthy introduction, unnecessary in Italy!

An Itavia DC9 showing logo and colour scheme

On 27 June 1980 the DC-9 aircraft I-TIGI owned by Itavia crashed into The Tyrrhenian Sea off the coast of Italy and near to the island of Ustica at approximately 1900 hrs GMT while flying from Bologna to Palermo. Most of the wreckage sank to a depth of some 3500 metres and all 81 on board died. Floating debris and 38 bodies were recovered during the following few days from an area of several hundred square kilometres. Very soon there were suggestions that the DC-9 had been shot down by a missile and this view has been expressed strongly 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, in fact practically everybody. There have been several TV programmes, at least one film and several books, most it is believed 'proving' a missile theory but not necessarily the same one!


There has been much misinformation circulated and many accusations of 'cover-up'. In Italy 'Ustica' is still a cause célèbre. At the end of 1997 one of Italy's more important newspapers stated that 30 fighters were in the vicinity at the time, all with their transponders intentionally shut off to avoid being identified; so far as is known there is absolutely no evidence to support the claim but this appears to be typical of the long series of such claims made over the years since 1980.

Over recent years internet web sites have appeared, some on general air safety matters but at least one devoted purely to the Ustica accident, the latter and almost all the others have supported the various missile theories, thus the disinterested observer may well wonder why the 'mystery' has still not been resolved. This paper seeks to shed some light on the mystery, to demonstrate that the key to the investigation lay in the wreckage which, at the time all speculation started, was

still some 3500 metres beneath the surface of the sea and to point out a few lessons learned from the Ustica investigations.

## 2 The investigations

The evidence available during the first few years after the accident was confined to floating bodies, seat cushions containing a considerable number of fragments, radar recordings and a variety of pieces of circumstantial evidence. As none of this was conclusive various Commissions failed to agree except that the aircraft probably did break up in flight and the cause of this was either a missile or an internal explosion.

In 1990, despite the recovery of a fair amount of wreckage from the sea bed during 1987-1988, found in three distinct areas and thus providing still more evidence of an in-flight break-up, the 'Blasi Commission', named after the Judge who was in charge of the enquiry, split and was also unable to decide whether the 'cause' was a missile or an internal explosion.

As a result a further Technical Commission, this one under the Tribunale di Roma was established in September 1990. This, the fifth Commission over all, was the first to be 'international', having two from the UK (including the author), two from Sweden and one from Germany joining five from Italy and serving under another Judge, Dr Rosario Priore. A second German, with specialist knowledge of missiles, was added to the team in 1993.

At the very beginning of the Priore investigation, in the autumn of 1990, it was stated that: 'The experts will examine all judicial records, documents, exhibits already found and to be found and will make every necessary investigation in order to ascertain the causes of the air crash and the means to effect it'. The unusual aspect for the non-Italians was that our report would form part of a Public Prosecution case against various named and unnamed people, principally Italian Air Force officers, for causing the accident and/or withholding evidence.

As is usual with Italian investigations the majority of the members had relatively little prior experience of accidents investigation although all were respected and experienced 'experts' in their own fields. Before very long this situation will change since Italy, along with many other European countries, will follow a European Directive and have its own new Accidents Investigation Agency, independent of the judiciary and of all other aviation agencies.

### 2.1 The situation prior to 1990

The most widespread theory was, as has already been suggested, that the DC-9 was hit by a missile fired by some unknown fighter aircraft. Although there have been several different variations upon this theme perhaps the most coherent was presented in 1982 on a BBC Panorama programme. As the wreckage recovered by the Blasi Commission during 1987/88 provided no hard evidence to effect this view the Panorama programme continued to provide an apparently logical argument for a deliberate missile attack on the DC-9. The argument may be summarised something like this:

- The bodies recovered showed no extreme injuries so the impact with the sea was at low velocity.

- The radar records showed another aircraft flying towards the starboard side of the DC-9 from the west, out of the sun.

- At least two metal fragments found in seat cushions showed evidence of an explosion.

- Splinters of window plastic and rivets from the fuselage skin also found in the cushions showed that the explosion was outside the aircraft and not inside.

- The DC-9 had therefore been hit by a missile and had subsequently spiralled slowly down into the sea.

- Other fragments identified as being from the front of the cabin were found embedded in parts from further back.

- The missile therefore exploded near the front of the cabin on the starboard side, driving these fragments back down the cabin.

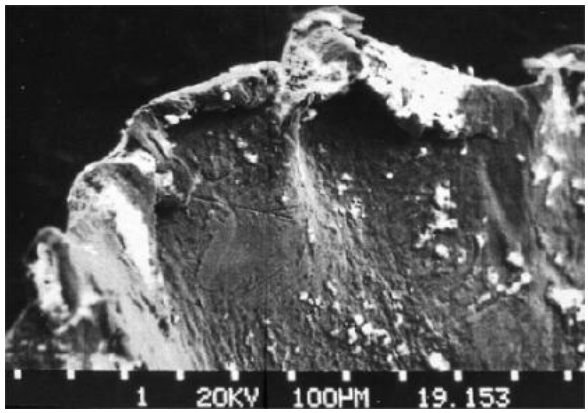
6 As the missile went towards the front of the aircraft and not to the rear, where the engines are located, it was not a heat seeking missile but a radar controlled one.

- The pilot of an aircraft approaching as shown by the radar returns and having released a missile that would lock onto the DC-9 would have had time to recognise that an error had been made and could have switched off the missile guidance system.

- As this was not done then the missile attack was deliberate and not accidental.

The programme might well have added that:

- As the material of the metal fragments showing evidence of an explosion did not appear to match any of those used in the DC-9 then they must have come from elsewhere, this could only have been from a missile.



Fragment showing hot gas wash & rolled edges – typical of damage by an explosion

As this paper unfolds information, comment particularly relevant to the above hypotheses and more general lessons to note, will appear in bold italic type.

## 2.2 Early stages of the Priore Commission

One of this Commission's first decisions was that it could not proceed far while having only the wreckage already available, it therefore immediately called for the recovery of more wreckage but of course this took some time to organise.

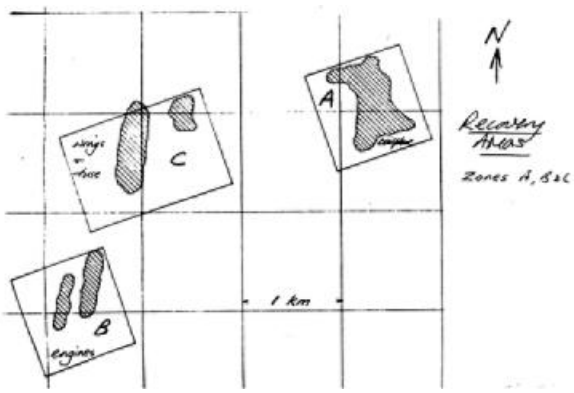

Wreckage recovered by the Blasi Commission

### 2.2.1 The wreckage

In the meantime some progress became possible as the wreckage already available was laid out and studied. From many areas of interest certain points stood out:

- The relative positions of the engines, of the fuselage pieces and wings, and of the tailcone and tailplanes, in recovery Zones B, C and A respectively, not only fitted the expected locus of debris expected

from an in-flight beak-up but also gave the approximate position of the break-up.



The three recovery Zones

- This position was sufficiently far to the east of the break-up point shown by radar as to suggest that there was first a partial break-up, followed by an 'S' shaped flight path and a second, main break-up with much of the wreckage falling into the three sites already found.

- The fuselage frames at the centre section were virtually undamaged; the few pieces from the nose were badly damaged; the leading edge of the starboard wing was badly buckled but the rest was only slightly damaged; the port wing was hardly damaged at all but appeared to have been torn up and over the fuselage.


Undamaged frames

- There were red and white paint marks on the port engine intake (the red already confirmed as being the same paint as on the fuselage side along the window belt), but nothing similar on the starboard intake.


Port engine intake

- There were red paint marks on and slight damage to the tailplane, also consistent with this being hit by pieces from the fuselage side.

### 2.2.2 The bodies

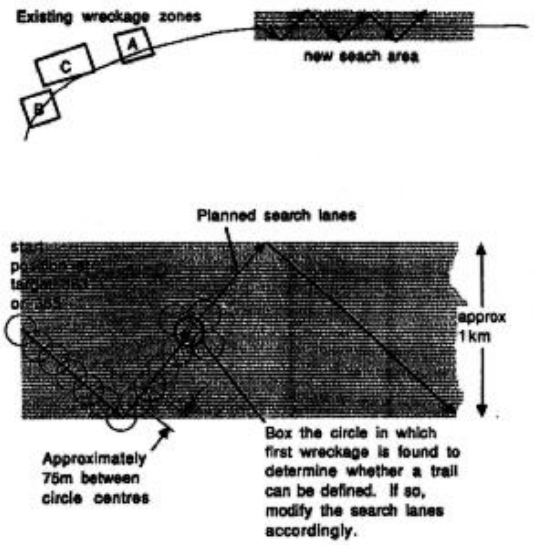
Photographs of the 38 bodies found floating on the sea surface shortly after the accident showed few with major injuries and most with no external injuries at all. Most were recovered with their clothes either stripped off or forced to the extremities of their arms and legs. These points suggested that they had not been within the cabin when it hit the sea but had fallen out following the opening of the fuselage, supporting the conclusion already suggested, from the wide spread of floating debris, that there had been an in-flight break-up. Autopsies and X-rays of the bodies had shown no external signs of an explosion nor any buried particles from an explosion and had thus given no valid reason for the break-up.

The statement made in the Panorama programme that the aircraft had spiralled slowly down into the sea was thus not the only valid possibility. Indeed the wide spread of floating debris, which included the cushions, made this interpretation rather unlikely but from this evidence alone we could not rule it out completely.

### 2.2.3 The recovery of further wreckage

Using a trajectory analysis program developed at Cranfield[1] and used during the Lockerbie B747 investigation[2], knowing the approximate position, height and velocity of the aircraft and of the wind at the time, it was

possible to predict the likely spread and extent of the wreckage trail. As the DC-9 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 the downwind trail would be long and distinct.




Proposed new recovery area

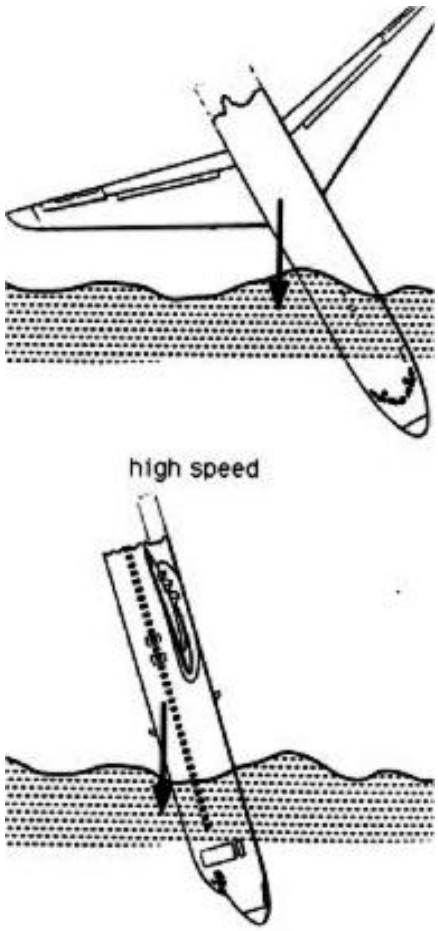
This information was presented to Commission members at one of the first meetings but was initially ignored in favour of raising more wreckage from the areas already located by the Blasi Commission. Since it is practically axiomatic that the first pieces to break away from an aircraft are also those most likely to indicate why they broke away the non-Italian members continued to press for the search and recovery to move to where these first pieces were likely to be found.

The delay in recovering direct evidence concerning the break-up seriously hampered the investigation although at least the recovery or wreckage from the original site and its reconstruction (by attaching pieces to a tube and mesh framework roughly the shape of the DC-9 fuselage) established how the various parts had entered the sea.

The majority of the additional wreckage recovered was soon identified as being from the forward fuselage with more debris from the engine nacelles and from the tail area, each from their respective recovery zones. The buckling of the fuselage skin was extremely severe at the front and gradually diminished further back and, consistent with the lack of damage to the centre section frames already noted, non-existent at the centre section. At that stage nothing had been recovered of the rear fuselage above floor level.

Starboard front fuselage

The buckling of the front fuselage, cockpit windows and the starboard wing clearly showed that these parts had entered the water at high speed, almost straight down, with the wing leading edge parallel with the sea surface and the fuselage just over the vertical.




Probable attitude on hitting water

Such an attitude was also consistent with the quite different damage to the port wing. At

that stage the significance of not having recovered the outer part of the port wing was not realised.

Detail showing tight buckling

Port front fuselage with gentler buckling but note the severe inward bending of the windscreen supports

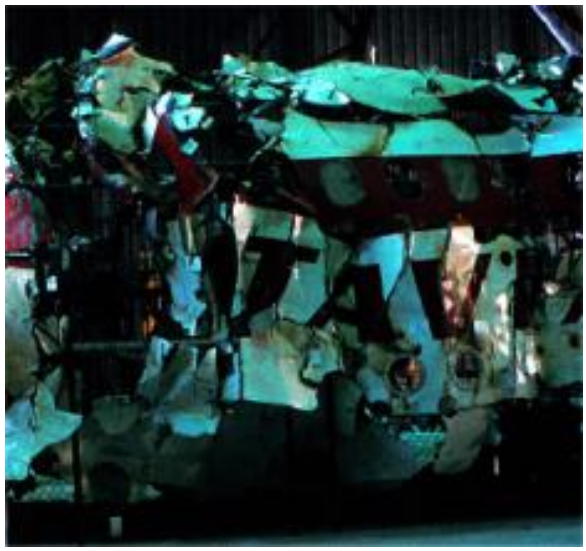
Thus the evidence from the wreckage totally contradicted the Panorama statement that the aircraft had spiralled slowly down into the sea.

The rapid buckling and breakage of the fuselage skin and windows, particularly on the more tightly buckled starboard side, was such as to have caused rivets and fragments to have been 'fired' in all directions, including into the passenger cabin.

Thus the presence of such fragments and splinters in the seat cushions was explained without the need for an explosion outside the aircraft!

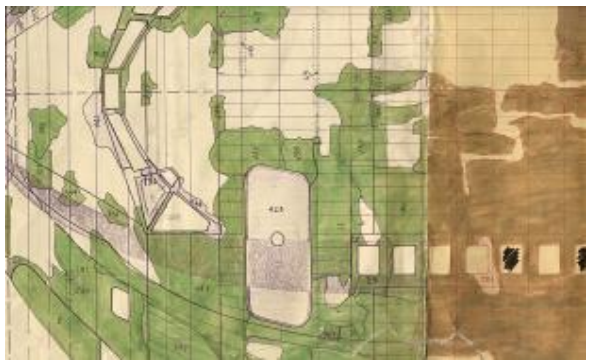
No evidence was found of the penetration damage normally associated with the explosion of a missile on the fuselage skin nor on the wings.

As the forward cabin had entered the water at high speed nose first, the contents of the cabin would have all continued forward until violently slowed down upon hitting something further forward. Thus finding fragments from the front of the cabin embedded in parts from further back was not surprising and did not imply that a missile had exploded near the front of the cabin.



Tight buckling to the rear of stiff door frame, port side

Note that several web sites show a picture similar to this with the claim that there is a large hole aft of the door, through which a missile passed. There is in fact no hole at all as can be seen from the following diagram depicting the pieces of skin as if opened out (unbuckled) to the original shape.



Skin diagram prepared during reconstruction

None of the port side of the fuselage ahead of the trailing edge of the wing showed any evidence of it having been in contact with the port engine intake, thus the section that DID make contact must have been from immediately in front of the engine.


No sign of contact with port engine intake cowling

At this stage the whole of the upper rear fuselage was still missing. Therefore as it appeared not to be in the same zone as the rest of the fuselage and as it must have made contact with the engine before the engine broke away, the failure of the rear fuselage skin was almost certainly associated with the initial failure and the pieces would be found downwind to the east within the area already predicted.

Since the statement made in the Panorama programme that the aircraft had spiralled slowly down into the sea had already been shown to be invalid and as in-flight break-up of the rear fuselage was almost certain it followed that the 38 bodies had come from the rear cabin.

At the time it seemed that there must have been some subtle influence from outside the Commission to prevent us from searching the downwind area, confirming that the parts to be found there were from the rear fuselage and, most importantly, establishing what had caused the break-up.

Despite repeating and elaborating upon our earlier arguments we could not convince most of the Italian members that this was where we should be searching. Even the reconstruction of the upper rear fuselage became contaminated by several dozen pieces that to a general observer appeared to fit, but which 'looked wrong' to those of us with a feel for the whole reconstruction.

Some pieces, it was later found, had been correctly identified and labelled by Alitalia engineers but then incorrectly positioned. Nevertheless it took several hours of close study to discover where other pieces actually came from and to show that they all in fact belonged to the forward fuselage.


Rear fuselage after 'contamination'


Rear fuselage after re-positioning of 'contamination'

Only then were the Italian members convinced and the search and recovery moved to the downwind trail. Here much of the remaining wreckage was located, recovered, identified and subsequently reassembled. With the exception of the port outer wing all pieces did come from the rear fuselage. However time and money were running out and the recovery was never completed; if indeed delaying tactics had been employed then they had been partially effective.

A very important lesson to be learned by all investigators is that one must continuously reassess evidence with a completely open mind. We as humans are all open to suggestion and thus, without being aware of the influences upon us, may otherwise reject a new idea with no proper justification.

2.3 The continuing investigation

In July 1992 while the reconstruction continued the author was asked to submit a report on the aircraft wreckage recovered. The initial version of this submitted in September 1992 was subsequently up-dated as fresh evidence emerged. Most of the final version may be found in the Commission's report[3] handed to the Judge, Dr 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 and 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 accepted by all parties.

With Dr Priore's permission the author's contribution formed the basis of a paper presented to the International Society of Air Safety Investigators (ISASI) in October 1994 and subsequently published in the ISASI journal[4]. The present, shorter paper is based on this and on the additions subsequently made to the ISASI paper to set the investigation into a wider context[5].

2.3.1 The radar evidence

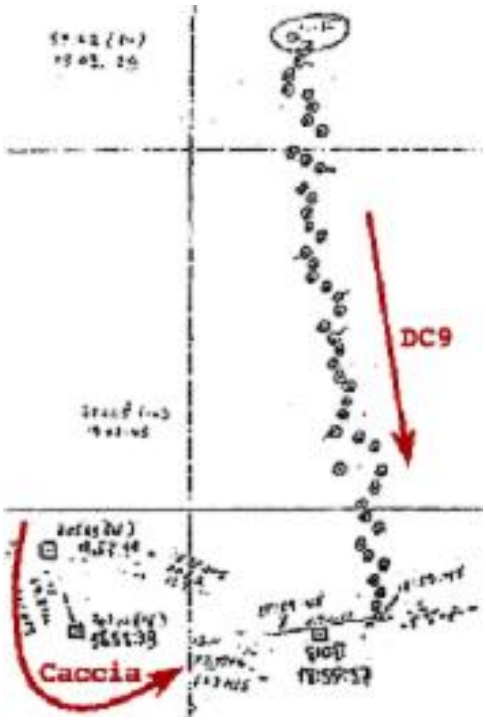
Much of the excellent work by the 'radar group' (an Italian, a Swede and the other UK member) in relating radar returns to the trajectories of falling debris is thought to be totally original but only two crucial parts will be summarised here.

Firstly, and coming just too late to help pinpoint the wreckage trail prior to searching downwind of Zone A, it was discovered that there had been errors associated with the data from Rome radar. When these errors were corrected the initial break-up point shown by radar almost exactly coincided with the second, final break-up point suggested by the shape of the wreckage trail. Thus there was no longer any need to consider two break-ups with a short flight in between, the major break-up started at a single point. This fitted the facts deduced from the recovery of wreckage from the upper rear fuselage.

Here was another lesson that one should never assume anything, everything must be checked and re-checked.

Secondly, a major argument in favour of the missile theory was that the radar recordings at Rome showed not only the clear trace of the DC-9 travelling southwards but also three addition points to the west of the DC-9, two some way out and one quite close to the DC-9.

These were interpreted as being returns from a fighter aircraft flying first parallel to and then converging on the DC-9. This theory had been gone into in considerable depth by several people knowledgeable in missile attack techniques, it was argued strongly that such returns did indicate the presence of another aircraft and indeed the Panorama programme's case appeared convincing.



The radar plot

In this context it was calculated that the probability of the returns being false echoes was approximately $10^{-5}$, or one in a hundred thousand, which certainly suggests that earlier statements were correct and that the returns were from an aircraft!

However, the Priore radar group's analysis continued by calculating what the probability was that an aircraft converging on the DC-9 along the path suggested would show only these few returns. The answer was also approximately $10^{-5}$; that is it was very unlikely that they were caused by another aircraft! Thus the returns proved nothing whatever either way and were thus totally inconclusive; the evidence to be obtained from the wreckage itself therefore became even more important.

The analysis of this matter proved to be an excellent lesson that probabilities must always be assessed from both ends, not just from one. Either approach on its own could give a very misleading impression.

The final conclusion was that while all of the radar returns could be explained by the falling wreckage the presence of another aircraft in the vicinity could not be ruled out. Thus although claims that another aircraft had attacked the DC-9 could not be dismissed, the detailed scenario of the kind presented on TV was clearly no longer justified.

2.3.2 The fragments

The Commission's report describes and comments upon a great variety of other evidence relevant to the wreckage, most notable being reports from DRA Fort Halstead (now part of DERA) describing small fragments with signs of 'rolled edges' and 'hot gas wash', a variety of small holes in baggage, globular ends to fibres and some minute traces of explosive. This evidence strongly supported the conclusion that there had been an explosion but was not sufficient in itself to prove whether the explosion had been inside or outside the aircraft.

Although, despite the evidence in favour of an explosion, it was still not unreasonable for other hypotheses to be considered, in order to avoid waste of time the proposer of any such hypothesis should have been asked first to offer reasons for ignoring the evidence of an explosion.

The materials of the metal fragments that 'had seen' an explosion could not initially be matched to any material known to be used in the aircraft, this gave some support to the idea that they must have come from a missile. Subsequent excellent and detailed analysis in Italy showed that there was in fact a perfect match with material from just under the surface of the aluminium rich cladding of aluminium alloy sheets used in the DC-9.

This provided yet another excellent lesson of how old evidence should always be reassessed. Many members of the technical commission were fully aware that the composition of sheet material varied across its thickness but none of us had put two and two together and questioned the original finding that there was no match.

Thus although this new finding did not prove that a missile was NOT involved, another obstacle to the other possible

explanation, an internal explosion, had been removed.

### 2.3.3 The Flight Data Recorder and Cockpit Voice Recorder

FDR on seabed after 12 years

Under normal circumstances these both took their power from the starboard engine. They were found detached from their aircraft mountings but within the same general area, the CVR was found and read out by the Blasi Commission, the FDR later by the Priore Commission.

The FDR was of an old, scratch foil type and confirmed only that the aircraft flight path was as derived from the radar data. It contained no data changes immediately before the cessation of power.


The FDR at the AAIB Farnborough

The CVR contained part of a word, possibly the Italian equivalent of 'Look ...' before the initial power failure. A fraction of a second later power was momentarily restored, consistent with a relay transferring power to the port engine supply. Electrical 'noise' at the end of each track on the recording rendered any other useful analysis impossible.

An interesting point found concerning the sequence of break-up is that both the FDR and the CVR stopped abruptly during normal flight, both as a result of electrical power failure. While apparently no really useful information was forthcoming from either the FDR or CVR, the fact that power failure did occur with no prior warning and therefore as part of the initial event is of significance and an important lesson to remember.

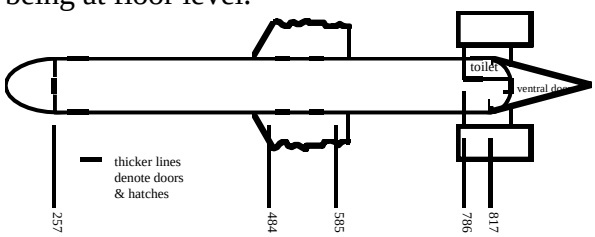
The cessation of power prior to any recorded data change or sound signal suggests that the initial failure was in the region of the starboard engine, the slight power 'hiccup' at the end of the CVR tape suggests that the port engine supply failed very soon after the starboard failure.

Evidence continued to point to the rear fuselage and, perhaps, to the starboard side!

## 3 The wreckage

Each piece of wreckage was allocated three reference numbers, related to its discovery, recovery and position (whether identified or not). The latter two numbers have been used to avoid ambiguity when similar pieces are described and so that reference may be made to the Commission's full report. 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 stringer numbers start at 1 along the top centre line with 18 being at floor level.




not to scale

The station numbers are of particular importance when relating individual pieces to the overall aircraft, certain key station numbers being shown in the figure. As will emerge later the rear fuselage becomes important and of particular interest are items

between station 786, which locates both the forward engine mountings and, on the starboard side, the forward wall of the toilet, and station 817 which is where the rear pressure bulkhead joins the fuselage skin, with part of the domed bulkhead itself forming the rear wall of the toilet.

### 3.1 The wreckage trail

The actual wreckage trail and where pieces of wreckage were found both provide very important lessons to the investigators.

The study of the wreckage itself provides a great deal of information regarding the sequence of break-up. Totally independent of this, the position of each piece within the wreckage trail also provides information regarding the sequence of break-up. The two methods together, when they suggest the same sequence, provide very powerful evidence indeed.

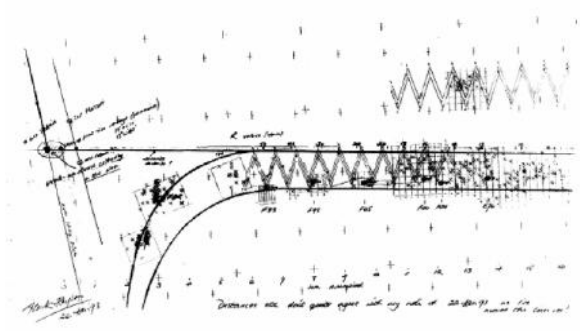
Fortunately no conflict between the two was ever found, the few apparent discrepancies being easily resolved. Some indeed only appeared because the framework upon which the pieces were assembled had been made too small so that adjoining skins sometimes overlapped.

A further independent source already mentioned is provided by the break down of the electrical supply, this and other features must all be consistent with the chosen hypothesis.

### 3.2 Selected detailed information

In the light of the statement above it is now worth looking at certain parts of the wreckage and the wreckage trail in more detail. However for a full description reference should be made to earlier papers[4,5].

The wreckage of the DC-9 was found to be distributed along an essentially west to east trail approximately 1.5 km wide and at least 16 km long. The Blasi Commission located wreckage in Zones A, B and C, initial recovery by the Priore Commission was from within this combined area but subsequently the search was continued some way downwind in Zone E and finally in Zone F, between A and E.



Sketch of the wreckage trail

Due to pressure of time the eastward search and recovery was stopped just over 16 km downwind of what was subsequently determined to be the initial point of break-up. 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. First it is necessary to refer to Zone D.

#### 3.2.1 The drop tank

In addition to the principal recovery zones, Zone D is to the north of Zone E and was within the area searched before the Rome radar data was corrected and thus before the aircraft wreckage trail was accurately defined. Zone D contained an aircraft drop tank, that is an external 'bomb' shaped tank slung beneath the wing of fighter aircraft to provide extra range. During hostilities these would be dropped on reaching the combat area to give the aircraft its full performance and agility, at all other times aircraft would return to base with these still attached. Although the tank was of a type still used in 1980 by several aircraft types it was not possible to identify it nor its time of loss.

A lesson from this was that one should expect 'red herrings' during any investigation. A further one here was that the drop tank had traces of red paint on its outer surface. Analysis showed that this paint did NOT match that of the DC-9;

neither, I hope, did it match the paint on my son's bicycle!

### 3.2.2 The engines

While the port engine cowlings had no significant damage other than the paint marks on the intake, the starboard engine cowlings had a variety of dents, cuts, holes, scratches and paint marks on the left side, that is on the parts adjacent to the fuselage side and thus to the toilet wall.

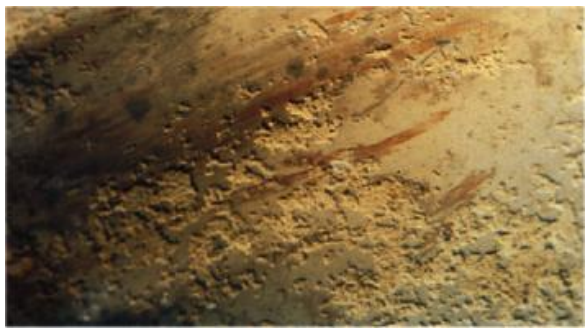
Rear toilet mock-up with engine cowling beyond - also note position of tissue holder referred to in 3.2.7

Part of the starboard engine cowling

A dent in and penetration of the right engine cowling

Outside view of penetration of right cowling

Inside view of the above penetration



Red paint marks in a depression or groove in the starboard engine cowling

Inside cowling under the traces of red paint

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 (nobody suggested anything other than that this was 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 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.

It is believed that no microscopic search was made for high velocity pitting of the cowlings.

It may or may not be of significance that some time before these dents, red marks and holes were discovered a statement was made (believed by myself, since there appeared to be no reason to doubt it, and consequently repeated by myself) that there

was no such damage to the cowlings. This delayed discovery by some weeks.

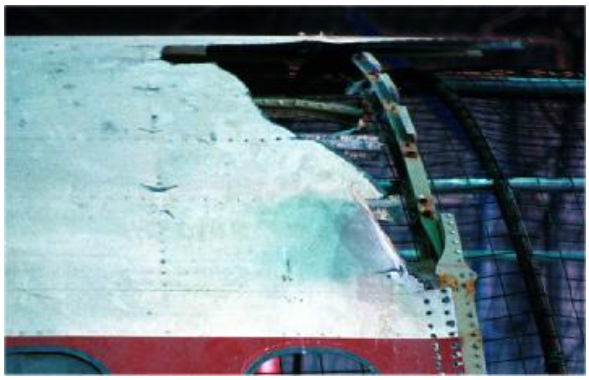
3.2.3 The centre wing section

The wing centre section was extensively broken although little of the bottom skin had been identified. The top skin was 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 were found intact.

There was no possible way through for an unexploded missile, as was at one time suggested.

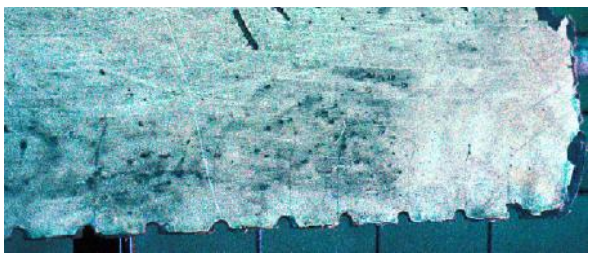
3.2.4 Centre fuselage

Shortly before the upper rear fuselage became contaminated the rearmost skin panel on the port side, AZ435, from station 630 to 660 at stringer 6, was found to be scratched laterally adjacent to some 22 rivet holes to a distance of from 80 to 30 millimetres.



Skin with scratches is at top of picture

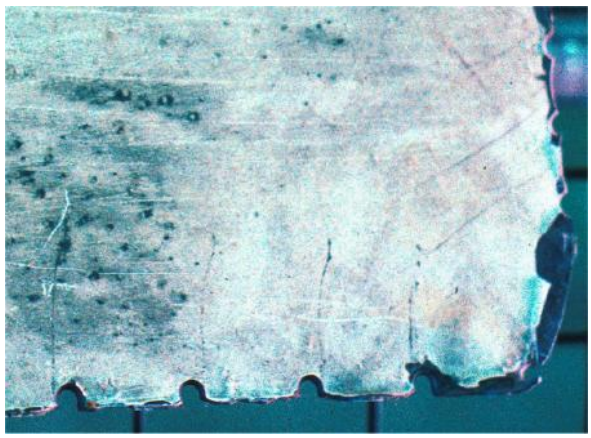
A few of these scratches then continue rearwards at an angle of approximately 30° to the aircraft centre line, to the rear edge of the panel at station 660.



Scratches across upper centre fuselage

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 over-pressure, 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).



Diagonal scratches to rear of panel

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. These features were pointed out by the AAIB engineer as being consistent with internal over-pressure.

Another important lesson learned was that all fuselage skins needed to be examined from both sides, even if this entailed a difficult climb onto the top of the fuselage or up high scaffolding.

3.2.5 Upper rear fuselage

As had been predicted much of this area was found downwind in Zones F and E but much

also remains on the sea bed. The larger parts showed little damage with the only smaller and more violently torn pieces coming from around the toilet. That it was the skin and window section immediately ahead of the port engine that had, as predicted, hit the

intake was confirmed on recovery of AZ523 and AZ522. These had the curved impression of the intake across them, showing that they had folded down as one piece and broken in two after hitting the intake.

Port skin showing contact with engine intake

The position of this piece on the sea bed had been accurately predicted after the recovery of the equivalent section from the starboard side.

Starboard skin next to and forward of engine

As the port piece had come off before the port engine it was deduced that it would be close to the northern edge of the trail. That it was found where predicted was encouraging for the whole recovery process.

### 3.2.6 Lower rear fuselage and rear cargo bay

Damage in this area was all consistent with an explosion nearby. The similar nature of the curvature of the aft cargo door and its frame suggested that the door was closed on impact with the water and that it moved inwards as a result of this impact. The rolling back of the cargo door skin was most likely to have been caused by over-pressure in the rear cargo bay.

Rear cargo door

The considerable distortion to the skin immediately forward of the rear pressure bulkhead and below the toilet and the failure of the cables running beneath the toilet indicated a severe over-pressure or event in this area. This damage appears to be more violent in this area than that elsewhere.

Because of frequent interruptions and what appeared to be totally unwarranted calls to keep on going over old ground with representatives of other parties, damage in this area was never completely charted. Perhaps the lesson is that although the exchange of information at meetings is essential, this should not be allowed to get in the way of the actual investigation.

### 3.2.7 Rear pressure bulkhead and toilet area

For a full description of this crucial area reference should be made to the previous papers[4,5] but the following points bear repeating:

- 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

Distorted frames adjacent to starboard engine

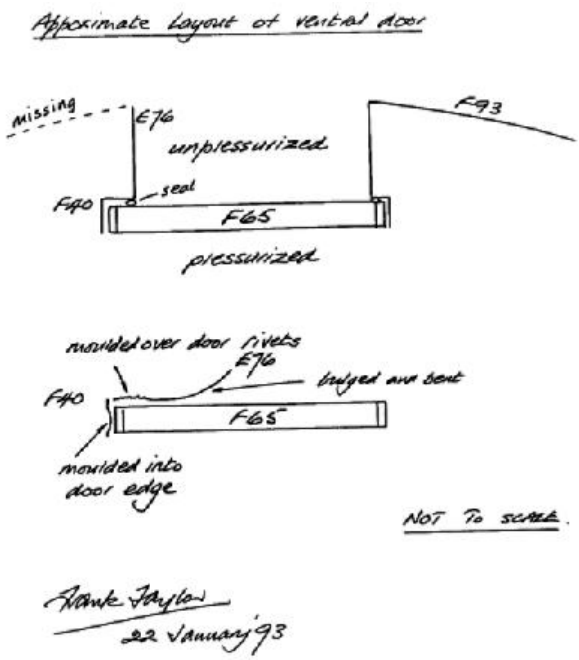
Forward bulging of lower front wall of toilet

- The downward bending and severe buckling of the floor beam AZ539 (F44), at station 817

Structure beneath toilet

- 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 (E76) and pillar AZ534 (F40) at station 817

Impressions in the ventral door frame




Sketch of ventral door and frame with impressions

- 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

Rear cabin with web containing forward engine mount

Distortion to ventral door frame

These all indicate an explosive over-pressure in the rear toilet inboard of the starboard engine.

Furthermore the flattened box or tissue holder, AZ511 (E183), on the toilet wall

'Opened out' tissue holder from the outside or back

'Opened out' tissue holder from inside toilet

Tissue holder in another DC9

and the flattened spray pipe AZ453 (E12) from within and to the rear of the toilet waste

Spray pipe from toilet waste tank

Close-up of the 'flattened' but not flat part of the pipe

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.

Intact pipe beneath a new toilet tank lid

Toilet door hinge – opened through $180^0$ then bent

A wash basin in the toilet of another aircraft

Wash basin with corrosion and unfolding

It is still firmly believed that no initial event other than an internal explosion in this area can explain this extensive, violent and consistent movement outwards and away from the toilet, nor the resulting break-up sequence.

### 3.5 Order of break-up

This section is taken with minimum change from earlier papers[4,5] but is included because of its importance to the general understanding of the event. It was concluded that although no sequence of events was ever likely to be proven without doubt the following appeared to fit all the known facts, was logical and, so far as could be seen, there was no evidence conflicting 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. 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.

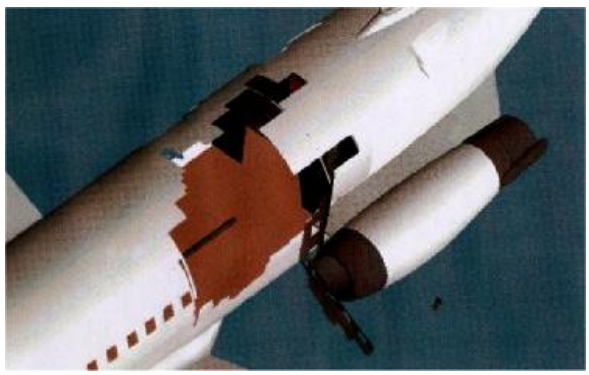
13. Pieces continued to come away from the remains of the aircraft during its subsequent near vertical dive into the sea. Such pieces would have formed a second, more southerly trail leading away from Zones B and C. This would tend to be progressively less well defined since the lower the break-up, the 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.

Time zero

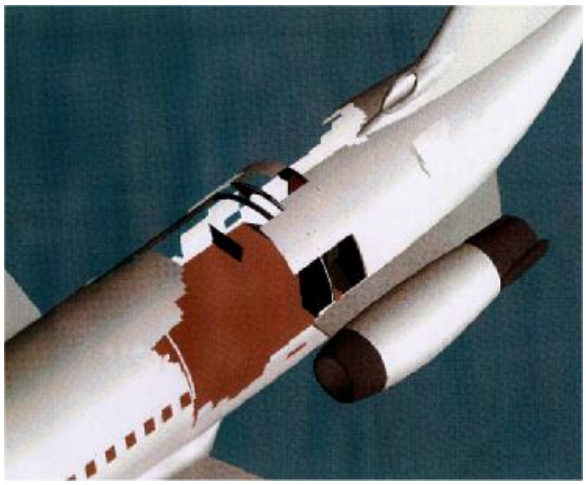
Approx 1 second from the explosion

As above

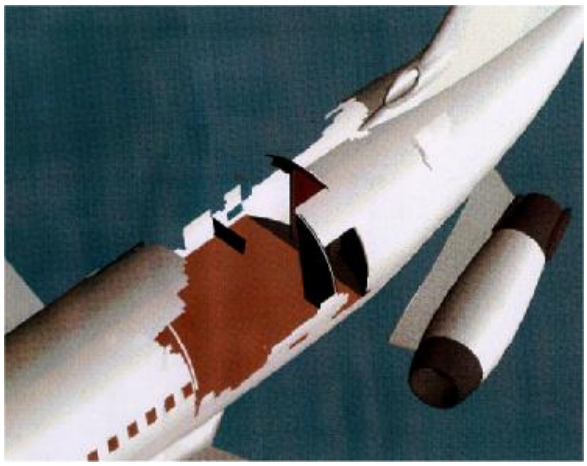


Approx 2 to 3 seconds from the explosion

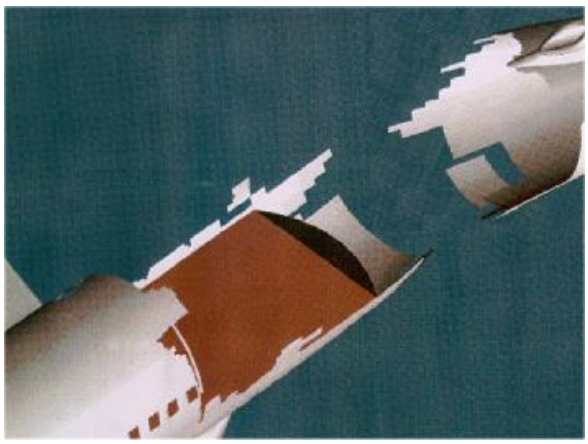
Pictorial views of break-up sequence



Approx 4 seconds from the explosion



Approx 5 seconds from the explosion



Approx 6 to 7 seconds after explosion

Pitch down breaks wing in down load

The parties proposing some of the alternative hypotheses set out below were on several occasions invited to back up their claims but so far as is known there has been no other such sequence put forward that attempts to explain the evidence and that supports any of these other hypotheses.

3.6 Alternative hypotheses

Apart from the original missile theory various other hypotheses were put forward, each one was examined in detail. The principal hypotheses and the conclusions reached were:

- The original hypothesis of a missile exploding close to the front of the aircraft, although tenable when little wreckage was available for examination, was irrevocably ruled out due to the total lack of appropriate damage to the almost complete aircraft skin that became available and, primarily, because such an event did not explain the damage around the toilet.

- The subsequent hypothesis of one or two missiles penetrating the fuselage without exploding was ruled out since no possible entry and exit points were found, nor appropriate internal damage. Neither of course did such an event explain the damage around the toilet.

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

- Structural failure whether due to fatigue, corrosion or overload was ruled out both by lack of evidence in the wreckage, on the FDR and CVR and because this could not have produced the actual damage present.

- The hypothesis of a near collision causing the port wing to fail did not explain the

damage in and around the toilet nor the other evidence of an explosion. Neither was there any evidence on the FDR and CVR prior to the power failure, thus this hypothesis too was ruled out.

- The hypothesis of an internal explosion turned out to be the only explanation that fitted the facts and did explain the power failure, the damage in and around the rear toilet and the overall break-up sequence.

## 4 Investigation findings

4.1 It was 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.

4.2 The charge was probably located in the outer wall of the toilet although other nearby positions cannot be ruled out.

4.3 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.

4.4 Other less likely but 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.

## 5 Comments and subsequent developments

The author's original proposed conclusions were more strongly in favour of Findings 4.2 and 4.3, however only the substance of Finding 4.1 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 since the position could not be stated with any certainty the size and nature of the explosive charge could not be ascertained.

Shortly after the submission of the 1280 page report the Technical Commission was asked a series of follow-up questions apparently seeking answers likely to clarify certain key issues. These were answered conscientiously and a meeting was held in November 1994 when it was anticipated that there would be an opportunity to explain any areas of doubt further and thus satisfy all parties that we had come to the correct and only possible conclusion. However our report was described as 'unusable' and no questions were asked nor any opportunity given to explain our findings.

The non-Italians (and no doubt many of the Italians present as well) found this situation totally unsatisfactory. It was believed that it was not the report that was 'unusable' but its findings. This appeared to be yet another example of how certain parties, having made up their minds in advance, were not prepared even to consider that there was another explanation.

Since then Dr Priore has been granted several 'extensions' during which certain additional work has been done on radar matters but with no reference to the Technical Commission, he is understood to have reported to the Public Prosecutor at the very end of 1997.

As suggested in the opening paragraph some parties have still not accepted the Technical Commission's findings as set out in Section 4, whether the present meeting will help to resolve this divergence of opinion remains to be seen.

## 6 Conclusions

6.1 Failing to differentiate between perfectly reasonable assumptions and proven facts can lead to the production of extremely convincing but ultimately incorrect conclusions.

6.2 The not inconsiderable circumstantial evidence that a missile or missiles brought down the DC-9 was not supported by the evidence from the aircraft wreckage. The study of the wreckage recovered from the sea bed provided the key lessons to the investigation.

6.3 Several years after the completion of the 'technical investigation' the finding that the Itavia DC-9 broke-up as a result of an internal explosion still stands but although this has not been seriously challenged it has still not been accepted by all parties. The reasons for this are unknown but are thought not to be of a technical nature.

6.4 Despite the integrity and impartiality of individuals involved, the judicial system used in Italy (and in some other countries) to investigate aircraft accidents is not appropriate to a complex technical accident investigation. Investigation should be vested in a totally independent specialist agency as called for by the European Commission.

## 7 Acknowledgements

Major contributions to the study of the wreckage, and hence to the reasoning behind this paper, were made by two members of the Commission, one Swede and one German, by a member of the UK Air Accidents Investigation Branch and, as a result of their excellent identification and reconstruction work, by two Alitalia engineers. I should like to acknowledge these contributions, those from other members of the Commission and those from various supporting individuals and organisations, with grateful thanks.

Appendix

As various parties still believing in a missile attack thought that the USS Saratoga might not have been in Naples harbour as was claimed and thus could have been involved

USS Saratoga

Dr Priore displayed some commendable lateral thinking when seeking to establish the truth about this, bearing in mind that most logs and records could have been 'amended' during the long period since the crash.

He called for those married on 27 June 1980 in a church with views of the harbour to bring forward their wedding photographs and marriage certificates. Apparently the USS Saratoga was shown to be in harbour as stated in its log.


Typical view of Naples harbour

## 8 References


1 A.F.Taylor — 'The effect of wind on the wreckage trail following in-flight break-up', Cranfield CofA 'Aerogram', Vol. 6, No. 3, May 1991

2 AAIB — 'Report on the accident to Boeing 747-121, N739PA at Lockerbie, Dumfriesshire, Scotland on 21 December 1988', Aircraft Accident Report 2/90, HMSO, August 1990

3 Tribunale di Roma — 'Technical Expert Report on the accident to Itavia DC-9 aircraft I-TIGI on 27 June 1980' Penal Proceeding No. 527/84A G.I., Criminal Court of Rome, Office of Investigations - Section 1, July 1994

4 A.F.Taylor — 'Accident to Itavia DC-9 near Ustica, 27 June 1980: wreckage and impact information & analysis' ISASI forum Vol. 28, No. 1, March 1995

5 A.F.Taylor — 'The study of aircraft wreckage: the key to accident investigation' Journal of the International Society for Technology, Law and Insurance Vol. 3, 1998


Postscript 2006

It is believed that, following Court proceedings in Rome, the above version of events is now officially, if not universally, accepted in Italy. Also Italy now has an Air Accident Investigation Agency.