ARROW AIR INC.
DOUGLAS DC-8-63 N950JW
GANDER INTERNATIONAL AIRPORT,
NEWFOUNDLAND

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DISSENTING OPINION

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1.0 Introduction/Summary

In our judgement, the wings of the Arrow Air DC-8 were not contaminated by ice — certainly not enough for ice contamination to be a factor in this accident. The aircraft's trajectory and performance differed markedly from that which could plausibly result from ice contamination. The aircraft did not stall. Accordingly, we cannot agree — indeed, we categorically disagree — with the majority findings.

The available evidence convincingly shows that the right outboard engine was producing little power before it contacted trees. The investigation of the other engines was inconclusive with regard to pre-impact status. We believe it possible that these engines were also operating at reduced power. All four thrust reversers may have been deployed.

The evidence shows that the Arrow Air DC-8 suffered an on-board fire and a massive loss of power before it crashed. But, we could not establish a direct link between the fire and the loss of power. The fire may have been associated with an in-flight detonation from an explosive or incendiary device. Consequential damage to various systems precipitated the crash.

2.0 Crew Competent and Alert

Associates of the flight crew unanimously testified that all three members were above average in thoroughness and proficiency.

During the month before their heavy December schedule, all crew members had relatively light flying duties. (The captain, first officer, and flight engineer had 22, 15, and 22 non-flying days respectively in November.) On arrival at Gander, the crew had just completed a flight of 6 hours and 18 minutes after a 17-hour stopover.

The dispatcher and other personnel at Gander International Airport reported that crew members were cheerful, alert, and had carried out duties as expected. This assessment was supported by the Arrow Air dispatcher in Miami who had talked with the captain by telephone. Recorded communications with air traffic controllers indicate normal alert, professional behaviour on part of the crew.

The crew calculated the aircraft's take-off weight according to accepted procedures. Other Arrow Air pilots testified that, conditions permitting, they would increase the margin of safety by using take-off reference speeds appropriate to an aircraft a few per cent heavier than calculated.

We can not agree that the crew may have used take-off reference speeds corresponding to a weight substantially below actual. To us, the post-crash location of the two remaining movable external "bugs" on the first officer's airspeed indicator yields no useful evidence regarding reference speeds. We put more faith in the internal, gear-driven bug on the captain's airspeed indicator which was "burned into position" corresponding to the target airspeed for the weight calculated by the crew. A horizontal stabilizer setting appropriate to the same weight makes our determination conclusive.

We found no basis for supposing that the crew's performance could have been affected by fatigue. In the absence of evidence of abnormal behaviour and in consequence of testimonials to the crew's professional competence, we conclude that no act or failure to act by any member of the crew contributed to this accident.

3.0 No Ice Contamination

3.1 No Ice on Aircraft

The findings of the majority with respect to ice contamination are based on theoretical possibilities. We confuted these in detail in our paper *Critique of the Ice Contamination Hypothesis Presented in Conditional Draft No. 1* (presented to the Board in May 1988).

The majority has adduced no direct evidence of ice on the aerodynamic surfaces of the Arrow Air DC-8. The only evidence of ice anywhere on the aircraft is one reference to a small amount on an unheated edge of a windshield. This reference was made by a refueller who spoke with the flight engineer in the cockpit just before departure. His words were as follows:

> "I noticed some ice buildup around the edges of the cockpit window, and I asked him if they picked up much ice on the way in. He said, "No it wasn't too bad, there's a tiny bit left around the window."

To us, this means that the crew had monitored ice during the approach, had used the airframe de-ice equipment if needed, and that the flight engineer knew from his inspection there was no ice on the lifting surfaces.

The Boeing 737 that took off from Gander shortly before the accident landed in St John's within an hour. This aircraft, which had to descend through the same cloud conditions as the Arrow Air DC-8 on its approach to Gander, did not need de-icing at St John's. The Boeing 737 that landed at Gander shortly after the accident did not pick up any ice during the approach.

The captain of the Arrow Air DC-8, an instructor and check pilot, was universally lauded for his professionalism and meticulous attention to detail. A close professional colleague testified that the captain was aware and wary of the effects of ice contamination, having cited these, for example, in discussions of the 1982 Air Florida crash at Washington.

The *Human Factors Group Factual Report* concluded that the flight engineer was "extremely conscientious and thorough in his approach to his professional duties" and that his "adherence to standards was noted by many sources."

Given the evidence of the crew's professionalism, we conclude that the captain checked the wing as he left the aircraft and that the flight engineer conducted a thorough external inspection. Had there been ice on the leading edge, the crew would have detected it and had the aircraft de-iced.

Two refuellers who could not fail to see the leading edge while connecting the fuel hose to the refuelling panels (see Figure DO1.) testified that they saw no ice. Had de-icing been necessary, it could have been provided on a fee-for-service basis. None of the four ground handlers who would have done the work noticed any ice. Earlier that morning, one of these workers recommended de-icing to the captain of an aircraft that had been at the airport for some time. This witness stated that the Arrow Air DC-8 did not need de-icing because there wasn't any ice on it.

The witness testimony and the detailed meteorological evidence (as presented at the Board's public inquiry and discussed in our previously cited paper) establish that the wing of the Arrow Air DC-8 could not have been contaminated with ice during the take-off run at Gander on 12 December 1985.

3.2 The Aircraft Did Not Stall

The majority based its finding that the aircraft stalled mainly on interpretations of the heading, vertical acceleration, and altitude traces from the flight data recorder. The aircraft's attitude at first contact is cited as supporting evidence. Our paper *Critique of the Ice Contamination Hypothesis* ..., particularizes why both categories of evidence are unconvincing.

We observed, for example, that the alteration in heading is more consistent with a gentle turn than with a stall. We also submitted that the "substandard" vertical acceleration trace (discussed but not reproduced by the majority) provides no support either for or against the notion of a stall.

The majority assessed fluctuations near the end of the altitude trace as an indication of stall buffet. Our paper noted that analogous fluctuations on the trace from the previous take-off disappeared when the aircraft reached about 100 feet above ground. Subsequent analysis by several consultants found: "A study of the altitude stylus marks during take-off going back to twenty flights before the accident ... suggests that such fluctuations tend to be associated with the longer range flights that were made at higher gross weights." That is, fluctuations in the altitude trace near lift-off are characteristic of the installation and not of the accident flight.

The majority cites the high angle of attack at first contact (estimated from the "tree model") as collateral evidence of a stall. Our paper cited a possible estimation error of about six degrees, along with the reduction of apparent angle of attack due to pitch rate, as reasons to be wary of this interpretation. The full upward deflection of the elevator at impact indicates that the pilots may have pulled the control column back in a last ditch effort to reduce speed and delay the crash.

We also note that ground effect could have had no substantive influence on the occurrence or non-occurrence of a stall during the accident flight. This is readily demonstrated by modifying the computer code used for the performance calculations cited by the majority. Recalculation of test cases with no allowance for ground effect produces minor differences (typically: reductions of some 15 feet in maximum altitude and some 350 feet in distance covered) without affecting the presumed stall.

The conclusion that the aircraft *did not* stall can be drawn from evidence of a number of witnesses about the level attitude of the aircraft as it crossed the Trans-Canada Highway. ("It was a normal departure... but that levelling-off effect was abnormal"; "The aircraft's attitude appeared to be level as it crossed the Trans-Canada Highway"; "The plane was levelled off. The plane wasn't nose up or nose down. It was level"; "It looked very flat, just two or three degrees"; "The nose was not pointed up"; "The aircraft was pretty level... Very level.")

In conclusion, the Arrow Air DC-8 did not stall before it crashed.

3.3 Performance Not Consistent with Ice on Wings

Our paper *Critique of the Ice Contamination Hypothesis* ... also points to misinterpretations of the performance calculations reported by the majority.

The computer models (and the flight simulator modifications) extrapolated lift and drag values beyond the range of experimental data. The resulting steeply rising drag curve generated very large increases in drag for modest increments of angle of attack. Thus, the calculations allow minute amounts of "equivalent roughness" to overpower all four engines at take-off power.

Even if we were to accept the assumed effect of ice on lift and drag, we would have to reject the computed results because they depend on unrealistic assumptions about the crew's reactions. To make the computed trajectories "crash" at about the right distance, it was necessary to further assume that, when confronted with decaying airspeed and negative rate of climb, the crew would pull up and hold the aircraft at an angle of attack of 18 degrees. At this angle, aerodynamic buffet would warn the crew to lower the nose — with or without ice on the wings, with or without synthetic stall warning. In any event, corresponding fuselage attitudes of about 10 degrees contradict the observations of the tower controller ("It was a normal departure... but that levelling-off effect was abnormal") and a number of witnesses ("The aircraft's attitude appeared to be level ... "; "The plane was leveled off. The plane wasn't nose up or nose down"; "It looked very flat, just two or three degrees"; etc.).

The calculations cited by the majority take no account of the turn and sideslip which, we feel, are essential features of the accident flight path. The stall presumed in the calculations should at least coincide with the beginning of the turn. Those cases that lead to approximately correct altitude gain and distance show no such coincidence.

We noted in our (previously cited) paper that the flight data recorder indicates a deceleration near the end of the short flight on the order of what would be produced by aerodynamic drag on the standard (i.e., not iced up) aircraft with all engines stopped. The computer program cited by the majority can be used, not only to verify this, but also to find a better fit to the known characteristics of the accident flight — through the assumption that the engines start to spool down shortly after lift-off.

The most natural, tractable assumption for computing the observed performance is that of a massive power loss followed by the expected crew reaction of lowering the nose to try to maintain airspeed. The turn to the right may indicate that the power loss was most severe on that side. It may also indicate additional control problems.

4.0 Pre-Impact System Failures

4.1 Power Lost Before Crash

There is no doubt that all engines were turning just before the crash, nor that the right outboard engine (the number four engine) was turning slower than the others. But air passing through a jet engine keeps it turning even after an in-flight shutdown, so rotational speed does not necessarily equate to power production.

The majority could not determine if the low rotational speed of the number four engine was "the result of an in-flight power loss" or was "the result of tree fragment ingestion prior to ground impact." In our opinion, the evidence is conclusive that engine number four was operating at low power before it contacted trees.

The "tree model" shows the fuselage pitched up about nine degrees and yawed to the right at about 10 degrees when the tail struck the first tree. With this pitch angle, the engines could have ingested "tree fragments" for only part of the time that the aircraft plunged through the trees — for less than one second.

The "tree model" also shows that, when the aircraft first hit trees, it was banked to the right at about seven degrees. Since the wing tips are tilted up at about seven degrees with respect to the roots (6.5 degree dihedral), the two right-hand engines (numbers three and four) entered the tree canopy at virtually the same instant. It follows that "tree fragment ingestion prior to ground impact" cannot account for the vast differences in damage to these engines.

The spare conifers and slender deciduous trees typical of the accident site could not have damaged the number four engine extensively during this short period. We know this from the inlet guide vanes which present the first obstacle to foreign material entering an engine. Seventeen (of 23 total) inlet guide vanes of the number four engine were available for inspection. The leading edges of the inlet guide vanes "generally were in good condition" with no apparent damage from trees or other foreign material.

The bottom of the number four engine case was crushed both front and rear. The fractured blades on the first two (low pressure) compressor stages indicate that the (low pressure) shaft was in fact turning as the front of the engine was crushed; that is, the engine was either windmilling or producing some (unknown amount of) power at this instant. The turbine stages, attached to the same shaft as these compressor stages, were damaged as the back of the case was crushed an instant later. These turbine stages "exhibited relatively little rotational damage." In fact, there is no detectable rotational damage on the final turbine stage. When the engine case was crushed against it, rotation had already ceased.

Low rotational damage to turbine stages at the rear of the engine is consistent with high rotational damage to compressor stages near the front if, and only if, initial impact on the engine was near the front.

Thus, the low pressure spool of the number four engine was stopped during the small interval of time between the instants when the blades were torn from the compressor stages (by crushing at the front) and when the final turbine stage was damaged. Power produced during this time interval would augment the inertial torque tending to twist the hollow shaft. Yet, this shaft remained essentially untwisted on the number four engine.

The low pressure turbine shafts on the other three engines were all twisted in excess of 30 degrees — even though both front and rear stages showed heavy rotational damage. This is clear evidence that the number four engine was rotating substantially slower (and by inference producing substantially less power) than the other engines. This finding is substantiated by the open bleed valve on the number four engine, corresponding to idle power or less. Wood fibres found in this valve also suggest that it was open (hence the engine was not producing power) prior to any ingestion of "tree fragments."

The majority reports that attempts to compare the pre-impact power output of the number four engine to that of the others led to contradictory results. The manufacturer of the engines found little difference between the rotational speeds (and hence between the presumed power) at impact. CASB investigators concluded that this difference was greater than 40 per cent.

We note that large percentage differences in rotational speed would be consistent with small absolute differences if all engines were at low speed. The observation that the bleed valves on engines one, two, and three were closed is based on inference, not conclusive evidence. We believe that the pre-impact power output of these engines remains uncertain.

Both witnesses who observed the "orange/yellow glow" from directly under the flight path believed that the engines were not running (*Witness 1:* "The airplane passed right over my truck ... When it passed right over us, the engines were not running. I did not hear any whine from the engines. I had gone by there hundreds of times when planes were taking off and you could hear the engines. But I could not hear the engines yesterday. There was no whine but there was some type of rumble... I'm certain that when the aircraft passed over us the engines were not working." *Witness 2:* "I heard the noise. I looked, I could see the plane coming over. It didn't sound like engine noise... I live fairly close to the Sydney Airport and I've heard planes taking off before. This one didn't sound right.... There was no roar from him at all"). This "ear witness" testimony is all the more striking since the engines would sound louder than normal as the aircraft flew lower than normal over the trucks.

To us, spooling down of all engines provides a more plausible explanation of the tremendous deceleration than does a massive increase in drag due to 0.03 or 0.04 inches of ice on the wing.

4.2 Thrust Reversers May Have Been Deployed

The sliders on the lower tracks of all four thrust reverser assemblies suggested that the reversers had not been fully forward (that is, not latched in the stowed position) at the time of impact. The position of the number four thrust reverser doors further suggested that they had been deployed prior to impact. The majority concluded that the displacement of all the reverser assemblies (translation rings) and the damage to the number four unit were due to rearward "dragging action during impact." Thus, the majority ruled out in-flight deployment of a thrust reverser as a factor in this accident.

A different appreciation of the evidence may be gained by considering how the rotational damage on all engines establishes the direction of the initial impact force.

We have noted that the engines could not have been in contact with the trees for more than about a second during which the aircraft was pitched up and yawing to the right. Consideration of the possible magnitude and direction of resulting forces shows that tree contact prior to the main ground impact can not account for "dragging action" on the thrust reversers.

The direction of the initial ground impact force can be readily established from the rotational damage on the engines. The direction of twist on the low pressure shafts of the numbers one, two, and three engines indicates that initial impact was at the front of these engines. The low pressure shaft of the number four engine remained essentially untwisted. But, the progressively decreasing rotational damage shows that the number four engine also struck ground first at the front. Thus, the initial axial deceleration would have exerted high forward G-forces on all components of all engines — including all the thrust reversers.

The reversers (translating rings) are normally latched to prevent rearward movement. But, once unlatched, they move relatively easily on their sliders. Had the reversers been stowed in their normal (forward) position when the front of the engine struck the ground, decelerative forces would have tried to drive them even further forward, forcing the latch links even more firmly into the locked position. Under these circumstances, the sliders and witness marks would have been found at extreme forward positions, not "near" the forward positions as observed.

If, however, the reversers had been deployed (that is, positioned at the rear of their tracks) at the moment of initial impact, decelerative forces would have driven them forward. The forward motion of the translating rings would have tended to close the deflector doors. Under such circumstances, the deflector doors could be deployed, stowed, or anywhere in between at the time of subsequent secondary impacts. Witness marks from secondary impacts could correspond to the stowed or nearly stowed positions, or anywhere in between.

Since the cylinders of the hydraulic actuators are double acting, they would split from rapid forward extension as readily as from the rearward extension postulated in the majority report. Detailed examination of scuff marks on the interior of the cylinder walls might have been able to establish which way the pistons were moving at impact.

We also note that the S-shaped bends in the number four thrust reverser lower track (evident in Fig. 1.10.) suggest buckling due to compressive forces. The apparent failure in tension of the attachment links of the deflector door mechanisms also suggests failure during forward movement. These observations support the hypothesis that the reverser was driven forward by decelerative forces.

Similar re-interpretation could be made of the majority findings with respect to the other three reversers. Figures DO2. and DO3. show the deflector doors of the number one reverser, for example. The orientation and lack of continuity of scratches and buckles across the door/housing interfaces suggest that the doors were deployed at initial impact.

At least two of the thrust reverser control valves (which are located in the engine pylons) were apparently recovered. The position of the sliders in these valves may have shed additional light on the pre-impact status of the thrust reversers. Unfortunately, these parts appear to have been discarded without examination.

We believe that all the evidence cited by the majority can be re-interpreted in the light of the large axial decelerative forces at initial ground impact. Such re-interpretation supports the hypothesis that the number four and likely the other three thrust reversers were deployed prior to the crash.

4.3 Multiple Malfunctions

The majority concluded that the Arrow Air DC-8's flaps were extended to the expected 18-degree take-off position even though the wreckage yielded inconclusive and contradictory evidence.

The piston in one of the six recovered flap actuators left a clear imprint corresponding to 25-degree extension. Another had two imprints corresponding to 17- and to 32-degree extension. The remaining four actuators with less clear indications were initially assessed as corresponding to 23, 27, 40, and 43 degrees. Eight of 10 flap track pairs were recovered. Most tracks showed multiple imprints corresponding to a range of settings from 5 to 50 degrees. The flap position indicator read 38 degrees.

All three flap lockout cylinders were recovered, although in severely damaged condition. Two suggested that the flaps were fully extended, while the third suggested a setting near mid-range. These findings could be explained by two simultaneous hydraulic line failures. The majority found this explanation improbable and attributed the contradictory indications to post-impact damage.

To us, this contradictory evidence does not support a determination of a pre-impact flap position of 18 degrees. We are less ready than the majority to rule out improbable multiple failures in such a complex accident.

Multiple failures are also suggested by the landing gear, which remained extended. The captain, an experienced instructor/pilot, would have reacted to declining airspeed after take-off by calling for full power and raising the gear. Disintegration of the cockpit area precluded determination of the position of the landing gear lever. But, if the crew did attempt to raise the gear, the extended landing gear could signal another apparently independent failure.

We believe it unlikely that the contradictory evidence about flaps, spoilers, EPR gauges, N1 tachometers, and other systems can be explained separately through unrelated hypotheses. To us, the extent of the contradictory evidence suggests simultaneous multiple system failures due to a common cause.

5.0 In-Flight Fire/Explosion

5.1 Witnesses Saw Fire

On the day after the accident, one of the witnesses who saw the aircraft pass over his truck testified, "I think the right-hand side of the aircraft was on fire." He later explained that the "yellow/orange glow" seemed to come from the right-hand side "fairly close to the body" and it was so intense that he could see writing on the aircraft's tail. When asked to locate the source of the glow at the Board's public inquiry, he pointed to the cargo compartment at the juncture of the right wing and the fuselage.

The other eyewitness who saw the aircraft pass directly overhead said, "My first impression of the glow was that it was a fire." He could only say that the glow came from the "bottom side" of the aircraft. It was bright enough to illuminate the cab of his truck. This witness also noted that he lived by an airport and this light was not like any other he ever saw on an airplane.

The eyewitness who saw the aircraft pass in front of him from right to left stated, "I couldn't see the right-hand side of the airplane. But I could tell that it was very bright on that side of the plane, like something was on fire."

A witness who is not mentioned by the majority observed the take-off run of the Arrow Air DC-8 from a parking lot near the Gander Airport terminal building. This witness saw the Arrow Air DC-8 taxi out, heard the take-off, and then saw a flash and what appeared to be a "large orange oval object" which then "blew up" and "went into a million pieces." The witness located this "object" low in the sky in a direction that would have placed it on the extension of the runway somewhere close to the Trans-Canada Highway.

The possibility of a fire prior to the main explosion is reinforced by the other witness observations. The crew of an aircraft in the vicinity saw "the sky light up" a few seconds before the fireball of the main explosion. A witness on the ground reported that "there was a second burst of flame that shot up in the air as well. It would appear to me that there was a second explosion."

Thus, a review of the testimony relating to the "orange/yellow glow" reported by eyewitnesses leads us to conclude that this glow may have been a fire burning through the lower right fuselage near the wing root.

5.2 Medical Findings Questioned

Lethal levels of combustion products in toxicological samples show that a large number of victims continued to breath while exposed to fire. Based on the Official Registration of Death certificates, which describe death as instantaneous for all victims, we would have to conclude that there was a fire on board before the crash.

In April 1988, consultants for the Board re-examined injury patterns recorded during the autopsies. They concluded that many of the victims could have survived for up to five minutes. Analysis based on this finding led the majority to impute all evidence of inhaled combustion products to post-impact exposure. This implies that several victims must have been decapitated after surviving the crash and inhaling lethal combustion products.

A consulting pathologist who studied the available information independently advised us that the analysis of the majority does not rule out the possibility of a pre-impact fire. We understand that injury patterns do not provide definitive indication of survival time, or more specifically, of the time the victim continued to breath after injury.

The cause of death may have been clarified by correlating specific injury patterns with carbon monoxide levels. The results are all the more ambiguous since carbon monoxide levels seem uncorrelated with ground fire patterns. In any event, correlations based on location within a grid mean that the conclusions, in so far as they are valid, apply only in some average sense.

To us, the massive destruction of the aircraft suggests unsurvivable decelerative forces. A detailed analysis of these forces could have provided a cross check on the results of the injury pattern analysis.

We also note that the medical examinations found that all injuries consistent with a blast wave or shrapnel from an explosion could also have been sustained during the crash. Nevertheless, the medical report submitted in support of the majority finding indicates that "an explosion within a cargo area might then have its effects on passengers deflected and thus leave no trace on the victims."

5.3 Significant Circumstances

A variety of indirect, circumstantial evidence gives substance to eyewitness testimony suggesting a fire on the lower right-hand side of the fuselage. Such a fire may also explain the evidence of seemingly unrelated systems failures.

The majority explains that "considerable speculation" about an in-flight detonation "was fuelled by the fact that military personnel and equipment were aboard the flight and by the increasing world-wide incidence of terrorist activity. Also contributory to this speculation was the point of origin of the flight ... ."

The point of origin, Cairo, was suspect in that the security arrangements for loading the soldiers and their baggage were not ideal. Previous operations of Arrow Air for the MFO in Egypt had used El-Gorah Airport in the Sinai Desert. Construction at El-Gorah necessitated a last minute switch to Cairo. Troops of the 101st Airborne arrived from the Sinai in two Egyptian Air 737s about five hours before the arrival of the Arrow Air DC-8. Baggage and other equipment were trucked in and parked in a holding area prior to loading. Only a portion of the hold baggage was inspected.

After the first 45 minutes, the ground stay at Cairo was in darkness. Baggage and cargo were loaded without military supervision. Testimony at the Board's public inquiry revealed a chaotic process. The auxiliary power unit failed twice, leaving the aircraft in darkness with only one "semi-uniformed" guard believed to be an Egyptian soldier. It is reported that fighting broke out among the ground handlers beneath the tail of the aircraft, possibly during one of the blackouts.

The security arrangements at Cairo take on added significance in light of the bomb that exploded aboard a TWA 727 in April 1986, tearing a hole in the fuselage and killing four passengers. The bomb was reported to consist of a small amount of plastic explosive about the size of two cigarette packs of a design favoured by Palestinian terrorists. It exploded under the seat of a passenger who had boarded in Cairo and left the aircraft during a stopover in Rome.

The day after the Arrow Air disaster, a group calling itself the "Islamic Jihad" claimed responsibility. We understand that the claim was made to the media and also by means of a telephone call from Lebanon to the CASB headquarters in Hull on 13 December 1985.

The "Islamic Jihad" or "Islamic Holy War", a secretive pro-Iranean terrorist group, had previously claimed responsibility for two separate car bombings of the U.S. embassy in Beirut, murder of the president of the American University of Beirut, laying mines in the Red Sea, and the kidnapping of American, Russian and French nationals. The organization had demonstrated great sophistication in the use of explosives and may have been responsible for the terrorist attack that killed 241 American members of the multinational peacekeeping force at Beirut Airport in October 1983. This attack was a major political setback for the U.S. administration who stood accused of failing to ensure the safety of American peacekeeping forces. Terrorist groups would certainly have been eager to repeat what, from their point of view, was a major success.

In July 1985, five months before the Arrow Air accident, the "Islamic Jihad" claimed responsibility for a bomb attack that killed 27 at Copenhagen, Denmark. Anonymous spokesmen for the organization announced that the attack was in retaliation for raids in Southern Lebanon and warned that terrorist operations would no longer be confined to the middle east.

At the time of the Arrow Air accident, the U.S. government was negotiating with the "Islamic Jihad" for the release of six American hostages.

The remaining factor leading to "considerable speculation" of in-flight detonation noted by the majority concerns "the fact that military personnel and equipment were aboard the flight."

On 26 February 1986, an incident described as a "catastrophe waiting to happen" occurred at Norton Air Force Base near San Bernardino, California. A bag being loaded on a DC-8 military charter broke open, revealing contraband explosive material. A search of the baggage found a variety of detonator cords, machine gun ammunition, blasting caps, slap flares, and other explosive materials.

Another military charter was involved in a similar incident at Oklahoma City on 19 April 1986. A precautionary search after a bomb threat "resulted in the recovery of various items of military ordinance which were being transported without authorization as souvenirs."

A bulletin issued by the Director of Civil Aviation Security noted that "among the items recovered was a trip flare with the triggering pin loosened, rendering it extremely dangerous." It went on to note that "if the trip-flare had been set off a magnesium fire would have resulted." The bulletin also stated that "the U.S. Army Explosive Ordinance Disposal Unit disclosed that the item, if triggered, would have resulted in a severe fire and probable crash of the aircraft."

These incidents, which occurred several months after the Arrow Air DC-8 accident, suggest that clues about the cause might be found in the uninspected baggage. The majority found that "the integrity of Class D cargo compartment was compromised because flight was undertaken with two missing side panels in the number three cargo pit." These panels provide a flame resistant lining and prevent ventilation so as to suffocate any fire that may break out. There are neither alarms nor extinguishing systems. Thus, a fire could propagate undetected in a cargo compartment missing some of these panels.

A magnesium fire resulting from accidental detonation of a "trip flare" in a forward cargo compartment could produce an intense glow with no apparent flames as it burns through the lower fuselage. The intense heat generated by such a fire could destroy control cables and other systems with unpredictable, catastrophic results. In addition to multiple system failures, the consequences could include false cockpit warnings. The crew may be disabled. If not, they may be unable to raise the landing gear, may discharge a fire bottle, and may even attempt to abort the take-off.

In short, a single hypothesis of fire or explosion in a cargo hold can explain many aspects of the accident which need diverse and at times far-fetched assumptions with the ice-contamination hypothesis. These include contradictory evidence about engines, thrust reversers, and flaps; right turn and yaw despite full opposite control; failure to raise the gear despite loss of airspeed; an intentionally discharged fire bottle; inconsistent EPR and N1 tachometer readings.

We would expect much of the evidence of in-flight detonation or fire to be obliterated by the subsequent ground fire. However, we would also expect that meticulous scrutiny of the wreckage might uncover definitive residual signs.

5.4 Incomplete Wreckage Analysis

The section "Fire Investigation" in the International Civil Aviation Organization's *Manual of Accident Investigation* outlines techniques for examining wreckage to determine if a post-crash ground fire could have masked evidence of an earlier in-flight fire.

The most potent technique is to attempt to "reconstruct the aircraft from the remaining parts in order to detect a pattern" in soot deposits or other signs of fire. Patterns in the flight direction would indicate the presence of an in-flight fire, as would continuity of patterns across lines of failure. Lack of soot deposits on fracture surfaces adjacent to a burned surface would indicate that the fracture occurred after the surface had been exposed to fire.

The examination of the wreckage conducted in support of the majority findings was described as follows:

> "All wreckage was recovered from the site and moved to a secure hangar at the Gander Airport, where it was arranged in a grid pattern which matched the grid pattern established at the site. A thorough examination of the wreckage was completed, and further selected components were forwarded to the CASB's Engineering Laboratory in Ottawa."

We understand that the examination of the wreckage in the hangar was completed in several days. There are no records of attempts to "reconstruct the aircraft from the remaining parts" in order to detect or disprove the presence of pre-crash fire. Wreckage not selected for forwarding to Ottawa was bulldozed into piles and later discarded. Accordingly, our efforts to evaluate the evidence for signs of in-flight fire had to be based on an incomplete photographic record.

Hundreds of photographs were taken of the vast destruction at the accident site. Most of the wreckage is unrecognizably fragmented, and the random scatter of the debris seems to belie a sequential breakup. We could not conduct a systematic review since the photographs not needed to support the majority analysis were not organized or labelled. An index relating specific items to the survey grid was not available.

We were particularly interested in the continuity of soot patterns between the edges and frames of doors, emergency exits, and access hatches. As can be seen on Figure DO4., sections of the fuselage with missing doors and windows and evidence of heat discoloration were available for study. We do not know how many doors were recovered, but photographs show that a number were available for analysis. Figure DO5. shows one of the emergency exits. Soot around the edges and blistering of the paint indicate that it had been exposed to severe fire. An attempt to mate this exit with its frame may have helped establish whether the fire occurred in the air or on the ground.

Figure DO6. shows the exterior surface of another door with fire evidence on the edges. This door shows post-crash damage, but no evidence of buckling that might be expected if impact forces had been transferred through the frames. Figure DO7. shows the inner surface of the same door. The burn marks spreading from one edge could suggest that an internal fire may have burned out the seal while the door was still attached. We note that the fire which damaged the upholstery and exposed the frame near the window did not melt the window's outer layer.

Stronger evidence can be observed on Figure DO8. and Figure DO9. which show exterior and interior surfaces of a section of fuselage around a window. Lack of burn evidence on the frames of the adjacent windows indicates a highly localized fire originating on the inside. The soot surrounding the exterior of the empty window opening suggests a flash from an explosion which shattered the window. The relatively light burn marks on the interior also suggest an explosion, since we would expect more severe burning from a fire sufficiently intense to melt both layers of the window. More concrete evidence may have been obtained from detailed microscopic analysis of the window edges.

Figures DO8. and DO9. provide convincing, if not conclusive, evidence that the soot was deposited around the window before the section separated from the fuselage. The fracture surface near the lower edge of the window opening is free of soot deposits or other evidence of exposure to fire. The piece of frame which separated from the top of the window also left a strip clear of soot. Thus, a fire must have occurred before the section separated; that is, before the crash. Since the part in question has been discarded and we could find no other photographs, we were unable to further substantiate this finding.

In the absence of documentation and explanation of apparently anomalous photographic evidence, we were unable to accept the majority's attribution of all burn damage to post-crash fire.

There is also evidence of detonations on the aircraft. Firemen who arrived on the accident scene some 15 minutes after the crash noted some 30 to 40 explosions, some of which were large enough to cause "mounds of rubble to lift several feet into the air." The majority attributes these explosions to "normal bursting of pressure vessels ... due to the heat of the fire." But pressure vessels are equipped with safety valves precisely to prevent explosion. More detailed consideration suggests the possibility of both post-crash and pre-crash detonations from explosive devices.

An explosive expert acting as a consultant for the insurer examined some of the wreckage in the hangar at Gander. He believed he found evidence of an in-flight explosion. This evidence included a roughly circular hole some 11 inches in diameter in a fuselage sidewall. The hole, located just above the floor line in the passenger cabin, seemed to be punched out explosively. The fuselage section showed no damage other than the outward pucker around the hole (Figure DO10.). The partial window frame above the hole seems to be distorted outward as if from an internal blast.

The consultant believed that the hole could not have been formed in the panel after it had separated without other damage to the interior surface. But, an explosion in the passenger cabin while the sidewall was still attached to the floor may well have produced such damage. As would be expected in view of the extensive weathering of the debris, forensic examination found no evidence of explosive residue.

The majority attributes the hole to damage occurring during impact. We believe that such a hole could not have been punched in an unattached section without further damage and without indication of what might have caused it. Accordingly, we hold the consultant's hypothesis credible.

Our own examination of photographs of the wreckage found more evidence of possible explosions. Figure DO11. shows a substantial explosively ripped hole apparently on the underside of the aircraft. Figure DO12. shows an interior view. We could not establish the location on the aircraft, but the wide extent of battered and crushed ribs might be supposed to be the result of impact by material blown about by an explosion. Additional detail shown in Figure DO13. shows chips removed with no apparent local deformation. Such damage suggests high fracture rates typical of explosions.

A host of complex control breakdowns could ensue if the kind of battering illustrated in Figure DO12. were to occur in the ceiling of a forward baggage compartment where cables pass on way to the engines and flight controls. Such common cause failures could account for seemingly improbable simultaneous runaway flaps, in-flight deployment of thrust reversers, along with inability to raise the landing gear.

We accept these and similar photographs as convincing evidence of an in-flight fire and possible evidence of an in-flight explosion. But, in view of the nature of our review, we cannot reasonably speculate on the resulting damage to aircraft systems.

6.0 Conclusions

6.1 Findings

The following findings are further to, or in contrast with, those of the majority:

- Members of the cockpit crew performed their duties without apparent fault.
- Weight and balance considerations were not factors in this accident.
- Ice contamination was not a factor in this accident.
- The right outboard engine (the number four engine) was operating at low power before contacting trees.
- All four thrust reversers may have been deployed prior to impact.
- Fire broke out on board while the aircraft was in flight, possibly due to a detonation in a cargo compartment.
- The determination of the causes and factors that led to this occurrence was severely hampered by the lack of information that could have been provided by a thorough effort to analyze and reconstruct the wreckage.

6.2 Causes

An in-flight fire that may have resulted from detonations of undetermined origin brought about catastrophic system failures.

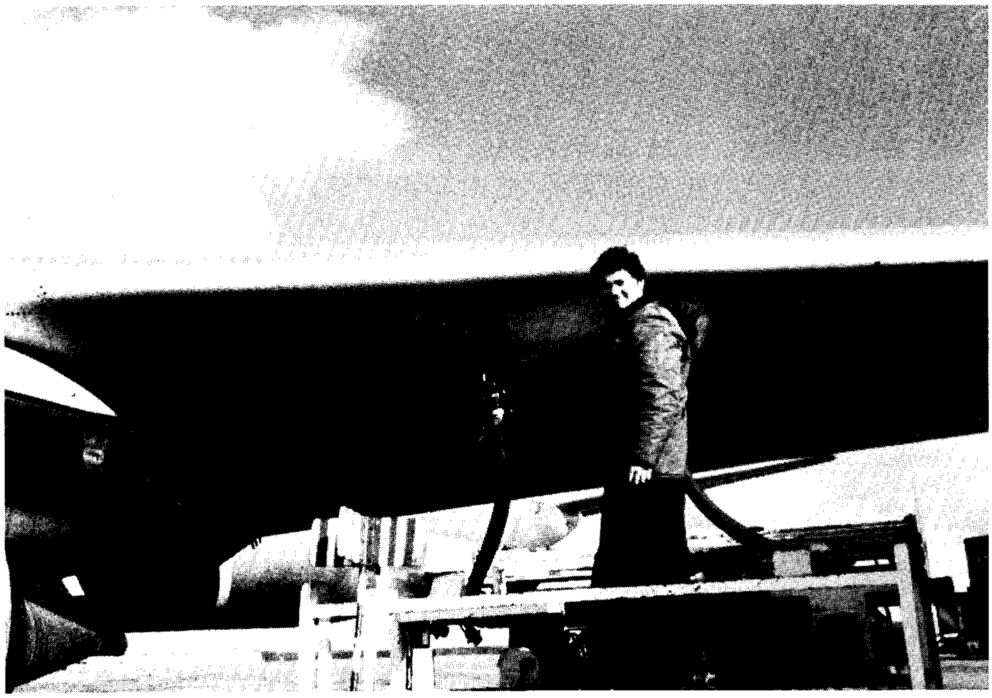

Figure DO1. Refueller's view of DC-8 leading edge

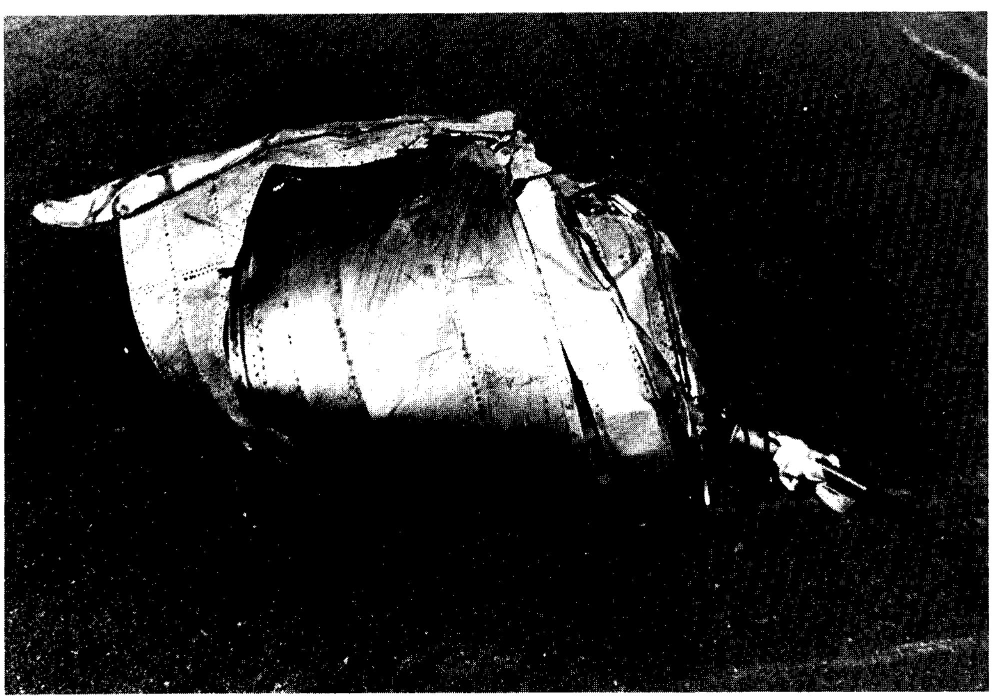

Figure DO2. Thrust reverser #1 — Outboard side

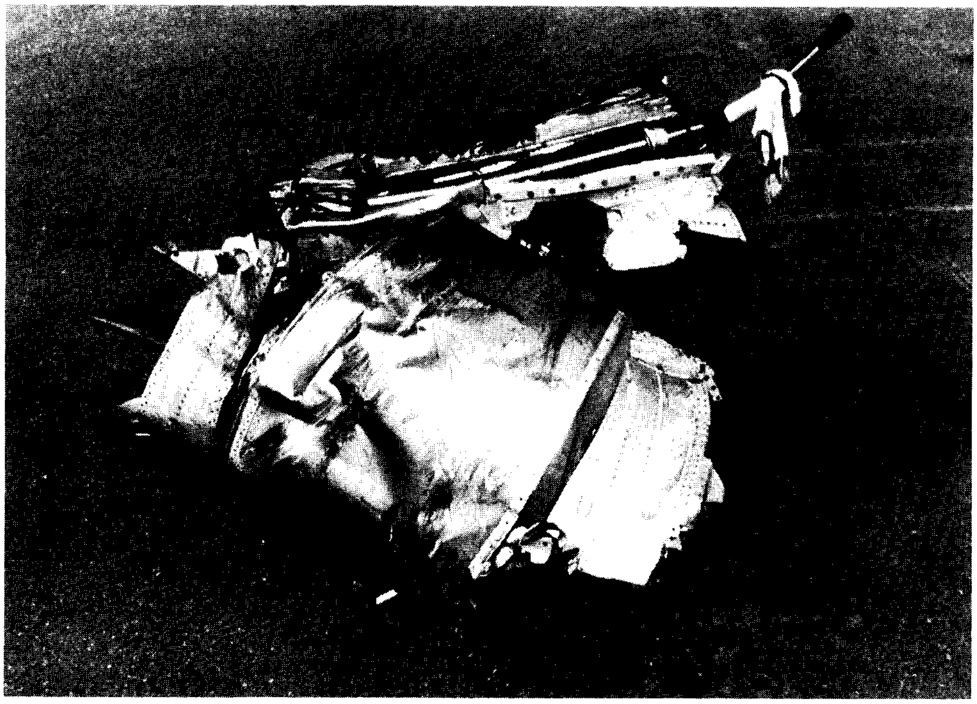

Figure DO3. Thrust reverser #1 — Inboard side

Figure DO4. Fire-damaged fuselage section

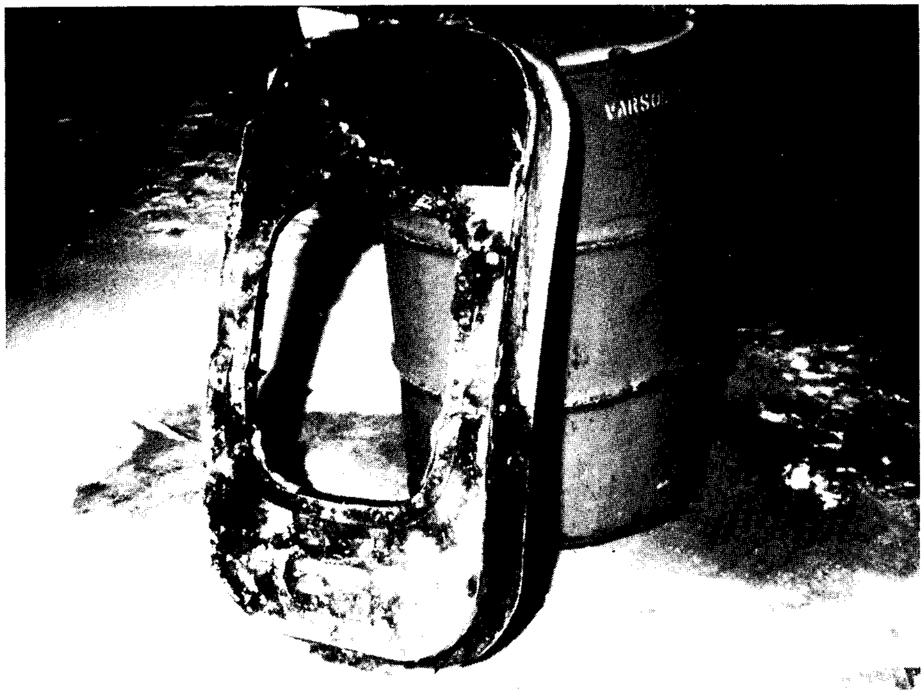

Figure DO5. Emergency exit showing soot deposits around edges

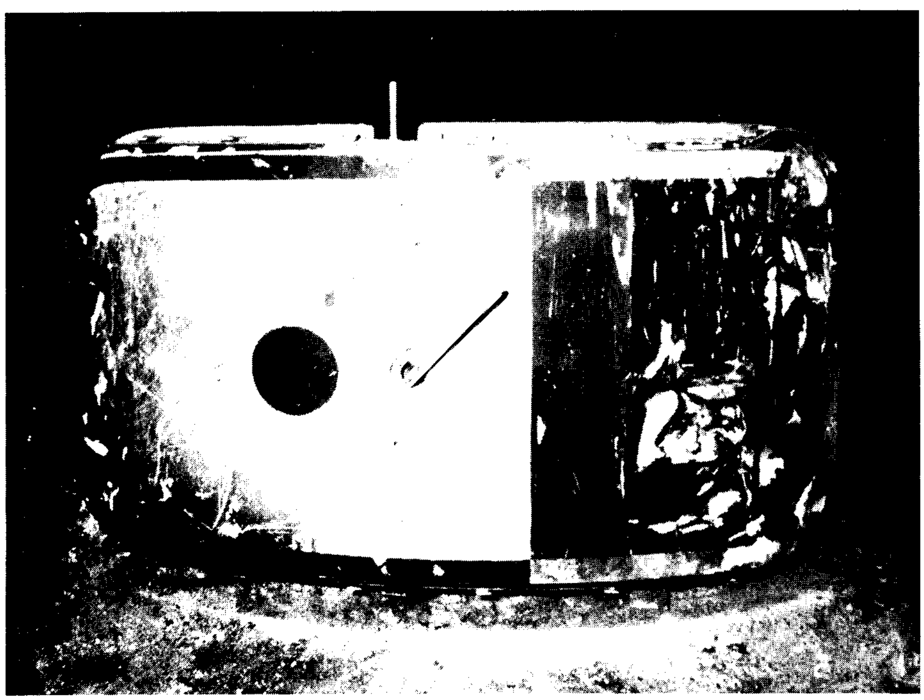

Figure DO6. Exterior of damaged door

Figure DO7. Inner surface of damaged door

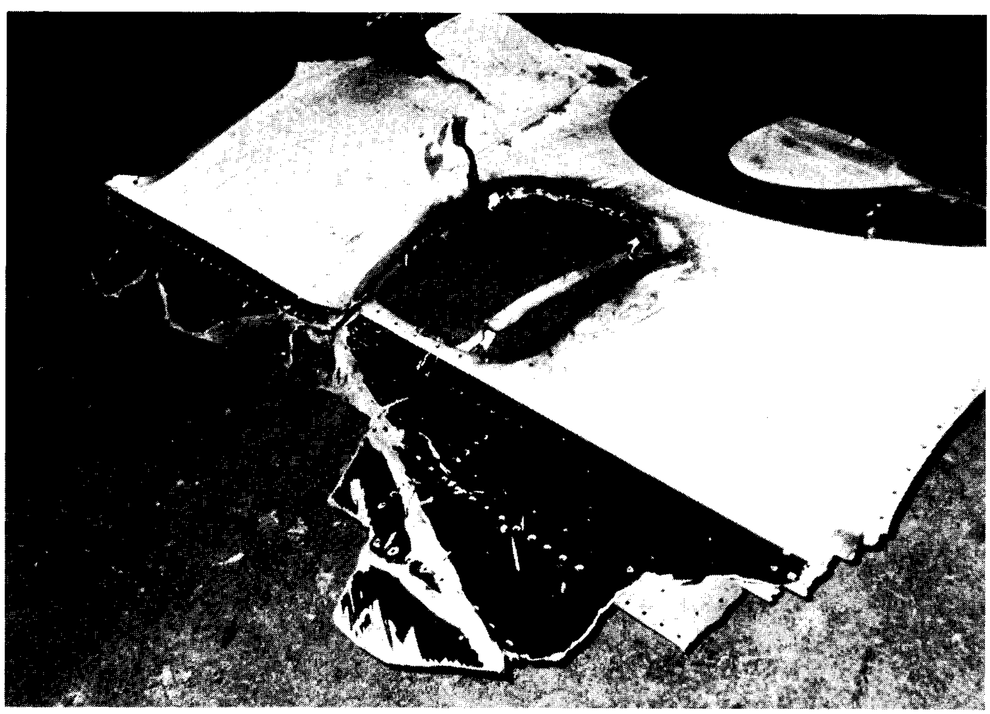

Figure DO8. Exterior surface of fuselage section

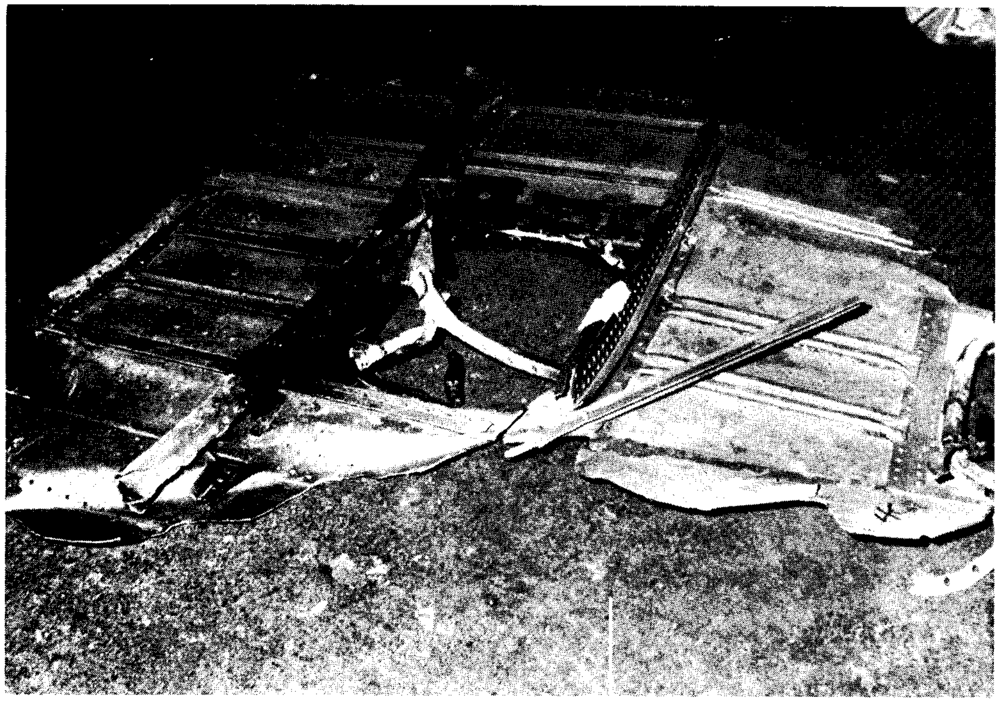

Figure DO9. Interior surface of fuselage section

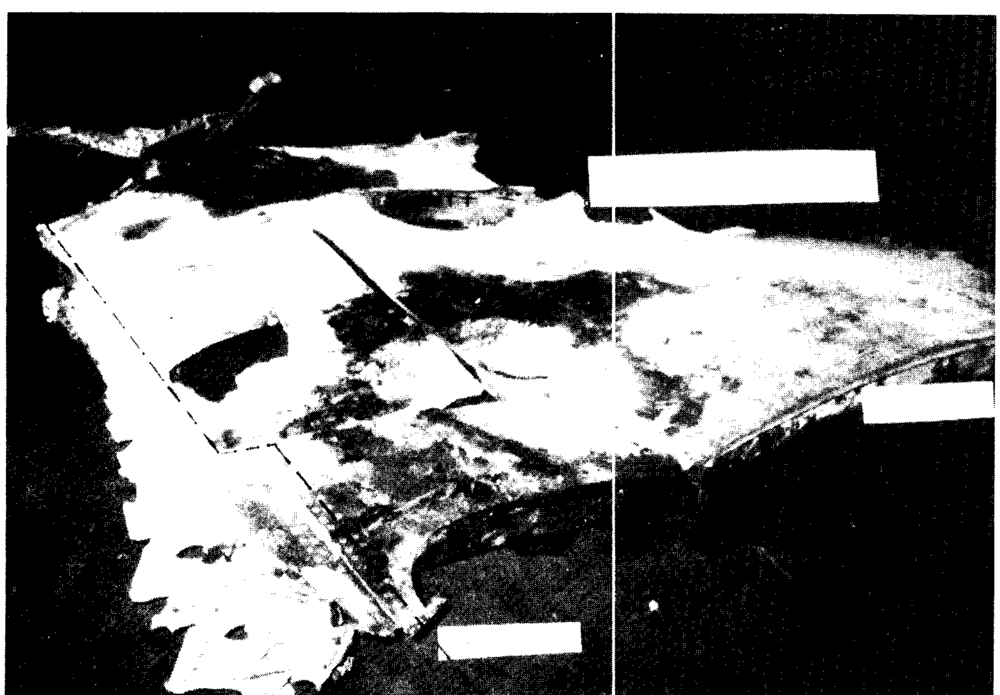

Figure DO10. Explosively punched hole in fuselage panel

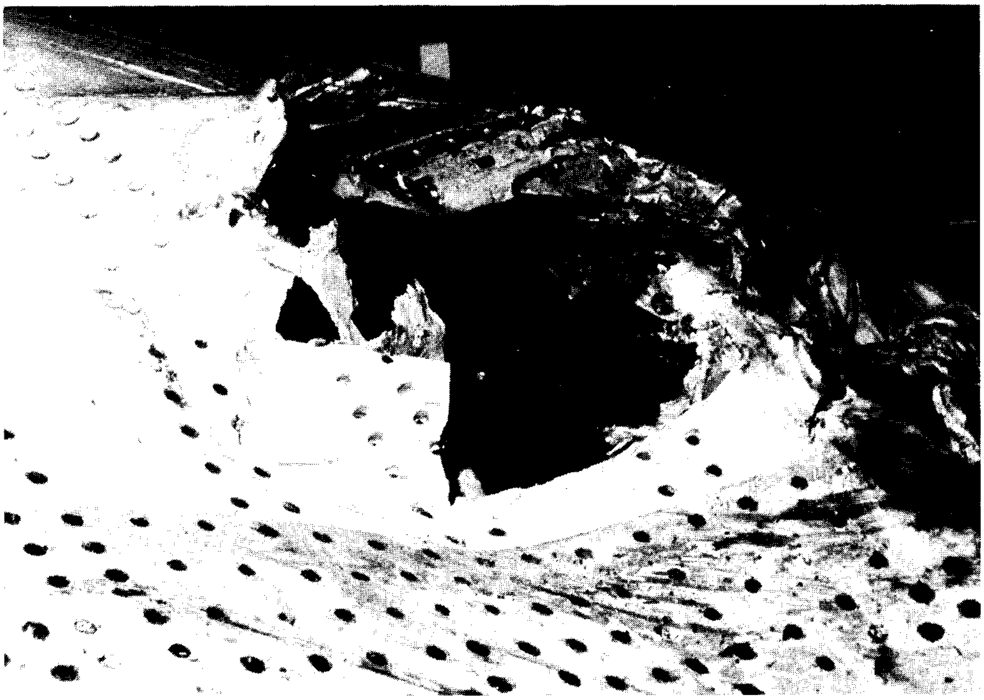

Figure DO11. Hole apparently ripped by explosion

Figure DO12. Interior view showing extensive battering

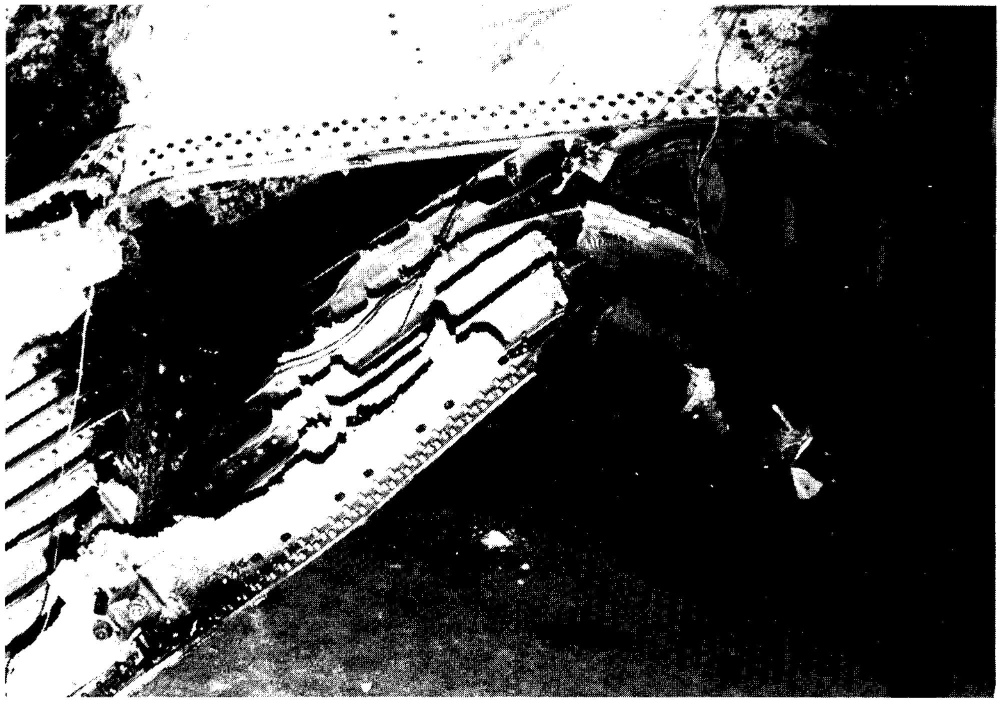

Figure DO13. Possible explosive fracture