(xi) Containers and items of cargo ejected from the fuselage aperture in the forward hold, together with pieces of detached structure, collided with the empennage severing most of the left tailplane, disrupting the outer half of the right tailplane, and damaging the fin leading edge structure.

(xii) The forward fuselage and flight deck area separated from the remaining structure within a period of 2 to 3 seconds.

(xiii) The No 3 engine detached when it was hit by the separating forward fuselage.

(xiv) Most of the remaining aircraft disintegrated while it was descending nearly vertically from 19,000 to 9,000 feet.
Figure C-1
1.12.4 Examination of engines

All four engines had struck the ground in Lockerbie with considerable velocity and therefore sustained major damage, in particular to most of the fan blades. The No 3 engine had fallen 1,100 metres north of the other three engines, striking the ground on its rear face, penetrating a road surface and coming to rest without any further change of orientation i.e. with the front face remaining uppermost. The intake area contained a number of loose items originating from within the cabin or baggage hold. It was not possible initially to determine whether any of the general damage to any of the engine fans or the ingestion noted in No 3 engine intake occurred whilst the relevant engines were delivering power or at a later stage.

Numbers 1, 2 and 3 engines were taken to British Airways Engine Overhaul Limited for detailed examination under AAIB supervision in conjunction with a specialist from the Pratt and Whitney Engine Company. During this examination the following points were noted:

(i) No 2 engine (situated closest to the site of the explosion) had evidence of blade "shingling" in the area of the shrouds consistent with the results of major airflow disturbance whilst delivering power. (This effect is produced when random bending and torsional deflection occurs, permitting the mid-span shrouds to disengage and repeatedly strike the adjacent aerofoil surfaces of the blades). The interior of the air intake contained paint smears and other evidence suggesting the passage of items of debris. One such item of significance was a clear indentation produced by a length of cable of diameter and strand size similar to that typically attached to the closure curtains on the baggage containers.

(ii) No 3 engine, identified on site as containing ingested debris from within the aircraft, nonetheless had no evidence of the type of shingling seen on the blades of No 2 engine. Such evidence is usually unmistakable and its absence is a clear indication that No 3 engine did not suffer a major intake airflow disturbance whilst delivering significant power. The intake structure was found to have been crushed longitudinally by an impact on the front face although, as stated earlier, it had struck the ground on its rear face whilst falling vertically.

(iii) All 3 engines had evidence of blade tip rubs on the fan cases having a combination of circumference and depth greater than hitherto seen on any investigation witnessed on Boeing 747 aircraft by the Pratt and Whitney specialists. Subsequent examination of No 4 engine confirmed that it had a
The No 3 engine had fallen 1,100 metres north of the other three engines, striking the ground on its rear face, penetrating a road surface and coming to rest without any further change of orientation i.e. with the front face remaining uppermost. The intake area contained a number of loose items originating from within the cabin or baggage hold. It was not possible initially to determine whether any of the general damage to any of the engine fans or the ingestion noted in No 3 engine intake occurred whilst the relevant engines were delivering power or at a later stage.
1. **Factual Information**

1.1 **History of the Flight**

Boeing 747, N739PA, arrived at London Heathrow Airport from San Francisco and parked on stand Kilo 14, to the south-east of Terminal 3. Many of the passengers for this aircraft had arrived at Heathrow from Frankfurt, West Germany on a Boeing 727, which was positioned on stand Kilo 16, next to N739PA. These passengers were transferred with their baggage to N739PA which was to operate the scheduled Flight PA103 to New York Kennedy. Passengers from other flights also joined Flight PA103 at Heathrow. After a 6 hour turnaround, Flight PA103 was pushed back from the stand at 18.04 hrs and was cleared to taxy on the inner taxiway to runway 27R. The only relevant Notam warned of work in progress on the outer taxiway. The departure was unremarkable.

Flight PA103 took-off at 18.25 hrs. As it was approaching the Burnham VOR it took up a radar heading of 350° and flew below the Bovingdon holding point at 6000 feet. It was then cleared to climb initially to flight level (FL) 120 and subsequently to FL 310. The aircraft levelled off at FL 310 north west of Pole Hill VOR at 18.56 hrs. Approximately 7 minutes later, Shanwick Oceanic Control transmitted the aircraft's oceanic clearance but this transmission was not acknowledged. The secondary radar return from Flight PA103 disappeared from the radar screen during this transmission. Multiple primary radar returns were then seen fanning out downwind for a considerable distance. Debris from the aircraft was strewn along two trails, one of which extended some 130 km to the east coast of England. The upper winds were between 250° and 260° and decreased in strength from 115 kt at FL 320 to 60 kt at FL 100 and 15 to 20 kt at the surface.

Two major portions of the wreckage of the aircraft fell on the town of Lockerbie; other large parts, including the flight deck and forward fuselage section, landed in the countryside to the east of the town. Residents of Lockerbie reported that, shortly after 19.00 hrs, there was a rumbling noise like thunder which rapidly increased to deafening proportions like the roar of a jet engine under power. The noise appeared to come from a meteor-like object which was trailing flame and came down in the north-eastern part of the town. A larger, dark, delta shaped object, resembling an aircraft wing, landed at about the same time in the Sherwood area of the town. The delta shaped object was not on fire while in the air, however, a very large fireball ensued which was of short duration and carried large amounts of debris into the air, the lighter particles being deposited several miles downwind. Other less well defined objects were seen to land in the area.
N739PA first flew in 1970 and spent its whole service life in the hands of Pan American World Airways Incorporated. Its Certificate of Airworthiness was issued on 12 February 1970 and remained in force until the time of the accident, at which time the aircraft had completed a total of 72,464 hours flying and 16,497 flight cycles. Details of the last 4 maintenance checks carried out during the aircraft's life are shown below:

<table>
<thead>
<tr>
<th>DATE</th>
<th>SERVICE</th>
<th>HOURS</th>
<th>CYCLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 Sept 88</td>
<td>C Check (Interior upgrade)</td>
<td>71,502</td>
<td>16,347</td>
</tr>
<tr>
<td>2 Nov 88</td>
<td>B Service Check</td>
<td>71,919</td>
<td>16,406</td>
</tr>
<tr>
<td>27 Nov 88</td>
<td>Base 1</td>
<td>72,210</td>
<td>16,454</td>
</tr>
<tr>
<td>13 Dec 88</td>
<td>Base 2</td>
<td>72,374</td>
<td>16,481</td>
</tr>
</tbody>
</table>

The Craf modification programme was undertaken in September 1987. At the same time a series of modifications to the forward fuselage from the nose back to station 520 (Section 41) were carried out to enable the aircraft to continue in service without a continuing requirement for structural inspections in certain areas.

All Airworthiness Directives relating to the Boeing 747 fuselage structure between stations 500 and 1000 have been reviewed and their applicability to this aircraft checked. In addition, Service Bulletins relating to the structure in this area were also reviewed. The applicable Service Bulletins, some of which implement the Airworthiness Directives are listed below together with their subjects. The dates, total aircraft times and total aircraft cycles at which each relevant inspection was last carried out have been reviewed and their status on aircraft N739PA at the time of the accident has been established.

N739PA Service Bulletin compliance:

**SB 53-2064**  Front Spar Pressure Bulkhead Chord Reinforcement and Drag Splice Fitting Rework.

Modification accomplished on 6 July 1974.
Post-modification repetitive inspection IAW (in accordance with) AD 84-18-06 last accomplished on 19 November 1985 at 62,030 TAT hours (Total Aircraft Time) and 14,768 TAC (Total Aircraft Cycles).
August 31, 1995

Mr. John Barry Smith  
551 Country Club Drive  
Carmel Valley, California 93924  

Dear Barry:  

Thank you for your letter of August 16th regarding the destruction of Pan Am 103 over Lockerbie, Scotland in 1988.  

The January, 1989 issue of Flight International does not contain the picture of the reconstructed aircraft located at the Royal Aircraft Establishment at Farnborough. That picture is contained in a much later edition of Flight International, and might be made available to you if you contact the publisher.  


I enjoyed our telephone conversation and I thank you for your continuing interest in aviation safety.  

Sincerely yours,  

[Signature]

JVB.amg
and outboard but also rearwards. The blast effects on the aircraft skin were onto stringer 39L but centered at station 710 (Figure F-12). Downwards crushing at the top, and rearwards distortion of frame 700 was apparent as well as rearwards distortion of frame 720.

With the two container reconstructions placed together it became apparent that a relatively mild blast had exited container 4041 through the rear lower face to the left of the curtain and impinged at an angle on the forward face of container 7511. This had punched a hole, Figure F-10, approximately 8 inches square some 10 inches up from its base and removed the surface of this face inboard from the hole for some 50 inches. Radiating out from the hole were areas of sooting, and other black deposits, extending to the top of the container. No signs were present of any similar damage on other external or internal faces of container 7511 or the immediately adjacent containers 14R and 21R.

The above assessment of the directions of distortion, comparison of damage to both containers, and the related airframe damage adjacent to the container position, enabled the most probable lateral and vertical location of the IED to be established as shown in Figure F-13, centered longitudinally on station 700.

8. Conclusions

Throughout the general examination of the aircraft wreckage, direct evidence of blast damage was exhibited on the airframe only in the area bounded, approximately, by stations 700 and 720 and stringers 38L and 40L. Blast damage was found only on pieces of containers 4042 and 7511, the relative location and character of which left no doubt that it was directly associated with airframe damage. Thus, these two containers had been loaded in positions 14L and 21L as recorded on the Pan Am cargo loading documents. There was also no doubt that the IED had been located within container 14L, specifically in its aft outboard quarter as indicated in Figure F-13, centered on station 700.

Blast damage to the forward face of container 7511 was as a direct result of hot gases/fragments escaping from the aft face of container 4041. No evidence was seen to suggest that more than one IED had detonated on Flight PA103.
With the two container reconstructions placed together it became apparent that a relatively mild blast had exited container 4041 through the rear lower face to the left of the curtain and impinged at an angle on the forward face of container 7511. This had punched a hole, Figure F-10, approximately 8 inches square some 10 inches up from its base and removed the surface of this face inboard from the hole for some 50 inches. Radiating out from the hole were areas of sooting, and other black deposits, extending to the top of the container. No signs were present of any similar damage on other external or internal faces of container 7511 or the immediately adjacent containers 14R and 21R.
part of the aircraft had broken away from the rear early in the disintegration process. The bodies of 10 passengers were not recovered and of these, 8 had been allocated seats in rows 23 to 28 positioned over the wing at the front of the economy section. The fragmented remains of 13 passengers who had been allocated seats around the eight missing persons were found in or near the crater formed by the wing. Whilst there is no unequivocal proof that the missing people suffered the same fate, it would seem from the pattern that the missing passengers remained attached to the wing structure until impact.

1.14 Fire

Of the several large pieces of aircraft wreckage which fell in the town of Lockerbie, one was seen to have the appearance of a ball of fire with a trail of flame. Its final path indicated that this was the No 3 engine, which embedded itself in a road in the north east part of the town. A small post impact fire posed no hazard to adjacent property and was later extinguished with water from a hose reel. The three remaining engines landed in the Netherplace area of the town. One severed a water main and the other two, although initially on fire, were no risk to persons or property and the fires were soon extinguished.

A large, dark, delta shaped object was seen to fall at about the same time in the Sherwood area of the town. It was not on fire while in the air, however, a fireball several hundred feet across followed the impact. It was of relatively short duration and large amounts of debris were thrown into the air. The lighter particles being carried several miles downwind, while larger pieces of burning debris caused further fires, including a major one at the Townfoot Garage, up to 350 metres from the source. It was determined that the major part of both wings, which included the aircraft fuel tanks, had formed the crater. A gas main had also been ruptured during the impact.

At 19.04 hrs the Dumfries Fire Brigade Control received a call from a member of the public which indicated that there had been a "huge boiler explosion" at Westacres, Lockerbie. However, subsequent calls soon made it clear that it was an aircraft which had crashed. At 19.07 hrs the first appliances were mobile and at 19.10 hrs one was in attendance in the Rosebank area. Multiple fires were identified and it soon became apparent that a major disaster had occurred in the town and the Fire Brigade Major Incident Plan was implemented. During the initial phase 15 pumping appliances from various brigades were deployed but this number was ultimately increased to 20.

At 22.09 hrs the Firemaster made an assessment of the situation. He reported that there was a series of fires over an area of the town centre extending 1/4 by ½ mile. The main concentration of the fire was in the southwest of the town around
process. The bodies of 10 passengers were not recovered and of these, 8 had been allocated seats in rows 23 to 28 positioned over the wing at the front of the economy section. The fragmented remains of 13 passengers who had been
7. Recorded radar information

7.1 Introduction

Recorded radar information on the aircraft was available from 4 radar sites. Initial analysis consisted of viewing the recorded information as it was shown to the controller on the radar screen, from this it was clear that the flight had progressed in a normal manner until Secondary Surveillance Radar (SSR) was lost. There was a single primary return received by both Great Dun Fell and Claxby radars approximately 16 seconds before SSR returns were lost. The Lowther Hill and St. Annes radars did not see this return. The Great Dun Fell radar recording was watched for 1 hour both before and after this single return for any signs of other spurious returns, but none was seen. The return was only present for one paint and no explanation can be offered for its presence.

7.2 Limitations of recorded radar data

Before evaluating the recorded radar data it is important to highlight limitations in radar performance that must be taken into account when interpreting primary radar data. The radar system used for both primary and secondary radar utilised a rotating radar transmitter/receiver (Head). This means that a return was only visible whilst the radar head was pointing at the target, commonly called painting or illuminating the target. In the case of this accident the rotational speeds of the radar heads varied from approximately 10 seconds for the Lowther Hill Radar to 8 Seconds for the Great Dun Fell Radar.

Whilst it was possible to obtain accurate positional information within a resolution of 0.09° of bearing and ± 1/16 nautical mile range for an aircraft from SSR, incorporating mode C height encoding, primary radar provided only slant range and bearing and therefore positional information with respect to the ground was not accurate.

The structural break-up of an aircraft releases many items which were excellent radar reflectors eg. aluminium cladding, luggage containers, sections of skin and aircraft structure. These and other debris with reflective properties produce "clutter" on the radar by confusing the radar electronics in a manner similar to chaff ejected by military aircraft to avoid radar detection.

Even when the target is not masked by clutter repetitive detection of individual targets may not be possible because detection is a function of the target effective area which, for wreckage with its irregular shape, is not constant but fluctuates wildly. These factors make it impossible to follow individual returns through successive sweeps of the radar head.
Figure C-8

The end of the recorded signals from the CVR of the final flight of N739PA.
The CVR tape was listened to for its full duration and there was no indication of anything abnormal with the aircraft, or unusual crew behaviour. The tape record ended, at 19.02:50 hrs ±1 second, with a sudden loud sound on the CAM channel followed almost immediately by the cessation of recording whilst the crew were copying their transatlantic clearance from Shanwick ATC.
Examination of the torn edges of the fuselage skin did not indicate the presence of any pre-existing structural or material defects which could have accounted for the separation of this section of the fuselage. Equally so, there were no signs of explosive blast damage or sooting evident on any part of the structure or the interior fittings. It was noted however that a heavy, semi-elliptical scuff mark was present on the lower right side of the fuselage at approximately station 360. This was later matched to the intake profile of the No 3 engine.
skin which formed a 'star-burst' fracture pattern around the shatter zone. Where these panels formed the boundary of the shatter zone, the metal in the immediate locality was ragged, heavily distorted, and the inner surfaces were pitted and sooted - rather as if a very large shotgun had been fired at the inner surface of the
fuselage at close range. In contrast, the star-burst fractures, outside the boundary
damage. It was evident, from the main wreckage layout, that the explosion had occurred in the forward cargo hold and, although all baggage container wreckage was examined, only items from this area which showed the relevant characteristics were considered for the reconstruction. Discrimination between
region of tearing and petalling around the shatter zone. It also identified a number of other regions of structural damage, remote from the explosion, which were clearly associated with severe and rapidly applied pressure loads acting normal to the skin's internal surface. These were sufficiently sharp-edged to pre-empt the resolution of pressure induced loads into membrane tension stresses in the skin; instead, the effect was as though these areas of skin had been struck a severe 'pressure blow' from within the hull.
The results of the post mortem examination of the victims indicated that the majority had experienced severe multiple injuries at different stages, consistent with the in-flight disintegration of the aircraft and ground impact. There was no pathological indication of an in-flight fire and no evidence that any of the victims had been injured by shrapnel from the explosion. There was also no evidence which unequivocally indicated that passengers or cabin crew had been killed or injured by the effects of a blast. Although it is probable that those passengers
fuselage skin. Calculations suggest that a charge standoff distance of approximately 25 inches would result in a shattered region approximately 18 to 20 inches in diameter, comparable to the size of the shattered region evident in the wreckage. This aspect is covered in greater detail in [Appendix G].
only 4 primary returns. It was concluded that the aircraft was, by this time, no longer a single return and, considering the approximately 1 nautical mile spread of returns across track, that items had been ejected at high speed probably to both right and left of the aircraft.
The items used to define the datum line, included those exhibiting positive evidence of a detonating high performance plastic explosive, would have been the first pieces to have been released from the aircraft. The datum line was projected
at which the loud noise was heard on the CVR (Point B). There can, therefore, be no doubt that the loud noise on the CVR was directly associated with the detonation of the IED and that this explosion initiated the disintegration process and directly caused the loss of the aircraft.
The analysis of the cockpit voice recording, which is detailed in Appendix C, concluded that there were valid signals available to the CVR when it stopped at 19.02:50 hrs ±1 second because the power supply to the recorder was interrupted. It is not clear if the sound at the end of the recording is the result of the explosion or is from the break-up of the aircraft structure. The short period between the beginning of the event and the loss of electrical power suggests that the latter is more likely to be the case. In order to respond to events that result in the almost immediate loss of the aircraft's electrical power supply it was therefore
Thus, there is little doubt that separation of the forward fuselage was complete within 2 to 3 seconds of the explosion.
The impact location of Nos 1, 2, and 4 engines closely grouped in Lockerbie was consistent with their nearly vertical fall from a point above the town. If they had
An improvised explosive device detonated in luggage container serial number AVE 4041 PA which had been loaded at position 14L in the forward hold. This placed the device approximately 25 inches inboard from the skin on the lower left side of the fuselage at station 700.
APPENDIX A

PERSONNEL CONDUCTING THE INVESTIGATION

The following Inspectors of the Air Accidents Investigation Branch conducted the investigation:

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr M M Charles</td>
<td>Investigator-in-Charge</td>
</tr>
<tr>
<td>Mr D P King</td>
<td>Principal Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr P F Sheppard</td>
<td>Assistant Principal Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr A N Cable</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr R G Carter</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr P T Claiden</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr P R Coombs</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr S R Culling</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Miss A Evans</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr B M E Forward</td>
<td>Senior Inspector (Operations)</td>
</tr>
<tr>
<td>Mr P N Giles</td>
<td>Senior Inspector (Operations)</td>
</tr>
<tr>
<td>Mr S W Moss</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr R Parkinson</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr J D Payling</td>
<td>Senior Inspector (Operations)</td>
</tr>
<tr>
<td>Mr C G Pollard</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr C A Protheroe</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr A H Robinson</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr A P Simmons</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr R G Vance</td>
<td>Senior Inspector (Engineering)</td>
</tr>
<tr>
<td>Mr R S T J Whidborne</td>
<td>Senior Inspector (Operations)</td>
</tr>
</tbody>
</table>

The Air Accidents Investigation Branch would like to thank the following organisations from the United Kingdom, United States of America, France, and Canada who participated in the investigation:

- Air Line Pilot's Association International
- Boeing Commercial Airplane Company
- British Airways
- British Army
- British Geological Survey
- Bureau Enquete Accidents
- Canadian Aviation Safety Bureau
- Civil Aviation Authority
- Cranfield Institute of Technology
- Federal Aviation Administration
- Federal Bureau of Investigation
- Independent Union of Flight Attendants
- National Transportation Safety Board
- Pan American World Airways
- Police Service
- Royal Aerospace Establishment
- Royal Air Force
- Royal Armaments Research and Development Establishment
- Royal Navy
- Royal Ordnance
- Royal Signals and Radar Establishment
- United Technologies International Operations (Pratt and Whitney)

The Air Accidents Investigation Branch would also like to acknowledge the excellent work of the Dumfries & Galloway Regional Council and to thank all the many voluntary organisations who gave such unstinting support to the investigation.
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Department of Transport
Air Accidents Investigation Branch
Royal Aerospace Establishment
Farnborough
Hants GU14 6TD

6 August 1990

The Right Honourable Cecil Parkinson
Secretary of State for Transport

Sir,

I have the honour to submit the report by Mr M M Charles, an Inspector of Accidents, on the circumstances of the accident to Boeing 747-121, N739PA which occurred near the town of Lockerbie, Dumfriesshire, Scotland on 21 December 1988.

I have the honour to be
Sir
Your obedient servant

D A COOPER
Chief Inspector of Air Accidents
Figures 9 and 10.—Exterior [top photo] and interior [bottom photo] views of cargo doors after removal of pull-in hooks, latch cams, lock sectors, and actuators.
Figure 1.—Overall view of forward cargo door area on the right side of the aircraft.