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FOREWORD

General

1. The purpose of the Aircraft Accident Digest is to disseminate accident report information to Contracting States. Publication of the Digest began in 1951. Over the years States have reiterated their interest in the Digest not only as a valuable source of information for accident prevention, but also as a training aid for investigators and educational material for technical schools.

Selection of accidents

2. The Digest contains accident reports selected by the Secretariat from those sent by States. Reports were selected on the basis of:

a) their contribution to accident prevention; or

b) the successful employment of useful or effective investigative techniques; and

c) compliance with Annex 13 provisions including the format of the Final Report.

The Digest should not be seen as being statistically representative of the world distribution of accidents.

Editorial practices

3. The Final Reports are usually published as received. Accordingly, some deviations from standard ICAO editorial practices may occur. Lengthy reports may be abbreviated by omitting redundant information, appendices, attachments or diagrams. Minor changes in presentation and terminology may be introduced to ensure compliance with Annex 13 provisions.

States' co-operation

4. States are encouraged to send to ICAO those Final Reports which meet the criteria of 6.12 in Annex 13. The reports must be submitted in one of the working languages of ICAO, and in the format presented in the Appendix to Annex 13.

Digest publication

5. The Digest is produced once each year and includes accidents and incidents which occurred during a one-year period.

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No. 1

Fairchild FH227B, F-GCPS, accident at Machault (Seine-et-Marne), France on 4 March 1988. Report released by the Investigation Commission, France

1. RENSEIGNEMENTS DE BASE

1.1. *Déroulement du vol*

Le 4 mars 1988, le Fairchild FH 227 B, immatriculé F-GCPS décolle de Nancy-Essey à 5 h 53 à destination de Paris-Orly. L'appareil effectue la ligne régulière de la compagnie Transport Aérien Transrégional (T.A.T.) 230 Nancy-Essey–Paris-Orly. Son indicatif d'appel radiotéléphonique est « TAT 230 YU ».

Le plan de vol opérationnel mentionne vingt-deux personnes à bord (trois membres d'équipage et dix-neuf passagers). Après l'accident, la présence d'une vingt-troisième personne bénéficiant d'un billet gratuit a été signalée. La soute ne contenait aucun frêt mais seulement quelques bagages.

Les bases aériennes militaires de Nancy-Ochey, Toul et Saint-Dizier, gestionnaires d'espaces aériens à statut réglementé, n'étant pas encore actives à cette heure matinale, l'autorisation initiale obtenue par le contrôle de l'aérodrome de Nancy-*Essey* auprès du *centre de contrôle régional de Reims* prévoit une route directe vers le VOR de Troyes (TRO) en montée vers le niveau de vol (FL) 140 (soit 14 000 pieds au calage altimétrique standard 1013,2 hPa) après le décollage.

Lors du premier contact radiotéléphonique à 5 h 54 mn 45 s, le contrôleur de Reims confirme à l'équipage l'autorisation de monter vers le niveau de vol 140, niveau de croisière demandé sur le plan de vol.

Le radar de Contrexéville indique que ce niveau est atteint à 6 h 5 mn 10 s.

A 6 h 9 mn 4 s, l'avion est transféré sur la fréquence du centre de contrôle régional d'Athis-Mons qui lui confirme l'autorisation vers le VOR de Troyes (TRO) puis le VOR de Melun (MEL), limite d'autorisation, et lui indique la piste en service (la 26) à Orly.

A 6 h 23 mn 30 s, alors qu'il approche de TRO, le vol est autorisé à faire route directe vers MEL et à 6 h 26 mn 30 s, le contrôle lui donne l'autorisation de descendre vers le niveau de vol 90 puis 70. A 6 h 31 mn 40 s, il le transfère sur la fréquence du contrôle d'approche d'Orly.

A 6 h 33 mn 15 s, le contrôleur d'Orly informe l'équipage que son heure d'approche prévue (HAP : heure à laquelle il est autorisé à quitter le VOR MEL pour poursuivre son approche vers la piste 26) est fixée à 6 h 37 mn.

Toutes les instructions et autorisations précédentes ont été exécutées normalement et sans délai.

A 6 h 35 mn 50 s, le F-GCPS est autorisé à descendre vers le niveau 60. Il collationne immédiatement ce message et libère le niveau *70 en descente. Ce sera son dernier message radio.*

A 6 h 37 mn 30 s, alors qu'il est tout proche du VOR MEL, le contrôleur lui donne l'instruction de virer par la gauche au cap 360, espérant ainsi débuter une régulation radar vers la piste 26. Cette instruction ne sera pas reçue. En effet, à 6 h 37 mn 22 s, l'aéronef s'est écrasé à proximité du village de Machault (77) après avoir coupé une ligne électrique à très haute tension.

Constatant simultanément la perte des contacts radio et radar, le centre de contrôle d'approche d'Orly déclenche immédiatement la procédure appropriée du service d'alerte (phase de détresse).

1.2. *Victimes*

	EQUIPAGE	PASSAGERS	TIERS
Tués....................	3	20	0
Blessés....................	0	0	0
Indemnes....................	0	0	0

1.3. *Dommages à l'aéronef*

L'avion est entièrement détruit.

1.4. *Autres dommages*

Tous les fils porteurs et conducteurs de la ligne électrique à très haute tension Le Chesnoy-Morbras ont été sectionnés.

Les autres dommages au sol (trou dans un champ labouré) sont négligeables.

1.5. *Renseignements sur l'équipage*

1.5.1. Commandant de bord

M. 46 ans.

Brevet de pilote privé n° 22828 du 11 septembre 1967.

Brevet de pilote professionnel n° 3042 du 27 février 1970.

Brevet de pilote professionnel de 1re classe n° 244 du 30 juin 1971.

Licence validée jusqu'au 17 mai 1988.

Formation :

Stage bimoteur à Merville en 1969 ;

Complément chez Fenwick Aviation : IFR sur Cessna 310 en 1970 ;

Stage PP 1 à Saint-Yan en 1971.

Qualifications :

MS 505 et PA 28 le 4 novembre 1969 ;

Cessna 310 : janvier 1970 ;

IFR bimoteur : 18 février 1970 ;

Pilote HS 748 : 29 juillet 1970 ;

Commandant de bord Fokker 27 : 23 avril 1974 ;

Pilote N 262 : 31 mars 1979 ;

Commandant de bord FH 227 B : 27 avril 1979 ;

Heures totales de vol : 10226 heures ;

Inscription au registre A du personnel navigant :

ATP n° 2730 du 1er mars 1970 ;

ATA n° 1644 du 1er mars 1970 ;

Aptitude médicale sans restriction déclarée à la dernière visite en date du 19 novembre 1987.

1.5.2. Pilote

M. , 38 ans.

Brevet de pilote privé n° 28912 du 1er septembre 1969.

Brevet de pilote professionnel n° 6341 du 1er octobre 1976.

Brevet de pilote professionnel de 1re classe n° 4522 du 21 novembre 1986.

Licence validée jusqu'au 20 mai 1988.

Formation :

Transair Le Bourget.

Qualifications :

IFR : 9 juin 1981 ;

Copilote F 27 : 4 juin 1981 ;

Copilote FH 227 : 16 septembre 1982 ;

Copilote BE 99 A : 26 avril 1983 ;

Heures totales de vol : 4431 heures ;

Inscription au registre A : ATP n° 5187 du 22 juin 1981 ;

Aptitude médicale sans restriction déclarée à la dernière visite en date du 20 novembre 1987.

1.5.3. Personnel navigant commercial

Mme

Age : trente-deux ans ;

Certificat de sécurité et sauvetage n° 9183 du 21 septembre 1978 ;

Inscription au registre D : ATP n° 8714 du 10 octobre 1978.

Remarque. – Le passager bénéficiant d'un billet gratuit signalé en 1.1 a effectué le vol assis sur le strapontin central de la cabine de pilotage.

1.6. *Renseignements sur l'aéronef*

1.6.1. Cellule

Constructeur : Fairchild Industrie INC (*) ;

Année de construction : deuxième trimestre 1967 ;

Type : FH 227 B ;

Numéro de série : 546 ;

Certificat d'immatriculation : n° B 17074 du 18 septembre 1987 ;

Propriétaires : Sofinabail, Barclay's Bail, Actibail (ancien propriétaire : Sasmat) ;

Certification primaire de type : US n° 7 A 1 certifié transport *aérien suivant les normes civiles américaines* (Air Regulation Part 4 B et Special Air Regulation 422 B). Manuel de vol FAA approuvé le 17 juin 1967.

(*) Fairchild Industrie (qui est également appelée Fairchild-Hiller Corporation) a construit entre 1958 et 1975 128 F 27 de différents modèles sous licence Fokker ainsi que 78 Fairchild FH 227. La partie industrielle du programme FH 227 a été rachetée à Fairchild par la société Maryland Air Industries mais Fairchild demeure responsable de la certification de type.

Le FH 227, dont une quarantaine d'exemplaires sont encore en service dans le monde, est une version allongée du F 27 J pour augmenter la capacité en passagers (jusqu'à 56) et en fret grâce à une soute avec porte cargo à l'avant. Le fuselage a été rallongé de 1,829 mètres (6 pieds) à l'avant des ailes. Les surfaces de la gouverne et du compensateur de profondeur ont dû être sensiblement augmentées pour compenser le surcroît de masse à l'avant. La génération électrique et les commandes moteur sont également différentes de celles du Fokker 27. La certification (juin 1967) de cet appareil est purement américaine. Le FH 227 B offre une vitesse opérationnelle et un poids total augmentés. Il est équipé de nouveaux pare-brises, de longerons, de cadres de fuselage et de trains d'atterrissage renforcés. Les moteurs sont plus puissants et les hélices ont un plus grand diamètre. La masse maximale au décollage a été portée à 20,640 tonnes et la masse maximale à l'atterrissage à 20,410 tonnes. En France toutefois, la masse totale autorisée au décollage a été limitée à moins de 20 tonnes pour des raisons de réglementation des brevets et licences du personnel navigant.

Certification française : certification de type française pour importation délivrée par équivalence par la D.G.A.C. le 8 février 1974 (réf. IM 78).

Manuel de vol en français (traduction du Airplane Flight Manual approuvé FAA le 17 juin 1967) approuvé par la D.G.A.C. le 28 mars 1979 de même que les révisions 1 à 24 et les suppléments 1 à 14.

Certificat individuel de navigabilité valide jusqu'au 9 octobre 1990.

Au départ de Nancy, l'avion totalisait 33 142 heures de vol et 55 843 cycles (un cycle : un décollage + un atterrissage).

1.6.2. Moteurs

Constructeur : Rolls-Royce (Royaume-Uni).
Type : DART 532.7.

	GAUCHE	DROIT
Position	1	2
Numéro de série	13953	14062
Temps de fonctionnement total	37 245,8 h	26 372,6 h
Cycles totaux	(Inconnu)	44 130
Temps de fonctionnement depuis révision générale	1 220,2 h	4 886,1 h
Cycles de fonctionnement depuis révision générale	1 296	5 104
Date de dernière révision générale	Novembre 1986	Octobre 1982
Lieu	Air France Toulouse	Air France Toulouse

1.6.3. Hélices

Constructeur : Dowty Rotol.
Type : R 257/4-30.

	GAUCHE	DROITE
Position	1	2
Numéro de série	2267	3367
Temps total de fonctionnement	26 858,8 h	29 562,1 h
Temps depuis dernière révision générale	1 664 h	1 084,7 h
Date de dernière révision générale	Février 1986	Juillet 1986
Lieu	Dowty Rotol Gloucester	Dowty Rotol Gloucester

1.6.4. Equipement

A la date de l'accident, l'équipement du F-GCPS satisfaisait aux règlements applicables aux avions exploités en transport public.

Il n'était pas encore équipé d'horizon de secours. Néanmoins après l'accident la compagnie a installé cet équipement sur toute sa flotte (*).

(*) L'article 6 de l'arrêté du 5 novembre 1987 relatif aux conditions d'utilisation des avions exploités par une entreprise de transport aérien prévoit que cet équipement devait être installé avant le 30 novembre 1988.

Faute d'approvisionnement, des pare-brise de F 27 avaient été installés. Le F-GCPS était de ce fait limité à 227 Kt en utilisation normale au lieu de 249 Kt.

1.6.5. *Entretien*

L'aéronef était entretenu par la société exploitante à Dinard. Les spécifications d'entretien de cette société ont été approuvées (agrément n° 17 du 5 juillet 1984).

Le manuel d'entretien du FH 227 B a été approuvé le 17 décembre 1980 (lettre 55590 SFACT/TE).

La dernière visite d'entretien de type D et E a été effectuée à 31 926 heures et 54 547 atterrissages le 12 novembre 1986.

Lors du vol de l'accident, une section de dégivrage des bords d'attaque de l'aile gauche (section CD) était déclarée hors service depuis le 1er mars 1988.

1.6.6. Masse et centrage

La cabine du F-GCPS était aménagée pour quarante-huit passagers.

Compte tenu du nombre de passagers (vingt) et de l'absence de fret en soute, la masse totale de l'appareil au décollage (environ 16 900 kilogrammes) était très largement inférieure à la masse maximale autorisée (19 970 kilogrammes en France). Il en était de même au moment de l'accident (environ 16 000 kilogrammes).

Ne connaissant pas la répartition exacte des passagers sur les sièges, il n'est pas possible de connaître avec précision le centrage de l'avion au moment de l'accident.

En cas de remplissage moyen (c'était le cas pour le vol de l'accident), le personnel navigant doit veiller à la répartition équilibrée des passagers sur les sièges de cabine. Une répartition toute avant ou toute arrière provoque en effet un dépassement des limites de centrage.

1.7. *Conditions météorologiques*

1.7.1. Situation générale

En surface, une zone dépressionnaire (980 hPa) centrée sur l'extrême Sud de la Norvège se prolonge en un vaste thalweg jusqu'au golfe de Gascogne. La perturbation associée intéresse les régions s'étendant du Sud de la Scandinavie à la partie orientale de l'Allemagne de l'Est et au Sud de la Belgique, puis ondule au niveau d'un minimum secondaire à 1 000 hPa sur la Picardie ; elle se poursuit en front froid actif vers l'Ouest de la région parisienne, les Charentes et la côte Nord-Ouest de l'Espagne.

Le courant général de surface est Sud-Sud-Ouest faible à l'avant de ce front froid et d'Ouest à Nord-Ouest à l'arrière s'orientant à Nord derrière un front froid secondaire axé du Havre à Nantes délimitant l'instabilité en air froid.

Sur l'ensemble de l'Ile-de-France, la zone de corps liée au front froid principal est caractérisée par des précipitations de pluie et de neige mêlées ou de neige.

A 6 h 30, ce front se situe encore à l'Ouest de Melun mais le corps pluvio-neigeux s'étend bien au-delà.

En altitude, aux niveaux 850, 700, 500 et 300 hPa, une zone de bas géopotentiels se situe au-dessus du Sud de la Norvège et du Danemark et se prolonge par un thalweg vers la Bretagne. Sur la face orientale de ce thalweg au-dessus des régions intéressées par le vol, les vents sont d'Ouest-Sud-Ouest 45 Kt à 500 hPa et 25 Kt à 700 hPa.

1.7.2. Temps sur le trajet Nancy–Paris

Ce temps est déduit des cartes d'analyse en surface et en altitude en tenant compte de l'évolution de la situation.

Sur ce trajet, on trouve à l'avant du front froid un ciel couvert par stratocumulus et altocomulus-altostratus ou nimbostratus doublés localement de stratus ; les visibilités en surface sont réduites par les chutes de pluie, de neige ou pluie et neige mêlées.

Les vents et températures estimés sur le trajet sont :

NIVEAUX	NANCY	ORLY
850 hPa (FL 50)	250°/25 Kt - 4 °C	260°/20 Kt - 5 °C
700 hPa (FL 100)	250°/25 Kt - 13 °C	250°/25 Kt - 14 °C
500 hPa (FL 180)	250°/45 Kt - 28 °C	250°/45 Kt - 28 °C

On observe donc peu de variation de ces paramètres le long du trajet de l'avion.

Les valeurs relevées montrent que l'avion a évolué en permanence dans des températures négatives (- 4 °C et - 14 °C). Le ciel étant couvert par diverses couches nuageuses aux sommets voisins de 5 000 mètres, le risque de formation de givre blanc ou transparent est grand (danger de givrage au moins modéré devenant fort au cours de la descente). Voir les cartes en annexe VIII.

A l'approche du front froid à caractère stable (hiver), la turbulence devait être faible.

1.7.3. Conditions particulières à l'arrivée

Les conditions météorologiques réelles au moment de l'accident et celles prévues pour la période allant de 6 heures à 15 heures le 4 mars 1988 issues des messages METAR de 6 heures à 7 heures et TAF de validité 6-15 heures sont présentées dans les tableaux en annexe VIII.

La température au sol sous abri est proche de 0 °C. On y observe des chutes de pluie et/ou neige et une visibilité faible de l'ordre de 3 000 mètres avec un ciel couvert par stratus et/ou altostratus.

Les équipages ayant survolé le VOR MEL peu avant et après l'accident confirment un givrage modéré à fort dans cette région aux niveaux de vol 60, 70, 80, 90 et 100. Ceux venant par l'Ouest de la région parisienne ont signalé un givrage beaucoup plus sévère dans la région de Rambouillet - Toussus-le-Noble.

Les témoins au sol confirment les observations des stations météorologiques d'Orly et Melun (pluie et neige, plafond bas, visibilité oblique médiocre).

Enfin, aucun événement « foudre », notamment aucun impact au sol, n'a été observé par le réseau de surveillance Météorage dans la région de Melun au cours de la journée du 4 mars.

1.8. *Aides à la navigation*

Aucune anomalie de fonctionnement des aides au sol à la navigation aérienne n'a été signalée ou constatée avant et après l'accident.

1.9. *Radiocommunications*

Depuis son départ de Nancy jusqu'au moment de la chute, et donc de la perte de contact radio-radar, le F-GCPS est resté en liaison radio bilatérale permanente avec les différents organismes de la circulation aérienne concernés par ce vol (Nancy Tour, Reims Contrôle, Paris Contrôle et Orly Approche).

A aucun moment, l'équipage n'a signalé ou n'a semblé éprouver une quelconque difficulté (voir en annexe 5).

La fréquence « opérations » de la compagnie aérienne TAT à Orly n'est pas enregistrée. Cependant les agents d'opérations en service et la transcription de l'enregistreur de conversations et d'alarmes sonores dans le poste de pilotage indiquent qu'à 06 h 27 mn l'équipage a pris contact avec sa compagnie pour annoncer son heure estimée d'arrivée et demander le changement, lors de l'escale d'Orly, d'une minuterie. Il s'agissait vraisemblablement de celle du système d'antigivrage d'un groupe moto-propulseur.

Le F-GCPS était équipé d'une radiobalise de détresse fonctionnant automatiquement à l'impact. Cependant aucune émission n'a été reçue après l'accident. La balise n'a pas été retrouvée dans les débris.

1.10. *Renseignements sur l'aérodrome*

L'aéroport de Paris-Orly est le cadre d'une intense activité de transport aérien commercial national et international. Situé à 89 mètres d'altitude, il est équipé de trois pistes. Les arrivées en provenance de l'Est et du Sud-Est se font en passant par le VOR MEL quelle que soit la piste en service. Les services de la circulation aérienne y sont assurés par une tour de contrôle et un centre de contrôle d'approche dotés de deux ensembles radar (images primaire et secondaire).

La perte de contact radar constatée immédiatement après la chute de l'avion au moment où le contrôleur le rappelait pour lui faire débuter des manœuvres de régulation radar a permis un déclenchement très rapide de l'alerte.

1.11. *Enregistreurs de bord*

Conformément à la réglementation française applicable aux avions utilisés en transport public de passagers, le F-GCPS était équipé d'un enregistreur de paramètres de vol (FDR) et d'un enregistreur de conversations et d'alarmes sonores dans le poste de pilotage (CVR).

1.11.1. FDR

L'enregistreur de paramètres de marque Sundstrand, modèle FA 542 M, numéro de série 2073, est un enregistreur graveur sur bande métallique à cinq paramètres (altitude, vitesse indiquée, cap, accélération verticale et référence de temps). De plus, sur le modèle « M », le signal des radiobornes à 75 MHz est également enregistré.

La précision de ce type d'enregistreur est faible. (Le constructeur donne ± 700 pieds pour l'altitude, ± 10 Kt pour la vitesse, ± 2 degrés pour le cap et ± 1 p. 100 en 8 heures pour le temps).

Cet enregistreur a été très endommagé par l'impact au sol. Le châssis électronique était séparé du chassis mécanique contenant encore le magasin et la bande métallique. Le boitier chargeur a été brisé et écrasé. Il était plein de terre. Le rouleau de la bande était plié et la bande métallique froissée surtout dans la dernière partie (la plus intéressante pour l'enquête). Elle a été totalement déchirée transversalement.

Ces déformations n'ont pas permis une exploitation directe et ont nécessité des travaux de restauration avant prises de clichés photographiques et agrandissements (voir annexe 7).

L'autre partie de la bande située après la déchirure transversale ne présente aucune trace de gravure visible.

Les paramètres enregistrés dans les parties lisibles ne mettent en évidence aucune anomalie particulière dans la trajectoire du vol. Ils sont compatibles avec les données (beaucoup plus précises) fournies par les enregistrements des radars des centres de contrôle d'Athis-Mons et d'Orly.

Le seul paramètre impossible à restituer avec les enregistreurs sol, à savoir l'accélération verticale (Jz), est resté constamment très proche de l'unité (1 g).

On note une perte qui semble simultanée de tous les paramètres à une altitude de l'ordre de 6 300 pieds en descente. L'avion a alors une vitesse de 220 Kt et un cap 288°. (Ces valeurs restent compatibles avec celles obtenues grâce aux enregistrements radar.)

1.11.2. CVR

L'enregistreur de conversations et d'alarmes sonores est un Sundstrand de type V 557, numéro de série 1224, à bande magnétique mylar stockée de manière aléatoire dans une cassette située dans un boitier protecteur.

A l'impact, la cassette contenant la bande a été éjectée de son boitier (lui-même éclaté) et projetée sur le terrain.

Ce type de cassette est très sensible aux fortes accélérations longitudinales et aux contraintes mécaniques qui entrainent des déformations permanentes de la bande.

La cassette a dû être découpée pour en extraire la bande écrasée à l'intérieur.

Celle-ci présente de très nombreuses pliures et des déchirures. L'examen visuel à la binoculaire met en évidence des lacérations et pliures longitudinales et/ou transversales, notamment en fin de bande. Par endroits, il n'y a plus d'émulsion et la bande est transparente.

Après recollage des cassures, la dorsale a dû être consolidée ou reconstituée sur plusieurs longueurs avant que puisse être effectuée la première copie.

Les premières écoutes ont mis en évidence que les conversations et bruits ambiants sont d'un niveau très faible et sont couverts par les communications radio reçues sur les haut-parleurs et d'un niveau beaucoup plus élevé. De plus de nombreux passages sont rendus pratiquement inintelligibles du fait de variations plus ou moins brusques de la vitesse de défilement de la bande à l'enregistrement.

Les blocages de bande dans les têtes d'effacement et d'enregistrement étant rares sur ce type d'enregistreur, ces variations de vitesse semblent plutôt être la conséquence de variations du courant d'alimentation (115 V/400 Hz) de l'enregistreur.

Lors d'essais effectués au sol ou en vol sur un avion de même type avec un CVR identique, on a pu constater le même phénomène.

Les analyses spectrales des passages les plus perturbés de la bande originale montrent des variations aléatoires et importantes de la fréquence du courant alternatif (400 Hz).

Pendant de nombreuses et plus ou moins longues périodes, on constate des décalages de fréquence de l'ordre de 50 Hz. Le phénomène se reproduit juste avant la coupure de l'enregistrement. A certains moments, la fréquence monte très rapidement à des valeurs très élevées avant l'arrêt total de la bande.

Compte tenu de toutes ces difficultés d'écoute, de nombreuses copies ont été effectuées tant en France que dans les bureaux enquêtes-accidents britannique et américain avec des matériels et techniques de filtrage différents pour tenter d'atténuer les signaux radio-parasites et les conséquences des variations de vitesse de défilement. Diverses tentatives de numérisation de certains passages se sont avérées infructueuses.

La transcription incomplète et imparfaite qui figure en annexe 6 est le résultat d'écoutes multiples de ces différentes copies.

La chronologie a été effectuée par corrélation avec les enregistrements des communications radio échangées avec les centres de contrôle de Paris et d'Orly.

L'enregistrement dure un peu moins de 33 minutes. Il débute peu avant que l'avion n'atteigne son niveau de croisière (140) et s'arrête brusquement quelques secondes avant l'accident alors qu'il est encore en descente vers le niveau 60.

Il nous indique que le commandant de bord assis en place gauche est aux commandes et utilise le pilote automatique alors que les annonces et les liaisons radio sont effectuées par le pilote assis en place droite.

Un passager occupe le strapontin central du poste de pilotage.

A l'exception de quelques interruptions pour dialoguer avec le pilote ou effectuer quelques vérifications, pendant toute la durée du vol enregistré et jusqu'au dernier moment, le commandant de bord fait un exposé détaillé au passager en poste sur les systèmes, équipements et commandes de l'avion ainsi que sur sa navigation.

Alors que le commandant de bord expose le principe de la génération électrique, la lecture et la compréhension de la bande CVR devient totalement impossible du fait de variations aléatoires de sa vitesse de défilement. L'équipage semble à cet instant évoquer des problèmes électriques dont il n'a pas été possible d'identifier l'origine.

Le commandant de bord reprend ensuite ses explications et en fin de bande, à nouveau, les conversations deviennent très difficilement compréhensibles.

1.12. *Renseignements sur l'épave et sur l'impact*

L'appareil s'est écrasé au lieudit « Le Placereau », sur la commune de Machault (77), dans une zone légèrement vallonnée composée essentiellement de champs cultivés avec quelques parcelles boisées.

Le premier point d'impact avec le sol est situé à 190 mètres au sud du chemin départemental 107 sous la ligne la plus à l'Est d'un groupe de cinq lignes électriques haute tension ayant une orientation Sud, Sud-Est/Nord, Nord-Ouest (une sixième ligne ayant une orientation légèrement différente dans cette zone se trouve à quelques centaines de mètres à l'Est).

Ce point d'impact se trouve sur le radial 100 (*) du VOR MEL, à 1,5 Nm de celui-ci.

Dans sa chute, l'appareil a coupé les huit câbles de la ligne électrique citée précédemment avant de percuter le sol avec une très forte assiette négative ainsi qu'une vitesse très élevée. Le fuselage s'est enfoncé dans le sol, composé de glaise, jusqu'à une profondeur d'environ 3 mètres en s'écrasant sur lui-même.

Les ailes ont percuté le sol de manière symétrique et y ont laissé une empreinte de 30 centimètres de profondeur environ sur toute l'envergure. On note de très légères traces de feu au niveau de l'aile droite. Il n'y a que quelques éléments d'ailes au niveau de ces empreintes, essentiellement des éléments de bords d'attaque écrasés sur eux-mêmes.

(*) Voir définition en page réservée aux signes et abréviations au début de ce rapport.

Les moteurs se sont également enfoncés très profondément compte tenu de leur densité ; les moyeux d'hélice (éléments de l'avion enterrés le plus profondément) ont été retrouvés à une même profondeur de 3,20 mètres environ.

Sur le bord Nord-Ouest de l'excavation contenant le fuselage et les moteurs se trouvent de nombreux blocs de terre (certains dépassant 1 mètre cube) projetés lors de l'impact au sol, ce qui atteste de la très grande vitesse verticale de l'avion.

L'axe longitudinal des moteurs et des éléments du fuselage, dans le sol, est incliné à plus de 60° par rapport à l'horizontale.

Le centre de gravité placé assez haut sur cet avion (ailes et moteurs en position haute) ainsi que l'impact du nez de l'avion sur le sol ont certainement provoqué une rotation d'ensemble ; l'assiette de l'avion devait donc être inférieure à l'inclinaison de l'épave dans le sol.

Le point de découpe des câbles haute tension par rapport au point de toucher au sol correspond à une pente de descente de l'ordre de 45°, ce qui est cohérent avec les précédentes constatations.

Les deux moteurs ont beaucoup souffert de l'impact : la plupart des éléments ont été cassés, disloqués et écrasés. Toutes les pales des hélices ont été arrachées et trois d'entre elles ont été projetées en dehors du cratère.

En dehors de l'excavation, les morceaux sont répartis suivant un cône axé au 280° environ et ayant une ouverture de l'ordre de 50°.

La plupart des éléments sont de petite taille et très déchiquetés, ils correspondent à toutes les zones de l'avion : instruments du cockpit, éléments de structure des ailes et du fuselage, gouvernes, empennages arrière.

Les principaux morceaux d'aile ont été retrouvés dans un rayon de 30 mètres par rapport au point d'impact principal. Un élément important de l'arrière de l'avion se trouve à environ 80 mètres de ce même point.

On trouve une pale d'hélice à 30 mètres sur la gauche du cône, une deuxième à 50 mètres sur la droite et une troisième à 170 mètres approximativement au centre du cône ; on note que cette dernière comporte une indentation très marquée sur le bord d'attaque résultant de l'impact avec l'un des câbles de la ligne à haute tension.

La plupart des pales d'hélice sont tordues vers l'avant, ce qui semblerait indiquer que les moteurs développaient une certaine puissance lors de l'impact, ce qui n'est pas cohérent avec les expertises effectuées (cf. 1.16.1 ci-dessous).

Un ensemble de fils électriques de plusieurs mètres est accroché à un câble de la troisième ligne électrique à 140 mètres.

D'autres fragments plus petits sont également restés accrochés dans les câbles des lignes haute tention.

Plusieurs éléments provenant du poste de pilotage (instruments, boitiers radio,...) ont été retrouvés à plus de 150 mètres de l'épave principale.

Les derniers éléments de l'épave se trouvent à 200 mètres environ du point d'impact.

Le CVR a été retrouvé à 30 mètres : l'enveloppe extérieure avait été déchiquetée, le boitier blindé était ouvert laissant apparaître la « cassette » contenant la bande magnétique. Les têtes d'enregistrement étaient couvertes de boue.

Le FDR a été retrouvé à 35 mètres ; lui aussi avait été disloqué lors de l'accident et le rouleau de feuille métallique support de l'enregistrement était isolé dans la boue ; la zone de la bande comportant la fin de l'enregistrement était endommagée.

Il n'a été trouvé aucun élément de l'avion en amont sur sa trajectoire lors de recherches en hélicoptère et à pied effectuées par la gendarmerie ; de plus, il a été possible d'identifier des éléments de chacune des gouvernes, extrémités d'ailes et empennage, attestant qu'il n'y a pas eu de rupture en vol.

1.13. *Renseignements médicaux et pathologiques*

Compte tenu de la violence de l'impact, les corps des occupants de l'appareil ont été réduits, à quelques exceptions près, à l'état de restes humains informes et de faibles dimensions éparpillés à la surface ou, plus généralement, enterrés dans le cratère principal, mêlés aux débris de l'avion.

Aucune analyse ou recherche toxicologique n'a pu être pratiquée sur ces restes humains.

Les pilotes passaient régulièrement les visites médicales d'aptitude tous les six mois. Cette aptitude était prononcée sans aucune restriction.

1.14. *Incendie*

Les impacts avec la ligne électrique à très haute tension, et au sol immédiatement après, se sont traduits par une explosion de très forte intensité. Les témoins visuels évoquent une « boule de feu » et/ou un « éclair ».

Sur le terrain, seules quelques traces d'incendie très localisées sont visibles, notamment au niveau de l'aile droite.

A l'arrivée des enquêteurs, certains débris et papiers (documents de bord notamment) continuaient de se consumer lentement malgré la pluie et la neige. Les petits incendies se sont éteints sans intervention extérieure.

Les divers extincteurs retrouvés, y compris ceux des moteurs, n'avaient pas été percutés.

1.15. *Questions relatives à la survie des occupants*

Compte tenu de la violence de l'impact, l'accident ne laissait aucune chance de survie aux occupants de l'appareil.

1.16. *Essais et recherches*

Après avoir sectionné la ligne électrique à très haute tension, l'avion s'est écrasé en explosant dans une terre meuble et fraîchement labourée en creusant un cratère (voir 1.12).

Plusieurs campagnes de ratissage du terrain et de creusement du cratère ont été effectuées. Tous les éléments collectés ont été rassemblés dans un hangar sur l'aérodrome de Melun-Villaroche.

Cinq opérations de tri des débris ont été effectuées et tous les éléments susceptibles de fournir des renseignements intéressants pour l'enquête ont été envoyés vers les laboratoires spécialisés aux fins d'examens détaillés.

1.16.1. **Groupes turbopropulseurs et APU**

Les moteurs, les hélices et leurs accessoires ont été expertisés au centre d'essais des propulseurs (CEPr) à Saclay puis envoyés en Grande-Bretagne chez leurs contructeurs respectifs (Rolls-Royce et Dowty Rotol) pour examens complémentaires.

Tous ces éléments ont été considérablement déformés à l'impact. Toutes les pales d'hélices ont été arrachées des moyeux. Les turbomoteurs, écrasés et cassés, et divers éléments sont entrés dans la terre meuble jusqu'à une profondeur d'environ 2,50 mètres. Un moyeu réducteur d'hélice dont l'absence avait été constatée après les différentes opérations de tri a été retrouvé à 3,20 mètres de profondeur dans la glaise lors d'une ultime campagne de ratissage à l'aide de détecteurs de métaux directionnels.

Malgré toutes les destructions et déformations constatées, les expertises pratiquées ont permis de mettre en évidence que les turbomoteurs du F-GCPS fonctionnaient mais ne délivraient pas une très grande puissance. A l'impact, il y avait une certaine dissymétrie de puissance entre les deux moteurs. Le moteur droit tournait à un régime plus élevé que le moteur gauche.

Après examen des moteurs et des pompes, les experts de Rolls-Royce ont estimé que le moteur droit tournait à mi-puissance à un régime voisin du régime d'approche (13 000 tours/mn et débit carburant de 900 livres/heure) alors que le moteur gauche était proche du ralenti vol (11 000 tours/mn).

L'examen détaillé des hélices chez leur constructeur Dowty Rotol n'a pas permis de tirer les conclusions définitives. Généralement les mécanismes de verrouillage de pas des pales situés à l'avant de celles-ci demeurent entiers et exploitables pour l'enquête. Dans le cas du F-GCPS, ils ont été totalement brisés en éclats lors de l'impact frontal.

Les marques relevées sur les pieds de pales indiquent des calages variant de 40 à 70° sur les deux moteurs ce qui exclut qu'un des moteurs soit arrêté. Si l'un d'entre eux avait été arrêté, avant d'aller vers la position drapeau, le pas de l'hélice en moulinet aurait été sensiblement plus faible que celui correspondant au moteur en fonctionnement.

Une réduction de puissance juste avant l'impact entraîne une augmentation du pas pouvant atteindre 10° avant que la position d'équilibre ne soit retrouvée. Ces calages ne sont donc pas forcément significatifs.

L'examen du groupe auxiliaire de puissance (APU) indique que celui-ci n'était pas en fonctionnement.

1.16.2. **Vérins des compensateurs**

Les positions des vérins des compensateurs d'aileron, de direction et de profondeur ont été relevées et mesurées. Elles indiquent un réglage moyen pour les ailerons et la direction.

Par contre, la position du vérin de profondeur indiquant un réglage proche du plein piqué, des essais complémentaires ont été effectués à Dinard dans les ateliers de l'exploitant sur un avion et sur une gouverne déposée à cet effet. Ces essais ont montré que sous l'effet d'un très faible effort de traction sur les câbles de commande, le vérin pouvait se déplacer très rapidement d'une position extrême à l'autre. Même si ce mécanisme n'est pas réversible, les experts sont d'avis de n'accorder qu'une confiance limitée à cette position de vérin. Compte tenu des efforts exercés sur les câbles lors de l'impact, celle-ci peut, en effet, être assez différente de la position réelle du compensateur de profondeur pendant la chute de l'avion. Néanmoins, on peut penser que la masse des gouvernes et la vitesse à l'impact ont dû entraîner une rupture en traction des câbles sans rotation excessive des cabestans. Par conséquent, un réglage à piquer avant l'impact est très vraisemblable.

1.16.3. **Equipements électriques**

Le FH 227 est équipé d'une alimentation électrique de base continue permettant de desservir toute une partie des accessoires de l'avion et entre autres des convertisseurs fournissant l'énergie alternative des instruments gyroscopiques et des équipements électroniques.

Chaque groupe turbopropulseur (GTP) entraîne une génératrice 28 V (courant continu = DC), un alternateur de secours 115 V (courant alternatif = AC) et un alternateur 208 V (AC) utilisé uniquement pour le dégivrage.

Des barres de distribution (BUS) permettent d'alimenter les différents équipements en fonction de leur tension.

En temps normal, les génératrices (une par GTP) débitent un courant continu nominal de 450 A sous une tension de 28 volts lorsque le régime GTP est au moins de 8 000 tours/mn. Deux convertisseurs identiques de type rotatif (axe unique avec partie moteur d'un côté et alternateur de l'autre) permettent de fournir du courant 115 V (AC). Un régulateur incorporé stabilise la fréquence alternative à 400 Hz. Un seul convertisseur débite à la fois et un interrupteur à 3 positions (main-off-spare) situé sur le panneau supérieur droit du poste de pilotage, permet la mise en œuvre manuelle de l'autre convertisseur en cas de panne du premier. Il n'y a pas de transfert automatique de l'un sur l'autre.

Lors d'une panne des génératrices, deux batteries 24 V/20 Ah situées sur un châssis dans le cône arrière (côté droit) permettent d'alimenter les éléments de secours indispensables au vol pendant 10 à 20 minutes après délestage.

Le groupe auxiliaire (APU), quand il est en marche, entraîne une génératrice 28 V (DC) et un alternateur 208 V (AC) identique à celui des GTP.

Les deux alternateurs de secours, situés sur chaque boîte d'entraînement des moteurs, peuvent alimenter les instruments à condition que le régime moteur soit supérieur à 11 300 tours/mn et que leur mise en œuvre (par des interrupteurs situés au bas de chaque planche de bord derrière les colonnes de commandes de vol) s'effectue dans les 10 secondes suivant la panne électrique alternative. En effet, leur faible puissance permet de maintenir la vitesse des gyroscopes mais pas de les réentraîner s'ils sont arrêtés. Il y a un interrupteur en place pilote pour alimenter en secours la planche pilote et un autre en place copilote pour la planche copilote.

La perte d'alimentation en courant 115 V/400 Hz entraîne l'arrêt des équipements suivants :

Enregistreurs de bord (CVR et FDR) ;
Jaugeurs carburant ;
Contrôle de dégivrage pare-brise ;
VOR 1 ;
VOR 2 ;
Pilote automatique ;
Directeur de vol ;
Radioaltimètre ;
Transpondeur radar ;
Radar météo ;
DME ;
Gyros de verticale 1 et 2 ;
Indicateur de position des volets ;
Débitmètres ;
Indicateurs de pression d'huile et de carburant ;
Conservateurs de cap 1 et 2 ;
ADF.

Les génératrices, alternateurs et convertisseurs, ainsi que différents moteurs électriques (ventilateur, essuie-glace, pompe de gavage, etc.) des lampes et des relais de circuits électriques ont été examinés en laboratoires, sans pouvoir aboutir à des conclusions définitives, compte tenu de l'état des éléments dû à la violence de l'impact. Ainsi, par exemple, l'absence de traces de frottements radiaux constatée sur les inducteurs des convertisseurs pourrait laisser supposer que ceux-ci ne tournaient pas à l'impact... La même constatation d'absence de traces de rotation peut être faite sur les génératrices bien que l'on ait la certitude qu'elles étaient entraînées par les moteurs. Dans ce cas la violence du choc est sans commune mesure avec l'inertie des rotors lorsqu'on coupe leur alimentation. On peut considérer qu'ils s'arrêtent instantanément ne produisant donc aucune trace de frottement.

En ce qui concerne les batteries les examens effectués au Centre d'essais aéronautiques de Toulouse ainsi que les comparaisons qui ont pu être faites avec d'autres batteries (l'une chargée, l'autre déchargée) larguées de 2 000 mètres depuis un hélicoptère pour s'écraser au sol dans des conditions comparables à celles du F-GCPS, tendent à démontrer qu'une certaine énergie, dont il n'est pas possible d'évaluer le niveau, existait encore dans ces batteries à l'impact.

L'examen des filaments des voyants de surchauffe batteries a démontré que ceux-ci étaient éteints à l'impact.

Les experts ont acquis la certitude que ces batteries n'étaient pas totalement déchargées au moment de l'accident en ce basant sur la présence de courts-circuits locaux engendrés lors de la déformation des coffres. Ces traces sont tout à fait analogues à celles observées sur la batterie de même type larguée chargée de l'hélicoptère bien que l'état de destruction de cette dernière soit nettement moins avancé. La batterie larguée déchargée ne porte, bien évidemment, aucune trace de court-circuit interne.

De nombreuses traces de courts-circuits ou de surchauffes apparaissent un peu partout dans les restes des fils électriques, bobinages ou débris métalliques.

L'examen des multiples traces de fusion (zones affectées thermiquement) visibles sur les débris de voilure et de fuselage, notamment de la partie gauche de l'avion, montre qu'elles sont beaucoup plus étendues que dans le cas d'un foudroiement. Ces traces sont la conséquence des arcs électriques à l'approche et au contact des fils de la ligne électrique à très haute tension.

Enfin, l'interprétation des indices relevés sur les éléments de l'épave, notamment ceux du système électrique, doit tenir compte du fait qu'il y a de très fortes chances pour qu'une panne électrique totale se soit produite lorsque l'avion a heurté la ligne électrique.

1.16.4. **Instruments de bord**

Quelques instruments de bord ont été retrouvés dans les débris et expertisés dans les laboratoires du Centre d'essais en vol de Brétigny.

Sur un anémomètre, l'aiguille de limitation de vitesse est positionnée sur 332 kt alors que l'aiguille d'indication de vitesse est absente. La capsule est dessoudée sur les trois-quarts de sa circonférence.

La rose des caps d'un indicateur de situation horizontale (HSI) est bloquée sur 280° et la route affichée est 248°. Le cap 280° correspond à la route constatée sur l'enregistrement radar d'Orly.

Le tambour de distance du DME (équipement mesureur de distance) est figé sur 27 NM. Ce type d'indicateur conserve la valeur DME et la position de la rose des caps en cas d'arrêt de l'alimentation électrique.

L'indication 27 NM correspond à la distance entre le VOR/DME d'Orly « OL » et la position de l'avion à partir de laquelle le transpondeur radar n'a plus été reçu.

Le lieu de l'accident se situe 2 NM plus loin (à 25 NM d'OL) et à 1,5 NM du VOR MEL (lui-même à 23,5 NM d'OL).

Deux rouleaux (un supérieur et un inférieur) d'indicateur directeur d'attitude (horizon artificiel ou ADI) sont déchirés par la maquette avion au droit de l'inscription « 90° UP ». Chaque spire des enroulements mobiles comporte les mêmes empreintes superposables de déchirure. Ceci signifie que cet instrument n'était plus alimenté électriquement au moment du choc.

Les essais effectués au CEV et à la TAT à Dinard avec des indicateurs de même type installés sur avion montrent qu'en cas de coupure de l'alimentation électrique, le rideau de l'horizon artificiel se positionne « 90° UP » face à la maquette avion en moins de 5 s (de 4,04, à 4,26 s) ceci avec apparition très rapide des drapeaux. La remise en fonction s'effectue en moins de 3 s (2,2 s à 2,7 s) en basculant les interrupteurs des alternateurs de secours situés en bas de la planche de bord devant les colonnes des commandes (voir page 13). Ces essais démontrent que la coupure électrique ne peut être qu'antérieure à l'impact avec la ligne électrique.

1.16.5. **Trajectoire du vol**

1.16.5.1. *Radar secondaire* (voir annexe 3)

Compte tenu de la très mauvaise qualité des informations fournies par l'enregistreur de paramètres de vol et surtout de l'arrêt des deux enregistreurs avant l'impact final (voir 1.11 ci-dessus) la trajectoire du vol n'a pu être reconstituée que grâce aux enregistrements des images radar.

Le premier contact radar (station locale de Contrexéville) a lieu à 05 h 54 mn 07 s. Le F-GCPS passe 2 400 pieds en montée vers le niveau de vol 60 et est transféré à Reims-contrôle qu'il contacte à 05 h 54 mn 45 s.

La montée s'effectue normalement en cap direct sur le VOR de Troyes (TRO). Le taux de montée moyen de 1 200 pieds/mn jusqu'au niveau 70 diminue progressivement à 1 000 pieds/mn jusqu'au niveau 100 puis à 900 pieds/mn avant d'atteindre le niveau de croisière 140 à 06 h 05 mn 10 s.

Le F-GCPS suit une route magnétique orientée 252° jusqu'à 06 h 23 mn 30 s où, environ 5 NM avant le passage de TRO, le cap augmente très lentement vers 286° vers BRY puis revient au 282°, route directe vers MEL.

On ne note aucun écart de cap significatif. La tenue du niveau de vol 140 est très rigoureuse.

A 06 h 27 mn 20 s, le F-GCPS quitte son niveau de croisière en descente vers le niveau 70, qu'il atteint à 06 h 32 mn 30 s. En fait, le palier est effectué 100 pieds plus haut (FL 71) puis l'avion remonte encore 100 pieds plus haut (FL 72) pendant 1 mn 30 s avant de reprendre la descente à 06 h 35 mn 40 s vers le niveau 60.

Le dernier écho radar secondaire apparaît à 06 h 37 mn 01 s environ 4 NM à l'est du VOR « MEL » (27 NM du VOR/DME « OL »), l'alticodeur indique 6110 pieds. Le lieu de l'accident se situe 2 NM plus loin.

1.16.5.2. *Radar primaire* (voir photos en annexe 4)

L'examen des enregistrements radar primaire analogique de l'approche d'Orly (enregistrement cinématographique) montre qu'après la dernière réponse secondaire de l'avion celui-ci reste encore visible sur quatre photographies, dont deux avec étiquette d'identification, avant de disparaître totalement à 25 NM de l'antenne radar qui est pratiquement co-implantée avec le VOR DME d'Orly (OL). Les échos primaires se rapprochent de plus en plus. Ceci prouve que la composante horizontale de la vitesse de l'avion a diminué fortement. La dernière image, qui se situe à la verticale du lieu de l'accident, n'a pas avancé par rapport à la précédente et sa luminosité est affaiblie. On peut affirmer que cette image est liée à la rémanence de l'écran et que l'avion a déjà disparu du radar.

L'antenne de ce radar fait un tour toutes les quatre secondes (15 tours/mn) mais seulement un tour sur deux est enregistré (une photo toutes les 8 secondes). On sait que l'étiquette d'identification reste accrochée à l'écho primaire pendant les deux tours d'antenne qui suivent la disparition de la réponse secondaire. Le tableau ci-dessous montre qu'entre l'arrêt du répondeur radar survenu entre les tours d'antenne numérotés 2 et 3 et la perte totale du contact radar entre les tours 7 et 9 il s'est écoulé entre 16 et 24 secondes.

Des essais en vol au-dessus du lieu de l'accident ont montré que la perte de contact radar primaire intervient en dessous de 500 pieds/sol en descente.

PHOTOS (1/8 s)	TOURS d'antenne (1/4 s)	TYPE D'INFORMATION		
		Image primaire	Mode C (alticodeur radar secondaire)	Etiquette « TAT-YU »
1	1	Oui	Oui (6110)	Oui
	2	Bien que non enregistrée la réponse ne peut être que positive car l'étiquette n'est maintenue que pendant 2 tours (compte à rebours).		
2	3	Oui	Non	Oui (1er tour)
	4	-		Oui (2e tour)

PHOTOS (1/8 s)	TOURS d'antenne (1/4 s)	TYPE D'INFORMATION		
		Image primaire	Mode C (alticodeur radar secondaire)	Etiquette « TAT-YU »
3	5	Oui	Non	Oui (rémanence tour passé)
	6			
4	7	Oui	Non	Non
	8	(Perte primaire avant car rémanence de la position visible sur photo 4.)		
5	9		Non	Non
	10			
6	11	Non	Non	Non

1.16.5.3. *Autres éléments d'appréciation de la trajectoire finale*

Les enregistrements des consigneurs d'état de la ligne électrique coupée totalement (Morbras 2) fournis par les services techniques d'E.D.F. montrent que les trois phases ont été affectées simultanément par une coupure à 06 h 37 mn 22 s 23/100e.

Une seule phase de la ligne suivante (Morbras 1) a été touchée suite à la projection des débris et 1,47 seconde plus tard la projection du faisceau de câbles restés accrochés à cette ligne a entraîné le déclenchement de la ligne Le Chesnoy-Villejust (la plus à l'Ouest).

Les horloges internes des consigneurs d'E.D.F. et des systèmes de traitement radar sont recalées à la même source mais à des fréquences et selon des techniques différentes. La précision de ces horloges reste nettement supérieure à la seconde.

Bien qu'il ne soit pas possible de connaître précisément le décalage entre ces différentes horloges on peut estimer qu'il s'est écoulé un peu plus de 20 secondes entre l'arrêt du répondeur radar du F-GCPS et l'impact au sol.

La dernière réponse alticodeur avant l'arrêt du répondeur radar secondaire donne 6 110 pieds (1 013,2 hPa). L'altitude du lieu de l'accident est de 377 pieds. Le QNH qui était de 1001 hPa situe l'isobare 1 013,2 hPa à 336 pieds au-dessous du niveau de la mer. On peut donc estimer que l'avion était à une hauteur de l'ordre de 5 400 pieds (1 650 mètres). Le taux moyen de la chute finale a donc été de l'ordre de 16 000 pieds/mn. Un tel taux ne peut être obtenu qu'avec une assiette très fortement négative au cours d'une descente en catastrophe. Il est voisin du triple de celui qui correspond à une descente d'urgence contrôlée par le pilote (voir ci-dessous en 1.16.6.3). Lors des essais de certification de cet avion des vitesses en piqué supérieures à 300 kt ont été démontrées.

La profondeur du cratère (plus de 3 mètres) situé à la verticale de la ligne électrique dont tous les fils ont été coupés ainsi que la relativement faible distance de répartition des débris en surface, malgré une vitesse très élevée à l'impact, montrent que la trajectoire finale avait une pente très fortement négative faisant avec le sol un angle de l'ordre de 45°.

1.16.6. **Essais en vol**

Des essais en vol sur avions identiques ont été effectués à Dinard les 18 et 19 octobre 1988 et à Brétigny le 15 novembre 1988 pour préciser les conséquences de défaillances du système de génération électrique.

Trois scénarios de panne électrique ont été simulés :

- variations aléatoires de la fréquence du courant alternatif ;
- courts-circuits intermittents ;
- baisse progressive de la tension du courant continu, l'avion ne fonctionnant que sur batteries.

Ces essais ont été effectués dans des conditions de masse identiques à celles de l'appareil accidenté (16 600 kg), le centrage retenu variant de 26,5 à 29 p. 100. Rappelons que le centrage réel du vol de l'accident n'est pas connu.

Ils ont été précédés le 30 août 1988 d'un vol de prise en main au cours duquel les performances du pilote automatique ont été évaluées.

Pour tous ces vols, les avions étaient équipés d'un accéléromètre et d'un peson. De plus, ils disposaient d'un horizon de secours alimenté et éclairé par une batterie indépendante.

Le vol du 18 octobre 1988 a consisté à évaluer le comportement longitudinal de l'avion dans les configurations « hors trim » ou en cas de déroulement intempestif du trim automatique ainsi que l'influence sur les systèmes de la dérive en fréquence du convertisseur en dehors de la plage de fonctionnement normal.

Le vol du 19 octobre 1988 avait pour objectif de vérifier l'effet d'une panne électrique totale sur les systèmes (cas d'un court-circuit ou suite à un fonctionnement sur batteries seules).

Le vol complémentaire du 15 novembre était destiné à évaluer l'autorité du servomoteur de profondeur du pilote automatique et le comportement longitudinal en position « hors trim ».

Toutes les bandes des enregistrements de conversations et d'alarmes sonores de ces vols d'essais ont été dépouillées et exploitées.

1.16.6.1. *Génération électrique*

Au plan électrique, ces essais ont démontré qu'une perte de courant alternatif 115 V/400 Hz provoque le débrayage du pilote automatique sans à-coup et sans alarme. Les drapeaux des instruments (ADI et HSI) pilote et copilote apparaissent immédiatement et les horizons partent lentement vers le haut (ceci avait déjà été démontré au sol : cf 1.16.4). L'état du système de génération électrique n'est pas signalé mais les drapeaux sur les instruments sont bien visibles s'ils sont bien éclairés. Si l'on n'est pas en conditions givrantes les informations altimétrique, anémométrique et de vitesse verticale restent bonnes.

La coupure totale de l'alimentation électrique par action sur la barre « coupe tout » (ou « barre de crash ») est sans effet ; l'avion reste pilotable mais il n'y a plus de référence d'attitude (sauf si un horizon de secours à l'alimentation indépendante existe, ce qui n'était pas le cas lors de l'accident).

La panne électrique totale par épuisement des batteries intervient dans la minute si la consommation est maximale (IFR de nuit, PA engagé) et si le relais de délestage est resté collé. A 17,9 volts le pilote automatique se désengage ; il y a une alarme mais très peu visible. Les drapeaux apparaissent et les horizons partent lentement vers le haut.

Si la fréquence du courant diminue lentement (2 Hz/seconde) jusqu'à 354 Hz, les performances des systèmes ne sont pas affectées. Si la fréquence varie plus rapidement (10 Hz/seconde), il y a déconnexion du PA sans embarquement et apparition des drapeaux.

En vol, il n'a pas été possible d'augmenter la fréquence au-delà de 406 Hz et donc de constater ce qui peut découler d'une augmentation de cette fréquence.

Il n'y a pas de signalisation de panne génératrice. Le voyant de panne par « perte de l'alimentation 115 V/400 Hz » en bas de la planche de bord derrière la colonne du manche est peu visible. Cette panne s'identifie par l'apparition des drapeaux sur les instruments gyroscopiques. Le sélecteur du secours alternatif situé en dessous du voyant de panne est peu accessible.

Enfin, les essais ont montré que la barre « coupe tout » qui permet de couper simultanément toute l'énergie électrique, située en bas du panneau supérieur droit sur le tableau de commande et de contrôle de la génération électrique peut être manœuvrée fortuitement en vol, notamment après avoir réglé ou orienté la liseuse située au-dessus (cet incident est déjà survenu en exploitation).

La génération électrique étant dans une configuration normale et le pilote automatique engagé sur maintien de cap et d'altitude, la mise en marche de l'alternateur de secours n° 1 (pilote) provoque un départ à piquer de 5° avec roulis à gauche puis un retour à cabrer avec roulis à droite. Lors de cet essai le pilote automatique a été débrayé à 14° d'assiette à cabrer.

La panne de génération électrique est sans effet sur le comportement longitudinal de l'avion s'il est correctement compensé, mais toutes les références d'attitude sont perdues si l'on ne dispose pas d'un horizon de secours.

L'écoute des bandes CVR de ces vols d'essais met en évidence des anomalies dans la vitesse de défilement de la bande tout à fait comparables à celles de la bande du vol de l'accident. C'est notamment le cas dès que la tension du courant continu est inférieure à 17 volts ou dès que celle du courant alternatif est inférieure à 95 volts (voir ci-dessus en 1.11.2).

1.16.6.2. *Pilote automatique*

Le pilote automatique (Collins AP 103) a des performances satisfaisantes dans le plan longitudinal mais l'on constate que l'autorité du servo-moteur de profondeur est importante. Ceci est la conséquence des caractéristiques de vol du FH 227 dans le plan longitudinal (profondeur).

Les indications d'efforts sur les trois axes situées sur la planche de bord gauche derrière le radar météo ne sont pas visibles par le pilote en place droite.

Le voyant « AP disconnect » est très peu visible et peut être confondu avec les indicateurs de modes de pilotage, car très proche et de même couleur.

Il n'y a pas d'alarme « hors trim ». L'analyse du schéma de câblage et les essais effectués en laboratoire ont montré qu'une panne simple, telle qu'une mise à la masse du circuit de commande du moteur de trim, pouvait l'amener à tourner indépendamment du servomoteur et, qu'un plus 28 V intempestif appliqué aux bornes du moteur de trim doublait sa vitesse de rotation.

En cas de débrayage volontaire ou accidentel du pilote automatique, si l'avion se trouve en position « hors trim », le mouvement longitudinal de l'avion est d'amplitude proportionnelle à l'écart entre la position de la gouverne et la position du compensateur et de même sens que cet écart. Compte tenu des caractéristiques longitudinales du FH 227, les efforts de reprise en main, fonction du « hors trim », du centrage et de la vitesse sont très importants (38 daN pour 6 graduations, soit un tour de volant à piquer correspondant à la limite d'autorité du servomoteur pour une vitesse de 178 Kt au FL 150 dans le cas de l'essai du 18 octobre 1988) et dans certaines conditions peuvent conduire l'avion dans une situation critique, voire catastrophique.

En effet, cet avion a été allongé à l'avant des ailes. De ce fait il a été nécessaire d'augmenter la corde et donc la surface de la gouverne et du compensateur de profondeur pour en améliorer l'efficacité.

En mode ALT (maintien d'altitude en croisière) quand le pilote automatique est enclenché, l'altitude ne sera plus maintenue au-delà d'un certain « hors trim » (5 à 6 graduations ou 1 tour complet du volant). Dans les autres modes (en montée ou en descente) le pilote ne pourra détecter l'anomalie de « hors trim » que par des variations d'assiette et des indications de variomètre et de l'anémomètre. Les essais ont montré que les changements de bruits aérodynamiques en cabine ne sont pas très significatifs sur cet avion.

Le débrayage volontaire du PA, sans précaution particulière, peut provoquer un couple longitudinal important et la reprise du contrôle peut nécessiter des efforts très élevés fonction de la vitesse, du centrage et de l'amplitude du « hors trim ».

1.16.6.3. *Descente d'urgence*

Deux descentes d'urgence (l'une en lisse, l'autre trains sortis) ont été effectuées pour déterminer le taux maximum de descente en secours. Avec les paramètres moteurs identiques (4 300 tr/mn et couple 40) les taux obtenus ont été de 5 000 et 4 700 pieds/mn. L'assiette était de 20° à piquer et les vitesses de 250 et 228 Kt.

1.16.7. **Essais électriques au sol**

L'établissement technique central de l'armement a effectué des essais avec un CVR identique à celui équipant le F-GCPS. Ils ont montré que l'entraînement de la bande CVR se fait à une vitesse proportionnelle à la fréquence du courant alternatif dans une plage 200 Hz - 540 Hz. Au-delà, le moteur synchrone d'entraînement de la bande décroche.

Les variations qui affectent la fréquence 400 Hz du courant alternatif de bord, enregistré de façon parasite sur la bande CVR du F-GCPS, démontre de façon indiscutable pour l'E.T.C.A. que le courant de bord a été fortement perturbé pendant des périodes plus ou moins longues représentant au total 12 minutes de vol sur les 30 minutes enregistrées. Certaines perturbations isolées sont particulièrement violentes.

Pour l'E.T.C.A., la coupure finale pourrait trouver son origine dans une défaillance du convertisseur dont le moteur a subi de fortes contraintes mécaniques ou plus vraisemblablement dans la défaillance d'un fusible suite à une augmentation importante de l'intensité du courant débité par le convertisseur. La coupure finale intervient en effet 2,5 secondes après la réapparition du phénomène.

1.16.8. **Antécédents FH 227**

Aucun accident de FH 227 n'a été répertorié dans la banque de données « accidents » de l'organisation de l'aviation civile internationale (A.D.R.E.P.).

Les enquêteurs ont passé en revue 206 événements divers (comptes rendus d'incidents techniques, constats d'événements ou difficultés rencontrées en exploitation...) portant sur la flotte mondiale d'avions du même type entre 1968 et 1988. On y constate qu'un tiers (67) sont des problèmes de génération électrique dont 23 intéressent le courant alternatif. Les pannes affectant les convertisseurs et les génératrices sont particulièrement fréquentes, notamment entre 1980 et 1988.

En plus de ces événements, après l'accident, la compagnie TAT a communiqué à la commission une liste de 31 pannes de convertisseur ayant affecté sa flotte dans la période 1986, juin 1988.

Les anomalies les plus significatives qui ont affecté le F-GCPS dans les douze derniers mois avant l'accident ainsi que les mesures correctives prises sont les suivantes :

2 mars 1987 : sous-tension de la génération. - Aucune anomalie par la suite.

18 juillet 1987 : pilote automatique en mode NAV/LOC route capturée, l'avion se met en virage à droite avec une inclinaison de 8° en s'écartant de la route. Les VOR sont croisés pour recherche de panne.

6 août 1987 : le pilote automatique déclenche très brutalement à cabrer en montée, en croisière ou en descente. Aucune anomalie détectée. Recherche de panne maintenue.

21 octobre 1987 : la génératrice n° 1 n'enclenche pas. La génératrice APU ne fonctionne pas. Echange standard de la boîte de contrôle de génératrice n° 1 et la génératrice de l'APU fonctionne normalement par la suite.

9 décembre 1987 : la génératrice n° 2 ne fonctionne pas et la génératrice APU ne démarre pas. La mesure prise après cet incident fait référence à un défaut de fonctionnement de la génératrice droite.

24 décembre 1987 : panne du convertisseur n° 1. La panne ne s'est pas reproduite.

13 janvier 1988 : les sections CD et EF du dégivrage pneumatique ne fonctionnent pas. La minuterie ne fonctionne pas. Echange standard.

14 janvier 1988 : le témoin de panne de l'enregistreur de paramètres reste allumé. La bande est repositionnée. Après changement de la minuterie de dégivrage pneumatique toutes les sections semblent fonctionner normalement.

15 janvier 1988 : fort bruit de fond sur l'interphone PNT/PNC. Visite assistant escale.

18 janvier 1988 : parasitage par la génératrice APU de l'interphone PNT. Echange standard de l'ampli interphone.

20 janvier 1988 : dégivrage pneumatique de l'aile gauche section CD et EF ne fonctionne pas. Visite assistant escale.

21 janvier 1988 : suite anomalie précédente, fonctionnement normal en croisière plus bas si la température est positive. A voir en atelier.

Problèmes si la température est négative. L'étanchéité du bord d'attaque au niveau du phare est effectuée.

Sur l'antigivrage du moteur gauche, il n'y a pas de cycle 23 A. Echange standard de la minuterie d'antigivrage.

Essais au sol OK.

Dégivrage du moteur droit. Aucun cycle correct. Idem.

30 janvier 1988 : l'APU ne fonctionne pas en vol. Essai de démarrage au sol OK. Travail reporté.

1er février 1988 : le drapeau d'alarme de l'horizon n° 2 (droit) ne s'efface pas quand on effectue l'essai de transfert sur alternateur de secours même avec un régime moteur supérieur à 11 300 tours/mn. A confirmer.

12 février 1988 : témoin de panne de l'enregistreur de paramètres reste allumé. Reprise de la bande.

17 février 1988 : la chaîne de direction du pilote automatique est toujours inexploitable. Travail reporté.

La génératrice APU donne des signes de faiblesse. Chute brutale de voltage. Travail reporté.

Témoin de panne de l'enregistreur de paramètres allumé de temps en temps. Réfection de la bande.

18 février 1988 : témoin de panne de l'enregistreur de paramètres reste allumé en permanence. Réparation en magasin.

25 février 1988 : confirmation APU. Voir liste des travaux reportés. Remis en liste de travaux reportés après modification d'un relais de ligne.

Deux essais infructueux de mise en route APU. Arrêt cause surchauffe. Transféré sur la liste de travaux reportés.

26 février 1988 : témoin de panne de l'enregistreur de paramètres allumé en vol. Remise en place de la bande.

1er mars 1988 : sections CD de dégivrage aile gauche ne gonflent pas (1 m 50 environ à gauche de la nacelle moteur 1 gonflant peu au sol). Transféré à la liste des travaux reportés.

Convertisseur principal ne fonctionne pas. Echange standard. Origine de la panne n'a pu être trouvée (voir plus haut le 24 décembre 1987).

3 mars 1988 : témoin de panne de l'enregistreur de paramètres allumé en vol.

Reprise de la bande. Essai OK.

Les comptes rendus mécaniques des douze derniers mois du F-GCPS font également état de nombreux problèmes sur le système de chauffage cabine et de dysfonctionnements de l'alarme sonore de survitesse se déclenchant à des vitesses trop faibles. (Cette alarme est perçue à plusieurs reprises dans le CVR au cours de la descente.)

L'origine des différentes pannes d'enregistreur de paramètres semble être plutôt attribuée à un mauvais positionnement de la bande du chargeur qu'à des problèmes d'alimentation de son moteur d'entraînement.

L'anomalie du 1er février 1988 n'a pas été réellement traitée et laisse peser un doute sur le bon fonctionnement de l'alternateur de secours no 2 (côté copilote).

La panne de convertisseur principal du 1er mars 1988, soit trois jours avant l'accident, fait suite à une précédente du 24 décembre 1987. Cette fois, il a été procédé à un échange standard mais lors du passage au banc aucune anomalie de fonctionnement n'a été constatée sur le convertisseur déposé. En conséquence, on peut penser que l'origine de ces deux pannes pouvait se situer en amont du convertisseur et affecter son courant d'alimentation. En effet, les pannes de minuteries des systèmes d'antigivrage sont fréquentes, or ces minuteries sont également alimentées en courant continu.

En conclusion, l'examen des incidents signalés par les équipages ayant utilisé le F-GCPS dans les douze derniers mois montre que cet avion présentait de nombreuses anomalies électriques dont l'origine n'a pas toujours été clairement identifiée.

1.17. *Témoignages*

Vingt-cinq témoins situés à proximité du lieu de l'accident ont été entendus.

Le plafond était très bas (environ 600 pieds) et la visibilité très réduite sous les averses de pluie et de neige mélangées.

En conséquence, deux ou trois seulement prétendent avoir vu l'avion mais tous l'ont très bien entendu pendant la descente tant l'intensité du bruit était forte.

Tous les témoins affirment que l'avion était en descente vertigineuse, qu'ils entendaient le vrombissement très fort et caractéristique d'un avion en piqué. La plupart d'entre eux évoquent le bruit d'une bombe ou d'un avion qui va s'écraser « comme dans les films de guerre ». Ils estiment que ce bruit a duré entre cinq et dix secondes. Certains disent avoir entendu avant comme des variations de régime moteur, d'autres un court silence puis un emballement final.

Les témoins les mieux placés, situés sous le vent et sous la trajectoire ont entendu des bruits de « tôles » ou de « bidons vides » qui pourraient indiquer que les structures de l'avion étaient très fortement sollicitées pendant le piqué.

Un seul témoin, situé assez loin du lieu de l'accident prétend avoir vu très nettement les phares d'atterrissage allumés. Il a signalé qu'ils étaient blancs, ce qui est exact. Techniquement ceci est tout à fait possible si aucune panne générale n'affecte le courant continu, par contre, aucune raison opérationnelle ne justifie cet allumage à une telle distance de l'aérodrome. En fait, compte tenu de la vitesse et des conditions météorologiques, il pourrait s'agir de filets marginaux créés par les pales d'hélices et/ou les extrémités d'ailes dans la descente.

Enfin, tous les témoins ont entendu une très violente explosion (avec ou sans son écho) qui accompagnait « l'éclair » ou la « boule de feu » de l'impact final.

2. ANALYSE

Depuis le 1er mars 1988, il avait été constaté que les sections C et D de dégivrage de l'aile gauche ne gonflaient pas. Le traitement de cette anomalie avait été reporté par les services techniques de la compagnie. La liste minimale d'équipement et le manuel d'utilisation FH 227 de la compagnie (page UTI 09.30.01) permettent de faire l'impasse sur ce système pendant quarante-huit heures, à condition de voler en conditions météorologiques non givrantes. Le dossier météorologique remis à l'équipage à Nancy avant le décollage mettait en évidence un risque de givrage important sur le trajet, notamment en fin de parcours.

Les enregistrements au sol et embarqués permettent de reconstituer la plus grande partie du vol de l'accident (33 minutes sur 45).

Dès le début de la bande de l'enregistreur de conversations et d'alarmes sonores dans le poste de pilotage, on note que le commandant de bord est en train d'exposer le fonctionnement et le pilotage des groupes turbopropulseurs au passager assis sur le strapontin central.

L'avion atteint le niveau de croisière 140 pilote automatique en fonctionnement. Le commandant de bord sélectionne le mode « ALT » (maintien d'altitude). Il reprend ses explications et démonstrations sans s'interrompre, sauf pour répondre aux questions de ce passager.

Quinze minutes plus tard, vers 06 h 20 mn, on peut noter les premières distorsions et variations de vitesse dans la bande du CVR alors même que le commandant de bord est en train d'expliquer la génération électrique de l'avion. Les conversations deviennent pratiquement incompréhensibles car il n'est parfois possible de saisir que des mots isolés.

Il semble cependant que pendant les cinq minutes que durent ces perturbations le commandant de bord poursuive ses explications sur les systèmes électriques tout en procédant à quelques vérifications et lectures de tensions et intensités de courant.

Les études comparatives avec les bandes des enregistrements des essais électriques effectués au sol puis en vol montrent que des distorsions tout à fait similaires sont obtenues quand on diminue la tension du courant continu ou en modifiant les caractéristiques du courant alternatif. Il n'est pas possible de savoir si l'équipage du F-GCPS s'est rendu compte de ces anomalies, mais en prenant contact avec les opérations de la compagnie deux minutes plus tard (06 h 27 mn), il ne signale qu'un problème de minuterie d'antigivrage. Il ne parle pas non plus de la section CD de dégivrage voilure défectueuse.

Ensuite, la densité des échanges radio entre le contrôle et les avions en vol ne permet plus de suivre totalement les conversations à bord. Il semble néanmoins qu'avant que le commandant de bord ne reprenne ses explications, cette fois sur la navigation et la trajectoire à suivre vers la piste en service, l'équipage ait été préoccupé par des problèmes électriques (entre 6 h 30 et 6 h 33).

On constate que pendant toute la durée du vol enregistrée le commandant de bord est très pris par ses explications et démonstrations et que la densité du trafic aérien à l'arrivée à Orly est très importante. Cela doit mobiliser une bonne partie de l'attention du copilote qui de plus assume aussi une partie des tâches normalement dévolues au pilote aux commandes (le carton d'atterrissage, par exemple).

Par ailleurs, on remarque que si l'équipage a constaté des problèmes électriques autres que ceux relatifs à la minuterie d'antigivrage, à aucun moment il ne les a jugés suffisamment sérieux pour alerter le contrôle ou sa compagnie ou demander une priorité à l'atterrissage.

Immédiatement après 6 h 37, l'enregistrement s'arrête brutalement alors que le commandant de bord explique comment on fait pour identifier la radiobalise Orly-Est (OYE).

Les enregistrements radar nous indiquent que le répondeur radar s'est également arrêté de fonctionner immédiatement après 6 h 37 à 27 NM d'Orly en approchant du niveau 60, dernier niveau vers lequel l'avion avait été autorisé à descendre.

La bande de l'enregistreur de paramètres de vol montre également que cet enregistreur s'est arrêté de fonctionner avant l'impact au sol.

Les examens des quelques instruments de bord récupérés dans les débris nous indiquent que le DME s'est aussi arrêté de fonctionner à 27 NM d'Orly et que les ADI n'étaient plus alimentés depuis plus de 5 secondes (temps nécessaire pour obtenir 90° UP).

Toutes ces constatations tendent à prouver que le F-GCPS a subi un arrêt de l'alimentation électrique, au moins alternative, immédiatement après 6 h 37 mn.

L'examen des débris des divers composants du système électrique n'a pas permis d'identifier de manière indiscutable l'origine de cet arrêt électrique, ni de savoir si des actions avaient été entreprises par l'équipage pour y pallier.

L'examen des batteries de l'appareil (et d'autres identiques larguées par hélicoptère) a prouvé que celles-ci n'étaient pas complètement déchargées à l'impact et donc que l'avion disposait encore de courant continu même dans le cas fort improbable d'une panne des deux génératrices.

L'étude des incidents électriques ayant affecté la flotte mondiale d'avions de même type nous montre que les pannes de convertisseur rotatif sont relativement fréquentes. Le F-GCPS en avait d'ailleurs subi une trois jours avant l'accident. L'origine de cette panne n'a pu être identifiée. L'origine des nombreuses anomalies électriques ayant affecté le F-GCPS dans la dernière période n'avait pas non plus été clairement identifiée.

Les recherches effectuées au sol en amont du lieu de l'accident, l'examen des débris et de leur répartition au sol ainsi que les témoignages indiquent qu'il n'y a pas eu rupture en vol à la suite d'une explosion accidentelle ou criminelle. Le FH 227 était entier lorsqu'il a percuté la ligne électrique avant de s'écraser au sol.

L'analyse des conversations, bruits et alarmes sonores audibles sur la bande CVR dans les instants qui précèdent l'arrêt de cet enregistreur permet d'éliminer l'hypothèse d'une perte de contrôle consécutive à un incendie à bord, un givrage cellule, un blocage accidentel des commandes, un foudroiement ou de tout autre événement extérieur.

Après avoir examiné différentes hypothèses dont les probabilités se sont toutes avérées plus faibles, la commission d'enquête a considéré que la panne de courant alternatif en vol en descente peu avant d'atteindre le niveau de vol 60 pourrait être la conséquence d'une coupure brutale du courant d'alimentation du convertisseur lors de la réapparition des manifestations intermittentes et fugaces d'une anomalie ancienne qui n'a pu être identifiée ni avant ni après l'accident.

En vol, l'équipage est prévenu d'une panne de courant alternatif par l'apparition des drapeaux sur les instruments de pilotage, l'allumage de voyants lumineux et le basculage de témoins électromécaniques. Ces alarmes ne sont pas immanquables surtout si l'équipage n'a pas à cet instant le regard fixé sur la planche de bord.

Ne disposant pas d'horizon de secours, en conditions de vol aux instruments (dans les nuages), s'il met plus de 5 secondes pour apercevoir le voyant de panne de courant alternatif et/ou les drapeaux d'alarme sur les instruments et analyser la situation, l'équipage ne dispose plus d'aucune référence instrumentale d'attitude. Il ne lui reste plus alors que 5 secondes pour activer les alternateurs de secours (voir 1.16.3, page 18).

Confrontés à une telle panne, la réaction normale des pilotes est de mettre immédiatement en œuvre les alternateurs de secours avant toute analyse de panne et sélection du convertisseur de secours. La position à 90° UP des ADI après l'accident nous indique que les alternateurs de secours n'ont pas été sélectionnés ou l'ont été plus de 10 secondes après la panne ou encore qu'ils ne fonctionnaient pas. Le doute reste permis pour ce qui concerne celui du copilote (voir panne signalée le 1er février précédent). Il est également possible que les pilotes n'aient pas pu les sélectionner si le départ en piqué a été très violent.

Une panne de courant alternatif entraîne en outre le débrayage du pilote automatique. Cette panne n'est pas immanquable, notamment si l'équipage n'est pas très attentif et si l'avion est déjà en évolution dans le plan vertical. Le débrayage du PA se produit sans à-coup s'il n'y a pas de « hors trim » important. Dans le cas contraire l'engagement longitudinal est très franc.

L'équipage ne disposait pas d'alarme « hors trim ».

De plus, l'analyse du schéma de câblage et les essais ont montré qu'une mise à la masse du circuit de commande du moteur de trim peut l'amener à tourner indépendamment du servomoteur.

On peut donc penser qu'en cas de mise à la masse intempestive le courant continu d'alimentation du convertisseur ainsi que le courant alternatif produit sont également perturbés.

Le « hors trim » et les perturbations électriques relevées sur le CVR pourraient alors avoir la même origine.

Tous les éléments d'appréciation dont dispose la commission tendent à démontrer que la chute finale du F-GCPS résulte d'une mise en piqué très brutale immédiatement après la panne électrique :

- témoignages ;
- images radar primaire ;
- vitesse très élevée ;
- taux de chute très important ;
- angle d'impact au sol ;
- profondeur du cratère ;
- orientation proche de la route suivie et faible longueur du cône de répartition des débris ;
- non-activation des alternateurs de secours ;
- etc.

Les caractéristiques aérodynamiques du FH 227 font que les efforts à appliquer sur la commande de profondeur peuvent alors être importants pour récupérer une assiette normale.

Les essais en vol ont mis en évidence qu'un débrayage du pilote automatique quand l'avion est en configuration « hors trim » importante pouvait amener dans une situation critique, voire catastrophique (cf. 1.16.6.2 ci-dessus).

L'absence d'indication des horizons artificiels ne peut que compromettre les possibilités de récupération.

3. CONCLUSIONS

3.1. *Faits établis par l'enquête*

L'équipage détenait les brevets, licences et qualifications exigés réglementairement pour le vol entrepris.

L'avion possédait les documents de navigabilité exigés par la réglementation.

La masse de l'appareil tant au moment du décollage qu'à celui de l'accident était à l'intérieur des limites approuvées.

L'avion était équipé conformément à la réglementation en vigueur.

L'avion n'était pas équipé d'horizon de secours.

Avant le départ, l'équipage connaissait l'existence de conditions givrantes sur le parcours. Il est néanmoins parti avec une section de dégivrage de l'aile gauche inopérante depuis trois jours.

Un passager a effectué le vol assis sur le strapontin central du poste de pilotage. Durant la majeure partie du vol, le commandant de bord lui a expliqué le fonctionnement de l'avion.

L'équipage a demandé par radio à sa compagnie le changement d'une minuterie d'antigivrage mais n'a à aucun moment signalé aux organismes au sol une quelconque difficulté.

Aucun indice de choc, explosion, rupture ou incendie pouvant être antérieur à l'impact avec la ligne électrique n'a été mis en évidence, et tous les débris de l'aéronef ont été retrouvés à proximité immédiate du point d'impact final.

Les traces d'incendie et d'arcs électriques relevées dans les débris de l'avion sont la conséquence du choc avec la ligne électrique à très haute tension et de la violente explosion qui a suivi.

A l'impact, les deux moteurs fonctionnaient. Le gauche avait un régime proche du ralenti « vol », et le droit un régime moyen.

Les batteries d'accumulateurs n'étaient pas complètement déchargées et ne portent pas de trace de surchauffe.

Le vérin de trim de profondeur a été retrouvé dans une position voisine du plein piqué mais celle-ci peut résulter en partie d'efforts dissymétriques sur les câbles de commande à l'impact.

Le répondeur radar, le DME et les enregistreurs de bord ont cessé de fonctionner en vol. De même, les indicateurs d'attitude (ADI) et de position horizontale (HSI) ont cessé d'être alimentés électriquement avant l'impact final. Tous ces faits se sont très vraisemblablement produits simultanément et tendent à accréditer l'hypothèse d'un arrêt de l'alimentation électrique (au moins alternative) affectant également plusieurs autres systèmes parmi lesquels le pilote automatique, les centrales de verticale et les directeurs de vol.

15 minutes avant l'arrêt total du CVR, on note de fortes variations dans la vitesse de défilement de la bande.

Les pannes électriques étaient particulièrement nombreuses sur ce type d'appareil notamment sur le F-GCPS.

La fiabilité des convertisseurs rotatifs assurant normalement la génération électrique alternative de cet avion est faible mais dans ce cas, la panne semble se situer en amont du convertisseur.

La chute finale de l'avion n'a duré qu'environ 20 secondes. Un taux de descente de l'ordre de 16 000 pieds/mn, trois fois supérieur à celui d'une descente d'urgence, ne peut être obtenu qu'en piqué prononcé consécutif à un phénomène brutal.

Les témoignages confirment que cette descente finale avait un caractère catastrophique.

CAUSES PROBABLES

Immédiatement après une panne électrique survenue en conditions météorologiques de vol aux instruments, l'avion s'est mis en piqué.

La commission n'a pu acquérir aucune certitude quant à la cause de cette mise en descente catastrophique.

Après avoir éliminé différentes hypothèses infirmées par les faits et constatations établis et après avoir pris connaissance des résultats des essais en vol effectués à sa demande, la commission a considéré comme étant affectée de la plus forte probabilité l'hypothèse selon laquelle la panne électrique entraînant la perte de toute référence d'attitude et le débrayage du pilote automatique se serait produite alors que l'avion était en configuration « hors-trim » à piquer importante.

En l'absence d'horizon de secours autonome, l'équipage n'avait aucune référence d'attitude immédiatement utilisable alors que l'avion était en piqué à grande vitesse.

4. RECOMMANDATIONS DE SÉCURITÉ

Le 28 décembre 1988, compte tenu des résultats des essais en vol et au sol pratiqués dans le cadre de cette enquête, la commission a été conduite à faire la recommandation suivante :

En attendant les conclusions de l'enquête, l'utilisation du pilote automatique Collins AP 103 doit être interdite sur les aéronefs type FH 227 et sur ceux qui pourraient présenter des caractéristiques semblables.

Au terme de ses travaux, la commission d'enquête est amenée à faire les recommandations de sécurité suivantes :

4.1. *Aspects techniques*

Recommandation nº 1 :

Compte tenu des insuffisances des signalisations des systèmes et des risques de fonctionnement anormal de la chaîne de profondeur du pilote automatique de cet avion la commission recommande :

- que *l'indicateur d'effort* du pilote automatique soit placé directement dans le champ visuel des deux pilotes et qu'un voyant rouge soit prévu pour les avertir des situations de « hors trim » importantes ;
- que la lisibilité des *voyants* de modes et d'alarmes du *pilote automatique* soit améliorée et qu'ils soient placés dans le champ visuel des deux pilotes ;
- que l'alarme « AP DIS » pilote automatique désengagé soit améliorée pour la rendre immanquable ;
- que la palette de déconnexion du P.A. en secours soit protégée afin d'éviter toute manœuvre accidentelle.

Recommandation nº 2 :

En ce qui concerne la génération électrique de cet avion, la commission d'enquête recommande :

- qu'en cas de panne du convertisseur principal le passage sur *convertisseur de secours soit automatique*, l'équipage en étant avisé par une alarme ;
- que la *logique de la signalisation de panne d'une génératrice* soit modifiée de telle sorte que les voyants soient allumés pour toute panne affectant non seulement une génératrice mais également son circuit ou lorsque un pilote désactive intentionnellement une génératrice ;
- que la *commande « coupe-tout »* dite « barre de crash » soit protégée pour éviter toute manœuvre accidentelle ;
- que la fiabilité des *convertisseurs rotatifs* soit nettement améliorée ou qu'ils soient remplacés par des matériels technologiquement plus fiables.

Recommandation nº 3 :

La commission d'enquête considère qu'une simple panne électrique ne devrait pas affecter le fonctionnement des *enregistreurs de bord*. En effet dans un trop grand nombre d'accidents, les causes n'ont pu être déterminées avec certitude parce que les enregistreurs de bord n'avaient pas été alimentés jusqu'au dernier instant. Ce fait est extrêmement préjudiciable à l'amélioration de la sécurité des vols.

En conséquence, pour tous les aéronefs équipés d'enregistreurs, la commission recommande :

- que la conception de leur alimentation électrique soit revue pour garantir leur bon fonctionnement jusqu'à la phase finale des accidents.

Enfin, la commission d'enquête considère que tout avion exploité par une entreprise de transport aérien doit être équipé d'un horizon de secours à alimentation autonome. En France, conformément aux dispositions de l'arrêté du 5 novembre 1987 relatif aux conditions d'utilisation des avions exploités par une entreprise de transport aérien, ceci est obligatoire depuis le 30 novembre 1988.

4.2. *Aspects opérationnels*

Recommandation nº 4 :

Sur cet avion, le débrayage du pilote automatique en conditions « hors trim » pouvant provoquer un couple longitudinal important et la reprise du contrôle manuel pouvant nécessiter des efforts élevés, la commission recommande : -

- qu'une *consigne opérationnelle* portant sur les précautions à prendre avant débrayage du pilote automatique figure au manuel d'utilisation du FH 227.

Recommandation nº 5 :

Compte tenu des très grosses difficultés rencontrées dans la transcription de l'enregistrement des conversations et d'alarmes sonores dans le poste de pilotage résultant du niveau sonore des radiocommunications également reçues par le micro d'ambiance, la commission d'enquête recommande :

- que des mesures soient prises pour favoriser l'utilisation systématique par les équipages des équipements de tête (micro-casques) avec interphone de bord en fonctionnement continu, dans certaines phases de vol.

Recommandation nº 6 :

La présence d'un passager dans le poste de pilotage pendant toute la durée du vol enregistrée ayant sans aucun doute eu une influence sur le niveau de vigilance d'un (ou des deux) pilote(s) la commission d'enquête recommande :

- que l'accès au poste de pilotage des avions de transport public soit limité aux strictes nécessités techniques et professionnelles de la compagnie et des organismes officiels.

Recommandation nº 7 :

L'équipage du F-GCPS a entrepris le vol avec une section de dégivrage de la voilure en panne depuis trois jours alors que des conditions givrantes étaient prévues sur le parcours. Même si l'enquête n'a pas établi de lien direct entre cette panne et l'accident, la commission d'enquête attire l'attention des exploitants et des équipages sur les risques que font courir de telles pratiques pour la sécurité des vols. Elle recommande :

- que les listes minimales d'équipement (LME) soient plus précises et appliquées de façon rigoureuse et que des contrôles plus fréquents soient effectués par les services compétents.

5. APPROBATION DU RAPPORT

Le présent rapport a été adopté à l'unanimité par les membres de la commission d'enquête le 24 avril 1990.

Suivent les signatures :

ICAO Note.— Names of personnel were deleted.

ICAO Ref.: 067/88

No. 2

Boeing 727-21, HK-1716, accident at El Espartillo, Cucuta, Colombia on 17 March 1988. Report released by the Civil Aviation Department, Colombia

1.0 OCCURRENCE INFORMATION

1.1 History of the flight

On 17 March 1988, HK-1716 operated by AVIANCA S.A. took off from Palonegro Airport, Bucaramanga, on Flight 0410 to Cúcuta, Cartagena and Barranquilla. HK-3133, which should have been used on that flight, had been replaced in Bogota by HK-1716 for maintenance reasons and the flight left Bucaramanga for Cúcuta at 12:09 local time, 2 hr 30 min behind schedule. The pilot in command of the aircraft was Capt. PTL-1036 (dec.); he was accompanied by Capt. PC-4570 (dec.) and flight engineer IDV-256 (dec.). The flight attendants were , ASA-2410, ASA-3014 and ASA-2407 (dec.).

The flight left Bucaramanga with 142 persons on board and 17,000 pounds of fuel. According to Palonegro Tower, the take-off was uneventful and at 12:16 local time, the flight reported level at 17,000 ft at ARENA intersection and then changed frequency to 119.9 (Cúcuta Approach).

The aircraft landed at Cúcuta at 12:28 local time [the flight engineer reported the arrival time as three five (35)], disembarked 71/5 pax and then boarded 76/7 pax (figures deduced from the passenger list). At 13:06:56 local time, the pilot requested clearance to initiate the flight to Cartagena ("To Cartagena, [requesting] clearance to start"). At 13:07:58 local time, the Tower informed him that there would be a 10-minute delay before taxiing (TW "You have a ten minute delay before taxiing"), and when asked "Could you tell me why?" he responded that he had three aircraft on the VOR on instrument procedures (TW "Traffic three aircraft on the VOR for instrument procedures"). The crew immediately requested clearance for a climb on course (C1 "Why not clear us to climb on course to avoid delaying this flight further? We're pretty far behind") and the tower granted their request at 13:08:34 local time (TW "OK, cleared for engine start, climb on course VMC, report ready to taxi, temperature 28°/ C2: OK/ TW: Correction, temperature 29°); a few seconds later the crew reported ready to taxi and at 13:10:00 local time the tower instructed them to taxi to position on runway 33 (TW "Avianca 1716 taxi to position runway 33, 360° 15 kt, time is 18:10, taxi Bravo, QNH 3002"). The aircraft taxied to that position and at 13:12:08 local time the tower reported, "Cleared to Cartagena via Uniform Whisky 19, Whisky 7, Whisky 10, climb and maintain two six zero after take-off, climb on course VMC, QNH ......, correction transponder Alpha 2216". Take-off clearance was issued at 13:13:14 local time (TW "Cleared for take-off, wind is 015° 10 kt/ C2: 1716") and the aircraft initiated take-off at 13:13:19 local time, completing it at 13:14:09 local time, at which time the pilot said, "Taking off and proceeding as cleared, Avianca 1716". At this point, the aircraft had 143 persons on board and 20,000 pounds of fuel. According to data obtained later, the initial climb path followed the extended runway centre line to the inner marker, at which point the aircraft entered a left turn, reaching headings of 319° in the first minute, 291.6° in the second minute, 310.6° in the third minute, 317° for another 17 seconds, and finally 310.1° in the last 8 seconds.

At 13:15:44 local time, the pilot informed his counterpart on HK-727 that they were turning left: "C1: Pablo, we're turning left here, towards La Cuchilla", and at the end of the CVR tape, at 13:17:44, the pilot said to the copilot, "In any case, start turning right." At 13:17:46 local time, the aircraft struck the peak of El Espartillo (located in the municipality of El Zulia, district of Norte de Santander, coordinates 08° 05' N 72° 41' 30" W) at an elevation of 6,343 feet, and was completely destroyed.

All 143 persons on board perished as a result of the impact and explosion. There was no fire. It was daylight, with thick fog in the area of the accident. The only witness to the crash stated that the aircraft had passed over his house at a very low height above ground.

1.2 Injuries to persons

INJURIES	CREW	PASSENGERS	OTHERS
Fatal	6-1	129/7	---
Serious	---	---	---
Minor/none	---	---	---

1.3 Damage to aircraft

The aircraft was completely destroyed. All parts and components were damaged as a result of the impact with the rocks and the subsequent explosion; there was no generalized fire; some parts were charred by small isolated fires.

1.4 Other damage

An area of 1,200 square metres of forest on El Espartillo was destroyed.

1.5 Personnel information

Pilot-in-command

Name	
Nationality	Colombian
Age	35
Licences	He obtained licence APA-2793 on 18 August 1971 to begin private pilot training at the Escuela Aerocentro. On 24 April 1972 he was issued PC-1772 with authorization to operate single-engined land aeroplanes up to 5 700 kg. He obtained co-pilot ratings for the DC-3 on 3 October 1972, the DC-4 on 11 May 1973, the B-727 on 20 February 1976 and the B-720/B-707 in June 1978. On 1 December 1980, he was issued PTL-1036 with an endorsement to act as pilot-in-command of the B-727.
Medical certificate	No. 11.356, valid until 2 August 1988

Last check -- aircraft type	He received three days (15 hours) of recurrent training on 10-12 August 1987, and was assessed as O.K. in all areas; he had four hours of B-727-200 simulator training on 16-17 August 1987 with instructor and was rated "satisfactory" with the comment: "Capt. knows and flies the aircraft very well. Above average pilot. Check satisfactory." Valid up to 16 August 1988.
Equipment flown as pilot-in-command	PA-18, DC-3, with weights up to 5,670 kg, and B-727.
Total time as pilot-in-command	5,722:27
Total time on type	9,727:35, of which 4,050 was as co-pilot of the B-727
Flight time last 90, 30 and 4 days	219:53, 73:25, 13:15 hours, respectively

Other information

His last vacation was from 15 November to 15 December 1987.

Comment following flight simulator check on 10 November 1983: "Had difficulty with flight director tracking on ILS, but corrected well. Satisfactory job."

Comment following CUC-SMR-BAQ-CUC line check attached to the foregoing: "Disciplined. Good pilot." Comment on annual simulator check carried out on 16 October 1985: "Satisfactory periodic simulator check."

His last period of continuous rest was on 12 and 13 March of the current year.

Under Administrative Order No. 02950 of 18 March 1987 from the Department of Civil Aviation Administration, he was cited for violation of the Manual of Aeronautical Regulations, para. 4.2.8.3 for exceeding the total annual flight time permitted in 1986.

Co-pilot

Name	
Nationality	Colombian
Age	23
Licences	Student pilot licence no. 7780 was issued on 21 December 1984 with the following limitations and privileges: Aerocentro received training as a commercial pilot valid for two years. On 16 September 1985 Escuela Aerocentro de Colombia requested authorization from the Department to conduct the final flight check of the course, a check that was conducted by Capt. , IVA-404, whose final evaluation was: "All ground material approved without

	difficulty. No difficulty in flight either; good aptitude and interest. Can be considered within the general average as a student. Passed final checks satisfactorily." On this basis, the Department of Civil Aviation Administration issued Commercial Pilot Licence no. 4570 to him on 16 October 1985 with the following limitations: "Single-engined land aeroplanes up to 5 670 kg." On 19 February 1986 he began B-727 ground school as a co-pilot with Avianca. The course lasted 59 days and totalled 295 hours. He flew 60 hours as an observer, received 22 hours of simulator training (with a 2-hour check ride) and 1 hour 15 minutes flight training, with a 30-minute final check in the aeroplane. He completed the course satisfactorily and received his rating as co-pilot on the B-727. On 27 August 1986, the Department re-issued Commercial Pilot Licence No. PC-4570 with an endorsement qualifying him as a B-727 co-pilot.
Medical certificate	No. 19444, valid until 3 June 1988.
Last check -- aircraft type	Received 3 days of recurrent training on the machine from 10 to 12 August 1987, for a total of 15 hours, and was assessed OK in all areas. Between 22 and 23 August 1987, he trained on the B-727-200 simulator with Instructor for 4 hours, and was assessed Satisfactory with the comment: "Capt. check ride was satisfactory; he was advised not to try to rush things. He showed himself to be studious and serious about his profession."
Aircraft flown as pilot-in-command	PA-28 (pilot)
Total flight time	The only time recorded is 205:24 hours flight time and 30:06 hours in the Link trainer.
Flight experience on type	340:22 hours
Flight time last 90, 30 and 3 days	147:35, 47:10 and 01:30 hours respectively

Other information

All the documents concerning Capt. were reviewed, and no reference to incidents or accidents was found.

According to Avianca records, he was off duty on 13, 14, 15 and 16 March.

Flight engineer

Name	
Nationality	Colombian
Age	44
Licences	On 28 November 1969 he was issued Aeroplane technician's licence TAV-1171, with the following limitations and privileges: Single and twin piston-engined aeroplanes up to 3,500 kg, C-45, DC-3, DC-4, and power plant technician's licence TPM-1543 for piston engines up to 1400 HP. According to Colombian Air Force records, having met the Department's requirements on 25 August 1976, he was issued Flight Engineer's Licence IDV-256 for the C-130, and on 24 November 1980 Licence IDV-256 was re-issued with an added endorsement for the B-727.
Medical certificate	No. 13657, valid until 28 July 1988.
Last check - aircraft type	He received recurrent training on the B-727 from 21 to 23 April 1987, a three-day course consisting of 15 hours and given by instructor ; rated OK. On 23 and 24 May 1987 he received 4 hours of simulator training supervised by , IDV-029, the result being: "Practised and clarified asymmetry/split flap landing procedure. Practised and clarified fuel dumping procedure. General performance and training satisfactory."
Aircraft flown as pilot-in-command	Not applicable
Total flight time	According to Certificate no. 148 issued on 27 June 1983 by the Department of Civil Aviation Administration, he had logged a total of 1,765 hours 34 minutes flight time as Engineer.
Total flight experience on type	5,687:50 hours
Total flight time last 90, 30 and 3 days	232:15, 85:00, 16:45 hours, respectively

Other information

A review of the documents concerning the flight engineer established that he had come from the FAC, an institution in which he worked for about 15 years as an aircraft technician specialized in the maintenance of C-45, C-47, C-54 and C-130 aeroplanes; he also held an FAA flight engineer's licence for turbo-jet aeroplanes.

Administrative Order no. 2955 of 18 March 1987, issued by the Department, cited him for having exceeded the monthly time limits in December 1986.

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*ICAO Note.— Information concerning the flight attendants and the air traffic controllers was not reproduced.

1.6 Aircraft information

Aircraft

Make	Boeing
Model	727-21
Serial number	18999
Registration	HK-1716
Date of manufacture	15 March 1966
Registration certificate	No number, 26 November 1974
Certificate of airworthiness	No. 0103, valid 31 May 1988
Date of last ADCA inspection	27 December 1987
Total time	43,848:02
Total time since overhaul	9,824:31
Date and nature of last servicing	Preflight inspection, 17 March 1988

Engines

Engines	No. 1	No. 2	No. 3
Make	Pratt and Whitney		
Model	JT8D-7A		
Serial number	653469	649611	653371
Date and nature of last servicing	March 17 1988. Preflight inspection		
Total time	27 642:52	33 566:43	30,179:03
Total time since overhaul	9 500:00	2 157:02	2,556:03

History

HK-1716, owned by Avianca S.A., came from Miami, Florida, U.S.A. and was registered with the Administrative Department of Civil Aviation on 30 October 1974.

Examination of the documentation for the aircraft established that the first overhaul was carried out in Barranquilla by airline technical personnel duly qualified for the equipment at 22,258 hours total time, and the last overhaul was carried out at 34,024 hours.

The technical log for 17 March 1988 contained only the following notes: "Please fix windshield wiper blades as per Maintenance Manual" and "Please clean cockpit windows". This was done before Flight 0410.

The regular periodic inspections were carried out normally, in accordance with the company programme.

The last inspection by Civil Aviation personnel was carried out at Eldorado airport on 24 December 1987, and the aircraft was certified as airworthy and in compliance with the requirements of the Manual of Aeronautical Regulations (M.A.R).

The line check was carried out on 23 January 1988 by Flight Inspector Capt. on the scheduled flight over the Bogota-Bucaramanga-Bogota route. There were no comments relating to technical matters affecting flight safety.

The aircraft was refuelled with jet fuel at Camilo Daza airport in Cúcuta and began the Cúcuta-Cartagena flight with 21,100 pounds of fuel.

The weight and balance of the aircraft were calculated and found to be within the limits established for that particular aircraft type.

1.7 Meteorological information

The meteorological conditions at Camilo Daza airport on the day of the accident, according to METARs, were as follows:

METAR 12:00 local time

Wind	360° at 18 km/h
Visibility	8 000 metres
Meteorological phenomena	Smoke in E/SW quadrants
Clouds	3/8 cumulus at 2 300 ft 5/8 cirrostratus at 20000 ft
Temperature	28°
Dew point	23°
QNH	1018
Relative humidity	74%

METAR 13:00 local time

Wind	360° at 28 km/h (15 kt)
Visibility	8 000 metres
Meteorological phenomena	Smoke in all directions
Clouds	3/8 cumulus at 2 500 ft 5/8 cirrostratus at 20 000 ft

Temperature	28°
Dew point	23°
QNH	1017
Relative humidity	71%

METAR 14:00 local time

Wind	360° at 22 km/h
Visibility	8 000 metres
Meteorological phenomena	Smoke in all directions
Cloud	3/8 stratocumulus at 2 500 ft 6/8 cirrostratus at 20 000 ft
Temperature	30°C
Dew point	23°C
QNH	1016
Relative humidity	66%

According to statements by residents of the area, at the time of the accident the crash site, El Espartillo, was surrounded by heavy fog which reduced visibility to a minimum.

1.8 Aids to navigation

Camilo Daza airport in the city of Cúcuta is equipped with VOR and NDB, both of which were operating perfectly on the date and at the time of the occurrence.

HK-1716 was equipped with the following instruments: ADF (2), VOR (2), DME, ILS, flight director, weather radar and transponder. All were in perfect condition and operating normally.

1.9 Communications

Both Camilo Daza airport and the aircraft were equipped with VHF and HF; voice recordings indicate that communications were normal at all times and took place on frequencies 118.1 and 119.9. *

1.10 Aerodrome information

Camilo Daza airport has 2 runways, with the following characteristics:

RUNWAY	No. 1	No. 2
Orientation	15/33	02/20
	107 000 kg	107 000 kg

**ICAO Note.*— The CVR transcript was not reproduced.

Elevation	1 096 ft	1 096 ft
	2 320 m	52.50 m
Length	2 320 m	1 920 m
Width	45 m	45 m
Class	C	C
Operating hours	10:00 to 02:00 UTC	
Operating permit	Indefinite	Indefinite
Owner	FAN	FAN
Runway surface	Asphalt pavement	asphalt pavement
Average slope	0.0095%	0.006%

The facilities provided to users and operators meet the requirements established for this type of airport.

The Fire Fighting Service has T-6 vehicles, each with a capacity of 1,585 gal. of water and 205 gal. of AFFF foam, one rapid intervention vehicle with 750 lb. of dry chemical powder and a total of 13 operators to handle any emergency.

1.11 Flight recorders

The aircraft flight data recorder was found approximately 20 days after the accident, and its condition was consistent with the impact it had been subjected to. It was taken to the NTSB laboratories in Washington, where the velocity, altitude, heading and G-force parameters recorded on the tape were found to be readable.

Below is a transcript of the results obtained, which are presented as a specific attachment in the appropriate section of the report.

TIME	VELOCITY	ALTITUDE	HEADING	Gs
00:00:0	0	1 113 ft	200.1°*	---
00:40:1	0	---	262.4°*	---
01:00:1	0	---	248.7°*	1.06
01:30:2	0	---	242.0°*	0.94
01:59:4	0	---	189.0°*	1.10
02:20:9	0	---	148.2°*	1.08
03:00:1	0	---	207.1°*	1.05
03:36:3	0	---	333.2°+	0.99

03:51:7	5	---	333.0°=	1.07
03:59:9	10.0	---	335.7°	1.07
04:14:1	116.0	---	334.0°	0.90
04:31:0	156.0	---	334.6°	---
04:39:8	162.0	---	338.3°	0.59
04:41:1	162.0	1154 ft R	355.8°	0.88
05:00:8	172.0	1 637 ft	329.3°	0.79
05:32:5	191.0	2 169 ft	324.4°	0.90
06:01:4	218.0	2 478 ft	314.0°	1.08
06:34:9	250.0	3 210 ft	305.1°	0.99
07:05;1	252.0	4 538 ft	287.0°	0.95
07:36:8	258.0	5 436 ft	296.0°	1.07
08:00:2	261.0	6 040 ft	314.0°	1.09
08:18:0	280.0	6 343 ft M	310.1°	---

NOTE * Variable ramp and taxiing
+ Take-off position
= Beginning of take-off roll
R Rotation
M Moment of impact

1.12 Wreckage and impact information

According to the field inspection carried out at the accident site, the marks left by the impact showed that the aircraft hit the flank of the mountain in normal flight attitude, nose up and slightly banked to the right. These facts were confirmed by the data read off the flight recorders. Both the figures and the graph of that reading indicated that at the time of impact the aircraft was travelling at 280 kt on a heading of 310.0° and at an altitude of 6 343 ft ASL, 657 ft short of clearing the peak.

The inspection also determined that the aircraft struck the rock at the angle between the right wing root and the forward right fuselage. As a result, the left wing and fuselage were propelled in an elliptical path by inertia, which threw the rest of that part of the aircraft towards the upper part of the peak to a distance of approximately 300 metres.

The central part of the fuselage and empennage were crushed at the point of impact and the remains were partially covered by the avalanche produced by the impact. Some parts of the aircraft rolled down between the trees towards the ravine and stopped at different depths, the deepest being calculated at 750 m.

Identification of the wreckage located established that the engines had practically disintegrated and only one retained its basic characteristics despite the damage. Parts of the main landing gear, right flaps and aft stairs were also identified.

The level of destruction produced by the impact precluded complete identification of the other parts of the aircraft, as numerous fragments of the fuselage, wings and other components were scattered about indiscriminately. Attached to this report is a polar diagram of the distribution of the remains over an area of 750 sq. m.

1.13 Medical and pathological information

The information obtained in this area indicates that the physiological state of the crew was normal before and during the flight. The voice recording made during the flight showed some animosity between the pilot and the flight engineer, while the co-pilot was in a calmer frame of mind. Attached to this report is the human factors study carried out subsequently on each member of the flight crew; it was established that they had all had a normal rest on the eve and day of the occurrence.

All crew members and passengers perished as a consequence of the crash and the state of their remains made it impossible to carry out the appropriate autopsies; indirect evidence indicates, however, that no member of the crew had ingested any alcohol or drug that could have affected his capacity for the flight.

Documentation on removal of the remains and death certificates are attached to this report.

1.14 Fire

It was clearly established that there was no fire aboard the aircraft prior to the impact.

Because of the explosion and immediate scattering of remains, there was no generalized fire at the time of the accident either, although pieces of the fuselage showed the effects of small isolated blazes that were no doubt produced by friction between the metal plates and the rock but did not spread.

1.15 Survival

Not applicable. The report of the Aerocivil SAR unit on their post-crash activities is attached.

1.16 Tests and investigation

The site of the occurrence was duly examined to determine the position of the aircraft at the moment of impact, information that was corroborated by the laboratory analysis of the voice and data recorders.

The NTSB readings of the latter are attached to this report and partially transcribed under the corresponding headings. The human factors investigation was conducted in consultation with the Aviation Medicine Division's Psychology Unit and interviews were held with family members and friends of the crew, as well as with Avianca personnel based in Bucaramanga. Important facts were established with regard to the personalities of the crew members, as well as their professional performance and habits. The psychologist's report is attached.

With regard to Capt. habit of taking off and landing in VMC at Camilo Daza airport, statistics for the current year were analyzed and showed that of 42 planned IFR landings, he cancelled 32 and proceeded VMC; with regard to departures, it was found that of 42 planned IFR departures, he cancelled 38 and proceeded on course VMC.

Of those flights, 7 were conducted via Airway W-19 to Cartagena or Santa Marta. Out of a total of 84 operations, he therefore cancelled 70, or 83.33%, of which 10% were VMC departures on course towards the coast.

1.17 **Additional information**

It should be noted under this heading that engine No. 3 of HK-1716 was changed on 2 February of this year because of a high EGT and stall. The JT8D-7, serial number 654518, was removed and replaced with a JT8D-7, serial number 653371.

In addition, the records of the Avianca Production and Control Department indicate that the aircraft was grounded on 12 February of this year due to problems with the rudder light and that the last servicing was carried out in Barranquilla on 28 February.

Documents provided by the Regional Manager of the Bucaramanga base indicate that on the day of the occurrence, the Bucaramanga - Cúcuta - Cartagena - Barranquilla - Bucaramanga flight was running 2 hours 30 minutes late because HK-3133-X, the aircraft scheduled for the flight, was replaced in Bogota by HK-1716 for technical reasons (failure of the right windshield heat resistor in the cockpit).

It should also be noted under this heading that according to the testimony of the only eyewitness to the accident, the aircraft flew over the house of at an altitude equivalent to 75 feet above the ground (the height of a guama tree) and at that time, 13:17 local time, there was dense fog over the peak. The aircraft disappeared into the fog and seconds later the witness heard the explosion of the impact with the mountain and saw what looked like "balls of fire rolling down the mountain."

1.18 **New investigative techniques**

Not used; proceedings were conducted in accordance with Circular DS-SA-09 dated 23 September 1985.

2.0 ANALYSIS

From the above information, it was clearly established that the delay in the schedule for 17 March, originally caused by a change of aircraft for technical reasons, put pressure on the pilot of HK-1716 at the time of departure for Cartagena, so that when the controller in the Camilo Daza Tower warned of a further 10-minute delay due to the presence of three aircraft on the VOR, Capt. decided to request a climb on course departure in order to avoid that delay. This, added to the anomalous presence in the cockpit of another pilot whose loquaciousness continually disrupted the work of all the crew members, affected the way in which the pilot supervised the actions of his co-pilot, who was flying the aeroplane. There was no crew briefing, nor did the pilot-in command give any instructions for the VMC departure. These factors, taken together, led the co-pilot, when he had taken off and barely reached the inner marker, to initiate a continuous turn to the left of the approach path. According to the FDR, the aircraft reached a heading of 286.4°, and from that point oscillated between 286.4° and 310.1°, at which heading it struck El Espartillo.

It was also noted from the conversations among the flight crew that they intended to achieve the highest possible speed first, then climb to the altitude needed to cross La Cuchilla, possibly through El Zulia canyon. This is inferred from the cockpit tapes of conversations, in which the pilot, when determining V1 and V2 referred to twenty-two ... thirty-eight, which is not consistent with calculations by aviation experts, according to whom V1 is 119 and V2 is 137.

Furthermore, the actual rotation speed of the aircraft (from the FDR) was 162 kt according to the NTSB; FDR data also show a constant increase in speed up to 280 kt, with a rate of climb lower than that required to clear La Cuchilla. These facts confirm the idea that the crew was more interested in speed than in altitude.

Another element to be considered is the fact that the presence of another aircraft on the approach path certainly created pressure and a resultant desire to keep turning to the left and avoid getting too close to the descending aeroplane. The deviation was so pronounced that three minutes after take-off, the non-crew pilot asked, "Do you think you're headed for Bogota? Stop fooling around," at which point the flight engineer, the only crew member who was attending to his job, said to the Captain, "Take a look at that fog ... Captain." (the flight engineer then laughed nervously) and the pilot-in-command told his co-pilot "in any case, start turning right." This shows the disorientation that prevailed in the cockpit at that moment.

In addition, the voice recorder established clearly that prior to the beginning of the flight the pilot-in-command did not brief the co-pilot on the flight parameters (crew briefing, class of flight, heading, separation from the airway, etc.), and it can be deduced that the co-pilot was acting solely on the few phrases uttered by the pilot-in-command regarding the sequence of the flight.

2.1 Fitness of the crew

From information obtained, we can confirm that the crew was physically and psychologically fit for the flight in question. Their colleagues at Bucaramanga base and their families described them as very professional. Nevertheless, it must be noted that while Capt.   and Engineer   had been with the airline for several years and could be considered by the latter to be good at their jobs, the co-pilot, Capt.   , was almost new and lacked experience, having taken his course on the equipment only between February and April 1986. Considering the professional calibre of his captain, he was almost certainly concerned about doing a good job as co-pilot, and in the absence of proper supervision this affected his performance on the day of the accident. This conclusion is borne out by the comment from his instructor during his last simulator training session in August 1987: "Don't try to rush things."

In conclusion, the capacity and fitness of the crew, generally speaking, could be considered good but affected by the talkativeness of the non-crew pilot, whose chatter continually interfered with work in the cockpit.

2.1.1 Fitness of the air traffic controllers

Examination of the CVs of the two controllers manning the frequencies 118.1 (Control Tower) and 119.9 (Approach Control) on the date and at the time of the occurrence established that both were qualified to carry out their functions and their actions throughout were consistent with the relevant international standards.

The fact analyzed earlier, regarding ... [text missing] ... at that moment; the clearance requested by the pilot could be given without there being any danger associated with the aeroplane leaving the VOR *because, by requesting to climb on course, the pilot assumed total responsibility for his separation from* the other aircraft and control of the airspace used to reach the required flight level.

2.2 Airworthiness status of HK-1716

Information received regarding the aircraft indicated that the latter was airworthy on the day of the occurrence, ruling out the possibility of technical failure. This conclusion is borne out by the contents of the voice and flight data recorders, which give no indication of any anomaly related to mechanical failure of the aircraft.

3. CONCLUSIONS

Results

- The crew in general met the technical and formal requirements for carrying out the flight in question;

- There was no flight planning (briefing) to cover the pre-take-off period or the procedure for executing the requested climb on course;

- The inappropriate presence of a non-crew pilot in the cockpit and his great talkativeness distracted part of the crew, which resulted in carelessness and disorientation in monitoring the heading and altitude necessary to cross La Cuchilla El Espartillo or to fly alongside it until reaching Radial 305 for airway Whisky 19.

- The aircraft was airworthy, as attested by Certificate no. 0103 issued by the Administrative Department of Civil Aviation, valid until 31 May 1988;

- The aircraft had been properly maintained in the Avianca shops by duly qualified technical personnel, in accordance with the standards established by the manufacturer and with the Aeronautical Regulations;

- It was learned that the technical statistics concerning airframe and powerplant flight time were not recorded on a daily basis in accordance with the M.A.R., para. 4.1.2.9;

- The actions of the air traffic controllers were consistent with international standards and the aeronautical regulations. Their psychophysical and technical fitness to handle the flight in question was normal;

- Weather conditions in the airport vicinity were such as to permit authorization of VMC flight, but at the actual site of the occurrence there was thick fog in all directions.

Causes

1. **Active**

A. **Personnel factors - Pilot-in-command - Procedures, Regulations and instructions**

a) Diverted attention from operation of aircraft and failed to exercise adequate and constant supervision over the performance of his co-pilot;

b) Tolerated inappropriate interference with cockpit discipline by authorized persons with access to the flight deck;

c) Continued VFR flight into IMC.

B. **Personnel factor - Non-crew pilot in cockpit - Procedures, regulations and instructions**

Interfered constantly with the normal operation of the aircraft, distracting the crew from the efficient execution of their duties.

2. **Passive**

A. **Personnel factor - Crew - Procedures, regulations and instructions:** lack of teamwork on the part of the crew, reflected in the failure to coordinate the instructions needed to take off and climb out in VMC using a profile established in accordance with the specific conditions.

B. **Other factors - Meeting the schedule:** The delays resulting from the change of aircraft for mechanical reasons contributed to the decision by the pilot-in-command to give inappropriate support to company priorities and request to depart, rather than waiting as recommended by the Control Tower, in order to avoid adding to the delays already experienced.

4.0 RECOMMENDATIONS

1. That airlines supervise the manner in which their crews comply with the standards established in the M.A.R., Part IV, Chapter I, Para. 4.1.1.2, which says: "**Authority and responsibility of the pilot-in-command.** The pilot-in-command is responsible for the operation and safety of the aircraft. Both crew members and passengers are subject to his authority."

2. Remind airlines and pilots that in accordance with Administrative Order no. 1219 of 5 February 1986, the use and application of the Manual of ATS Standards, Routes and Procedures, developed by the Administrative Department of Civil Aviation, is mandatory for all airlines, for pilots flying in Colombian airspace and for air traffic controllers within the country.

3. That airlines comply with the regulations in the M.A.R., Part IV, para. 4.1.2.9, concerning daily recording of the flight time of airframes, powerplants and other components that require such records.

ICAO Note.— Names of personnel were deleted. Information concerning the flight attendants and the air traffic controllers was not reproduced. The CVR transcript and the appendices were not reproduced.

ICAO Ref.: 066/88

No. 3

Airbus A300B2, EP-IBU, accident in the vicinity of Qeshm Island, Islamic Republic of Iran on 3 July 1988. Report released by ICAO.*

Note: All times in this report are Co-ordinated Universal Time (UTC). Local time in the Islamic Republic of Iran was UTC + 3 hours 30 minutes and in United Arab Emirates UTC + 4 hours.

1. FACTUAL INFORMATION

1.1 History of flight

1.1.1 On 3 July 1988 the Airbus A300B2-203, registration EP-IBU, was scheduled for four sectors of Iran Air scheduled passenger flights as follows:

Flight	Route	Scheduled time (UTC)
IR451	Tehran - Bandar Abbas	0330 - 0520
IR655	Bandar Abbas - Dubai	0620 - 0715
IR654	Dubai - Bandar Abbas	0815 - 0910
IR452	Bandar Abbas - Tehran	1010 - 1200

The crew reported for routine briefing and flight preparation in Tehran 1 hour 30 minutes prior to scheduled departure time. The first sector from Tehran to Bandar Abbas was on a repetitive flight plan. Take-off was at 0342 hours. The flight was uneventful and landed at Bandar Abbas at 0510 hours.

1.1.2 During the stop in Bandar Abbas the crew remained in the aircraft. No discrepancies or comments had been recorded in the Aircraft Technical Flight Log during the first sector, and this was confirmed to ground personnel by the flight crew. A turn-around check was carried out and no maintenance action was required.

1.1.3 A flight plan had been filed in Tehran for the sector from Bandar Abbas to Dubai (IR655). The departure from the terminal at Bandar Abbas was delayed 20 minutes due to an immigration problem involving one passenger. Prior to take-off from Bandar Abbas IR655 was given an enroute clearance to Dubai via the flight planned route A59 and A59W at FL140 following a simulated MOBET 1B departure with SSR mode A code 6760. The flight was instructed to contact Bandar Abbas approach control after take-off.

1.1.4 The flight took off from runway 21 (magnetic bearing 206 degrees) at 0647 hours and climbed straight ahead enroute (A59 magnetic track 203 degrees). Shortly after take-off IR655 contacted the Iran Air office at Bandar Abbas on company frequency 131.8 MHz and passed a departure message with an estimate for Dubai. IR655 contacted Bandar Abbas approach control at 0649:18 and reported climbing out of 3500 ft estimating MOBET at 0652, the FIR boundary (DARAX) at 0658, and Dubai at 0715. Whilst still under the control of Bandar Abbas approach IR655 contacted Tehran ACC (southern sector) on frequency 133.4 MHz and at 0651:04 reported out of FL70 for FL140, estimating the FIR boundary (DARAX) at 0658 and Dubai at 0715. This message was acknowledged by Tehran ACC with

*ICAO Note.— The ICAO fact-finding investigation was not an ICAO Annex 13 investigation.

instructions to report maintaining FL140 and passing DARAX. Tehran ACC also requested IR655 to confirm squawking SSR code 6760 and received an affirmative reply. At 0654:00 IR655 reported to Bandar Abbas approach control passing MOBET out of FL120. Bandar Abbas instructed the flight to contact Tehran ACC which was acknowledged by IR655 at 0654:11. No further communication was received from IR655 by either Bandar Abbas approach control or Tehran ACC, nor was any communication from the flight received by Emirates ACC or Dubai approach control.

1.1.5 At 0654:43 the aircraft was destroyed by two surface-to-air missiles whilst climbing from FL120 to FL140 well within airway A59 south of MOBET, in the vicinity of Qeshm Island.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	16	274	---
Serious	--	---	---
Minor/None	--	---	

1.2.1 Of the 274 passengers 238 were of Iranian nationality, ten were nationals of India, one of Italy, six of Pakistan, thirteen of the United Arab Emirates and six of Yugoslavia. The 274 passengers comprised 209 adults, 57 children and eight infants.

1.2.2 The crew included the pilot, the co-pilot, the flight engineer and thirteen cabin crew members. All sixteen crew members were of Iranian nationality.

1.3 Damage to aircraft

1.3.1 The explosion of two missiles destroyed the aircraft. The tail and one wing broke off in the air. The aircraft impacted the sea and the wreckage sank.

1.4 Other damage

1.4.1 There was no other damage.

1.5 Personnel information

1.5.1 Pilot-in-command

1.5.1.1 The captain, 38 years of age, held an air transport pilot licence issued on 2 May 1983 and valid until 5 August 1988. His rating for Airbus A300 was issued on 21 July 1985. He had also been rated for B737 (co-pilot) on 20 November 1975, B727 (co-pilot) on 10 August 1977, B747 (co-pilot) on 7 August 1979 and B737 (captain) on 2 May 1983. His last medical check was on 7 February 1988 with no waivers. His total flying experience was 7000 hours of which 2057 hours were on Airbus A300. His last proficiency check (simulator) was on 26 April 1988.

1.5.1.2 The captain's duty hours in the seven days prior to 3 July 1988 were 29 hours 30 minutes. His rest period when reporting for duty on 3 July 1988 had been 32 hours. During the ten weeks prior to 3 July 1988 he had flown over the Gulf area three times on the route Tehran - Shiraz - Dubai and return, and four times on the route Tehran - Bandar Abbas - Dubai and return. His previous flight on the route Bandar Abbas - Dubai had been on 30 June 1988.

1.5.2 Co-pilot

1.5.2.1 The co-pilot, 31 years of age, held a commercial pilot licence (with instrument rating) issued on 2 May 1984 and valid until 27 December 1988. His co-pilot rating for Airbus A300 was issued in July 1987. He had also been rated for B737 (co-pilot) in January 1985. His last medical check was on 28 December 1987 with no waivers. His total flying experience was 2200 hours of which 708 hours were on Airbus A300. His last proficiency check including instrument rating (simulator) was in December 1987.

1.5.2.2 The co-pilot's duty hours in the seven days prior to 3 July 1988 were 48 hours 15 minutes. His rest period when reporting for duty on 3 July 1988 had been 14 hours 15 minutes. During the ten weeks prior to 3 July 1988 he had flown over the Gulf area five times on the route Tehran - Shiraz - Dubai and return.

1.5.3 Flight engineer

1.5.3.1 The flight engineer, 33 years of age, held a flight engineer licence issued on 6 February 1985 and valid until 19 December 1988. His rating for Airbus A300 was issued on 14 June 1987. He had also been rated for B737 on 6 February 1985. His last medical check was on 20 December 1987 with no waivers. His total experience as flight engineer was 2800 hours of which 736 hours were on Airbus A300.

1.5.3.2 The flight engineer's duty hours in the seven days prior to 3 July 1988 were 30 hours 35 minutes. His rest period when reporting for duty on 3 July 1988 had been 14 hours 15 minutes. During the ten weeks prior to 3 July 1988 he had flown over the Gulf area four times on the route Tehran Shiraz - Dubai and return.

1.6 Aircraft information

1.6.1 The aircraft was an Airbus A300B2-203 manufactured by Airbus Industrie in March 1982. The serial number was 186. The aircraft was registered as new in 1982 as EP-IBU in the Islamic Republic of Iran, and was owned and operated by Iran Air.

a) Airframe

Certificate of Airworthiness :	Transport category (passenger, cargo, crew training), last renewal 29 April 1988 and valid until 29 April 1989
Maintenance * :	Last "C" check 5 June 1988 at 11396 hours Last "I/L" check 12 May 1987 at 9254 hours
Total flying time :	11497 hours
Maximum mass authorized :	142900 kg
Mass at take-off :	130921 kg
Fuel at take-off :	18000 kg
Centre of gravity range :	18-33%
Centre of gravity at take-off:	23.9%

b) Engines: Two General Dynamics CF6-50-C2

	No. 1 (left)	No. 2 (right)
Serial number	455942	528149
Time since new	7419 hours	8020 hours
Cycles since new	6125	6086
Last "C" check	5 June 1988	5 June 1988
Time since last "C" check	102 hours	102 hours

c) Equipment:

The aircraft was equipped with the following communication and avionics equipment relevant to the occurrence:

		No. 1 serial no.	No. 2 serial no.
VHF	KING KTR 9100A	3759	3989
Transponder	Collins 621A-6	3800	2881
ADF	Collins 51Y-7	6627	3129
VOR	Bendix RVA-33A	1776	1865
DME	Collins 860E-5	1166	7043
Weather radar	Bendix RDR-1F	2554	3681
Radio altimeter	TRT AHV5-011A5	6060	5441
GPWS	Sundstrand 965-0376-070	1722	--

1.7 Meteorological information

1.7.1 At 0600 hours the weather at Bandar Abbas airport was: Wind 180/6 kt, visibility 6 km in haze, surface pressure 997.2 hPa, clouds one okta

*Note: The times between overhaul recommended by the manufacturer are C - check 4000 hours and I/L - check 16500 hours or 48 months.

stratocumulus at 3500 ft, four okta altocumulus at 10000 ft, temperature 35 degrees C and dew point 26 degrees C.

1.7.2 The weather in the area to the south of Bandar Abbas at 0700 hours was fair to partly cloudy with scattered stratocumulus at 3000 ft, scattered altocumulus at 10000 - 12000 ft and high cirrus. Visibility ranged from 5 to 10 km in haze. The air temperature over adjacent coastal areas was 35 to 38 degrees C and over the sea 28 to 30 degrees C. Surface pressure was 997 hPa.

1.7.3 The approximate wind profile in the area to the south of Bandar Abbas at 0700 hours was: Surface 190/8 kt, 1000 ft 210/8 kt, 2000 ft 290/6 kt, 3000 ft 310/6 kt, 5000 ft 010/6 kt, 7000 ft 020/10 kt, 10000 ft 030/10 kt, 12000 ft 140/5 kt, 14000 ft 090/18 kt and 18000 ft 080/25 kt.

1.7.4 The approximate air temperatures were: 5000 ft +29 degrees C (ISA +23.5), 6400 ft +29 degrees C, possible inversion (ISA +26.6), 10000 ft +18 degrees C (ISA +13.4), 18000 ft -3 degrees C (ISA +18.0).

1.7.5 Low tide at Bandar Abbas was at 0615 hours. In the area to the south of Bandar Abbas at the time of flight IR655 the tidal flow was estimated as 3 kt towards the west.

1.8 Aids to navigation

1.8.1 The following navigational aids were available at Bandar Abbas International Airport:

VORTAC: Identification BND, frequency 113.1 MHz, transmission Channel 78, continuous day and night service, position 27 13 05 N, 056 22 50 E.

NDB: Identification BND, frequency 250 KHz, continuous day and night service, position 27 13 03 N, 056 21 35 E.

1.8.2 There were no reported discrepancies to the navigational aids on 3 July 1988. The Bandar Abbas VORTAC was the subject of a NOTAM (A532 - 21 May 1988) stating that the flight check had expired on 21 May 1988. A flight check was subsequently carried out on 30 July 1988. The VORTAC was found operational with no discrepancies.

1.9 Communications

1.9.1 The radio communications between IR655 and civil ATC units were normal with no indication of difficulties in establishing and maintaining communications.

1.9.2 Bandar Abbas TWR/APP. IR655 was in contact with Bandar Abbas TWR on 118.1 MHz and Bandar Abbas APP on 124.2 MHz. In addition, Bandar Abbas provides for frequencies 121.9 MHz and 121.5 MHz. All communications on these frequencies were recorded.

1.9.3 Iran Air at Bandar Abbas. Shortly after take-off IR655 was in contact with the Iran Air office at Bandar Abbas on company frequency 131.8 MHz.

1.9.4 Tehran ACC. IR655 was also in contact with Tehran ACC on 133.4 MHz through a remote control air-ground (RCAG) facility at Bandar Abbas operated via a microwave link. The RCAG facility coverage was approximately 100 NM. All communications were recorded in Tehran ACC.

1.9.5 Emirates ACC. Communications on 243 MHz from United States warships and between such warships and military aircraft at the time of flight IR655 were recorded in Emirates ACC (Abu Dhabi).

1.9.6 Communications from United States warships. Transcripts and recordings of communications on 121.5 MHz were made available from a United Kingdom warship and United States warships. Also, transcripts and recordings of communications on 243 MHz were made available from United States warships.

1.9.7 Communications between ground stations. Communications related to IR655 took place between Tehran ACC/Bandar Abbas APP, Tehran ACC/Emirates ACC, Tehran ACC/Muscat ACC and Emirates ACC/Dubai APP. All these circuits were operating satisfactorily.

1.9.8 Communications recordings. The recordings available from Bandar Abbas TWR/APP, Tehran ACC and Emirates ACC also contained ATS direct speech circuit communications between Tehran ACC/Emirates ACC and Tehran ACC/Bandar Abbas APP. Thus, the recordings could be synchronized and time referenced although the time signal on the Bandar Abbas recording was unserviceable.

1.10 Aerodrome information

1.10.1 Bandar Abbas International Airport is located 4.5 NM north-east of Bandar Abbas. The geographical co-ordinates for the reference point are 27 13 07 N, 056 22 39 E. Runway 21 is asphalt, 3664 m long, 45 m wide and elevation is 22 ft. The magnetic bearing of runway 21 was 206 degrees.

1.11 Flight recorders

1.11.1 The aircraft was equipped with a digital flight data recorder and a cockpit voice recorder. Neither had been recovered by 16 October 1988.

1.11.2 The flight data recorder was model Sundstrand 573A manufactured by Sundstrand Data Control Inc., part number 981-6009-010, and serial number 2669. It records the following parameters: Gross altitude, fine altitude, computed air speed, Mach number, magnetic heading, pitch attitude, roll attitude, right inboard flap position, leading edge flap extended, leading edge flap in transit, engine pressure ratio, thrust reverser operating, thrust reverser in transit, radio transmission keying, and time (UTC).

1.11.3 The cockpit voice recorder was model A100A manufactured by Fairchild Weston Systems Inc., and serial number 5424. The cockpit voice recorder provides a continuous 30 minute record of all voice communications in the cockpit, the individual crew stations and the public address system.

1.12 Wreckage and impact information

1.12.1 The wreckage had not been located by 16 October 1988. Most of the recovered bodies and floating parts of the aircraft were found at a location of

26 43 N, 056 02 E approximately 40 NM south-west of Bandar Abbas airport in the waters of the Gulf.

1.12.2 The recovered aircraft parts included two slide rafts (Garrett-Air Cruisers Co.), half of the nose cone, ventilation ducting and attached insulation, interior roof trim panels, cabin interior divider, forward left cabin divider, three large pieces of engine cowling of which at least two were from engine no. 2, fire extinguisher bottle from cargo hold fire protection system, frame of a pair of seats, life-jackets, wash basin and structure of stand, sections of overhead baggage lockers of which one bore seat sign no. 27B, part of cabin attendant seat, large sections of five of the flap track housings, several pieces of aerodynamic surfaces from the flaps, all-speed ailerons, low-speed ailerons and spoilers. One of these surfaces carried an identification plate as follows: TYPE OF MATERIAL A300B, FOKKER BV SCHIPHOL, ASSY NO. A 5.79 68400 - 180, SERIAL NO. FS 1189, DATE OF MANUFACTURE 12.8.81.

1.12.3 One of the large pieces of engine cowling showed external damage, some 15 - 20 penetrations, 1 - 10 cm in size and in a horizontal direction in a 45 degree angle from behind. The cowling originated from the aft left side of one of the engines. The penetrations were consistent with missile detonation beneath the aircraft, between the wing and the tail.

1.13 Medical and pathological information

1.13.1 The bodies of the flight crew had not been recovered by 1 October 1988. By early August 1988 the remains of some 192 victims had been recovered. Few of the bodies recovered were complete. Some 180 victims were identified, many based on circumstantial evidence.

1.14 Fire

1.14.1 There was no indication of fire prior to the explosion of the missiles.

1.14.2 There were signs of burns on some of the bodies recovered which could be an indication of fire caused by the explosion of the missiles, or an indication of a surface fire following the impact with water.

1.15 Search and rescue

1.15.1 At 0651:04 hours IR655 reported to Tehran ACC out of FL70 climbing to FL140, estimating the FIR boundary (DARAX) at 0658, and Dubai at 0715. In the absence of any further communications with Tehran ACC, the controller assumed that IR655 had contacted Dubai APP. However, no radio or radar contact was made with the flight by either Emirates ACC or Dubai APP. At 0718 Emirates ACC contacted Tehran ACC and requested the position of IR655. Recognizing that the flight had not arrived at its destination, the controller at Tehran ACC contacted adjacent ATS units for information on the flight. When no further information could be obtained, search and rescue action was initiated, and the assistance of the United Arab Emirates was requested.

1.15.2 Following a report from Tehran ACC at 0800 hours that IR655 was last seen on radar two minutes south of DARAX, search and rescue action was taken by the Emirates Rescue Co-ordination Centre (RCC). Four aircraft from the United Arab Emirates participated in the search around DARAX, one CASA C-212 aeroplane from Bateen airport (Abu Dhabi), two Bell 212 helicopters from Sharjah and one helicopter from Ras-Al-Khaimah.

1.15.3 Simultaneously, search and rescue efforts were undertaken by the Islamic Republic of Iran Navy (IRIN), the Islamic Revolutionary Guard, the National Iranian Oil Company (NIOC), and the authorities at Bandar Abbas. On the basis of eyewitness reports, a search was carried out between MOBET and DARAX. Bodies and floating parts of the wreckage were located more than 30 NM north of DARAX and Emirates ACC was informed by AFTN at 0925 hours. At about 1030 hours Bandar Abbas authorities took over search and rescue operations, and advised that assistance from the United Arab Emirates was no longer required.

1.16 Additional information

1.16.1 Warships and boats involved

1.16.1.1 It was reported that Iranian boats of the Islamic Revolutionary Guard were involved in surface action with United States warships at the time of the IR655 flight. The Iranian units were reported to have employed small boats of the Boghammar and Boston Whaler types.

1.16.1.2 Details of the Boghammar 13 metre craft given in the 1988/89 edition of Jane's Fighting Ships were as follows: Displacement 5.3 tons, length 12.8 m, main machinery 2 Volvo Penta TAMD 70 E diesels, 610 hp, 2 shafts, maximum speed 50 - 55 kt, range 500 miles at 46 kt, complement 5 - 6; Guns: one 12.7 mm machine gun, one RPG-7 rocket launcher, one 106 mm recoilless rifle.

1.16.1.3 Three United States warships were directly involved: USS Vincennes, USS Elmer Montgomery and USS John H. Sides. The information given below was taken from the 1988/89 Edition of Jane's Fighting Ships.

USS Vincennes: Guided missile cruiser - AEGIS, maximum displacement 9600 tons, length 172.5 m, main machinery 4 General Electric LM 2500 gas turbines, 80000 shp, 2 shafts, maximum speed 30 kt, complement 358 (24 officers).
Radar: Air search/fire control RCA SPY 1A phased arrays, 3 D, E/F band; air search Raytheon SPS 49 (V), C/D band, range 457 km.
Fire control: AEGIS Mk7 multi-target tracking; link 11 OE-82 satellite communications antenna; Lockheed SPQ 9, I/J band, range 37 km; four Raytheon/RCA SPG 62, I/J band.
ESM/ECM: SLQ 32V (3), combined radar warning and jammers.
SSR: Four SSR 1 receivers.
Anti-aircraft weapons: Surface air missiles, 68 GDC Pomona Standard ER-SM2, command/inertial guidance, semi-active homing to 137 km at 2.5 Mach, two twin-rail launchers.
Guns: Two FMC 127 mm/54 Mk 45, max elevation 65 degrees, anti-aircraft range 15 km, surface range 23 km; two General Electric/General Dynamics 20 mm/76 6-barrelled Mk 15 Vulcan Phalanx, range 1.5 km.

USS Elmer Montgomery: Knox class anti-submarine frigate, maximum displacement 4200 tons, length 133.5 m, maximum speed 27 kt, complement 288 (17 officers).
Radar: Air search Lockheed SPS 40, E/F band, range 320 km.

Fire control: Western Electric SPG 53A, I/J band; OE-82 satellite communications antenna.
ESM/ECM: SLQ 32V (2), combined radar warning and jammers.
SSR: SSR 1 receiver.
Guns: one FMC 127 mm/54 Mk 42, max elevation 85 degrees, anti-aircraft range 14 km, surface range 24 km; one General Electric/General Dynamics 20 mm/76 6-barrelled Mk 15 Vulcan Phalanx, range 1.5 km.

USS John H. Sides: Oliver Hazard Perry class guided missile frigate, maximum displacent 3585 tons, length 135.6 m, maximum speed 29 kt, complement 206 (13 officers) including 19 aircrew.
Radar: Air search Raytheon SPS 49, C/D band, range 457 km.
Fire control: Lockheed STIR (modified SPG 60), I/J band, range 110 km; Sperry Mk 92 (Signaal WM 28), I/J band, range 7 km; OE-82 satellite communications antenna.
ESM/ECM: SLQ 32V (2), combined radar warning and jammers.
SSR: SSR 1 receiver.
Anti-aircraft weapons: Surface air missiles, 36 GDC Standard MR-SM1, semi-active homing to 46 km at 2 Mach, one Mk 13 launcher.
Guns: one OTO Melara 76 mm/62 Mk 75, max elevation 85 degrees, anti-aircraft range 12 km, surface range 16 km; one General Electric/General Dynamics 20 mm/76 6-barrelled Mk 15 Vulcan Phalanx, range 1.5 km.

2. ANALYSIS

2.1 Background information on the situation in the Gulf

2.1.1 As a result of difficulties experienced by international shipping in the Gulf, naval forces of several States entered the area to provide a protective presence and safeguard the freedom of navigation. The extent and intensity of hostile activities varied considerably from time to time. The incident on 17 May 1987 in which the USS Stark was severely damaged by two air-launched Exocet missiles was of particular relevance in the chain of events leading to the destruction of flight IR655.

2.1.2 The increasing tension in the area prompted warships to be concerned in particular with the identity and intentions of approaching aircraft. This led to a large number of challenges from warships to both civil and military aircraft. The challenges had been made to aircraft in low level transit, in high level cruise on airways, and on approach to or departure from airports in the area. Some challenges were reported to have been made to aircraft well inland and at a considerable distance from the warship concerned. Frequently, civil aircraft on ATS routes had been requested by warships on the emergency frequency 121.5 MHz to change course and to stay clear of the warships. In some cases, compliance with such instructions had caused air traffic conflicts of a potentially hazardous nature.

2.2 Notice promulgated by the United States

2.2.1 In early 1984 the United States had issued a notice that their naval forces in the Gulf, Strait of Hormuz, Gulf of Oman and Arabian Sea (north of 20 degrees north) were taking defensive precautions. Aircraft below 2000 ft which were not cleared for approach to or departure from an airport were requested to avoid flying closer than 5 NM to United States warships. The notice further requested that aircraft approaching within 5 NM of United States warships must establish and maintain radio contact with them on 121.5 MHz or 243 MHz. It also stated that aircraft approaching within 5 NM below 2000 ft and whose intentions were unclear to United States warships may be held at risk by defensive measures.

2.2.2 Following the USS Stark incident a NOTAM Class I was issued in September 1987 to advise that United States warships in the area were taking additional defensive precautions. The notice stated that aircraft (fixed wing and helicopters) operating in the area should maintain a listening watch on 121.5 MHz or 243 MHz and that unidentified aircraft whose intentions were unclear or who were approaching United States warships would be contacted on these frequencies and requested to identify themselves and state their intentions. It also stated that in order to avoid inadvertent confrontation aircraft may be requested to remain well clear of United States warships. Failure to respond to requests for identification and indication of intentions, or to warnings, or operating in a threatening manner could place the aircraft at risk by United States defensive measures. Furthermore, illumination of a United States warship with a weapons fire control radar would be viewed with suspicion and could result in immediate defensive reaction. These measures would be implemented in a manner that would not unduly interfere with the freedom of navigation and overflight. The content of the NOTAM was also included in subsequent issues of the United States International Notices to Airmen publication, and was current on 3 July 1988.

2.2.3 The NOTAM was distributed to those States which had requested to be on the distribution list for NOTAMs issued by the United States FAA NOTAM Office under heading KFDC (Washington/National Flight Data Center, D.C.). In addition the NOTAM was distributed through official civil and military channels as well as through United States Embassies in the area.

2.2.4 Aeronautical information service authority. In accordance with the provisions of ICAO Annex 15, ICAO Contracting States provided an aeronautical information service and published aeronautical information concerning the territory of the State as well as areas outside its territory in which the State was responsible for air traffic services. International NOTAM Offices were designated by States for the international exchange of NOTAMs in accordance with the ICAO regional air navigation plans. The United States NOTAM concerning the Gulf, Strait of Hormuz, Gulf of Oman and Arabian Sea covered an area within the responsibility of International Notam Offices Abu Dhabi, Baghdad, Bahrain, Bombay, Karachi, Kuwait, Muscat and Tehran. Therefore, the promulgation of the NOTAM was not in conformity with the provisions of ICAO Annex 15.

2.2.5 Safety implications. The full implications of the rules of engagement of the United States warships were not sufficiently reflected in the notice promulgated by the United States. It was not specified what was considered to be "operating in a threatening manner", what distance was considered "well clear of United States warships", and what was meant with "could place the aircraft at risk by United States defensive measures". The safety risks imposed by the presence of naval forces in the Gulf area to civil aviation may have been underestimated, in particular as civil aircraft operated on promulgated tracks including standard approach and departure routes from airports in the area.

2.3 Problems to international civil aviation in the Gulf area

2.3.1 The presence and activities of naval forces in the Gulf area have caused numerous problems to international civil aviation. There were instances where civil ATC units overheard challenges to civil aircraft on the military air distress frequency 243 MHz (with which civil aircraft were not equipped) and were able to alert civil pilots to that effect. At least one flight had come into imminent danger of defensive measures before its identity could be established by the warship with the assistance of the civil ATC unit concerned. In some cases, flights chose to re-route in order to avoid challenges and possible danger from warships, thus accepting a significant mileage penalty with its economic consequences and inconvenience to passengers.

2.3.2 Civil aviation requirements such as airways, standard approach and departure procedures, and the fixed tracks used by helicopters to oil rigs were not a consideration in warship positioning. This resulted in warships challenging civil aircraft often in critical phases of flight, i.e. during approach to land and during initial climb. In the absence of a clear method of addressing challenged civil aircraft, such challenges were, on occasion, mistaken by pilots to whom the challenge was not addressed, causing additional confusion and danger.

2.3.3 Whilst some naval forces operated aircraft in communication with the appropriate ATC unit, others used aerodrome control zones and promulgated restricted areas without communication or co-ordination. This caused concern to the responsible ATC units in that it hampered the provision of positive air traffic control as a collision avoidance service.

2.4 Frequency and regularity of traffic on ATS route A59

2.4.1 Iran Air flight IR655 was a regular scheduled passenger service from Bandar Abbas to Dubai. During the month preceding 3 July 1988 the flight was operated twice a week, on Tuesdays and Sundays, with the exception of Sunday 19 June 1988. In addition there were 28 other Iran Air flights between Bandar Abbas and Dubai (or Sharjah). Furthermore, there were seven flights between Kabul and Dubai, and 23 flights between Kabul and Jeddah via ATS route A59.

2.4.2 Between 2 June 1988 and 3 July 1988 the traffic on route A59 amounted to a total number of 66 flights with an average of two flights per day and a maximum of six flights on 23 June 1988. Delays of flight IR655 were relatively small and these flights normally departed from the gate close to scheduled departure time.

2.5 "Red alert" procedure applied by Iranian air traffic services

2.5.1 ATS units in the Islamic Republic of Iran were notified through a "red alert" procedure of those military activities which posed a risk to the safety of civil aircraft. When a "red alert" was in effect, no ATC clearances were given to civil aircraft intending to operate through the affected airspace. In some instances Iranian aircraft already enroute had been recalled. On 3 July 1988 no "red alert" status was in effect and the ATC units at Tehran and Bandar Abbas were unaware of any activities at sea.

2.6 Radar coverage on airway A59

2.6.1 Radar Approach Control (RAPCON) at Bandar Abbas. The RAPCON unit at Bandar Abbas provided radar control service to military aircraft, and to civil aircraft on request. It was not normally used to monitor civil traffic and on 3 July 1988 the track of IR655 was not monitored. The equipment comprised an ASR-8 airport surveillance radar (primary radar) and a TPX-42 secondary surveillance radar (SSR), with a nominal coverage of some 60 and 200 NM respectively. However, the operational use was normally limited to some 30 NM. In addition precision approach radar (PAR) was available. It was stated that the military emergency frequency (243 MHz) receiver had been unserviceable and was still inoperative on 4 August 1988. Consequently, on 3 July 1988 communications on 243 MHz were not received.

2.6.2 Kish air defence radar. Flight IR655 was observed by the Iranian air defence radar located on Kish Island for approximately 48 seconds (four radar sweeps). The approximate position was given as 26 30 N, 056 00 E.

2.6.3 Radars in the United Arab Emirates. The controllers at Dubai and Abu Dhabi did not establish radar contact with flight IR655, nor did they normally monitor flights on airway A59 north of DARAX. The radar display at Dubai approach control was normally selected to a range of 60-80 NM to establish radar contact with inbound flights near DARAX.

2.7 IR655 VHF radio procedures

2.7.1 The Airbus A300, registration EP-IBU, was fitted with two King KTR 9100A VHF radios. Each transceiver was controlled by a dual selector control box on which two frequencies could be selected. A transfer switch allowed change from one selected frequency to the other.

2.7.2 Flight IR655 was in contact with Bandar Abbas control tower (118.1 MHz) whilst on the ground and with Bandar Abbas approach (124.2 MHz) after take-off. Whilst under the control of Bandar Abbas approach the flight passed a departure message to the Iran Air office at Bandar Abbas (131.8 MHz) and contacted Tehran ACC (133.4 MHz).

2.7.3 On 16 September 1986 Iran Air had issued a company advisory notice to flight crews operating in the Gulf area requiring the monitoring of frequency 121.5 MHz at all times. This notice was included in the briefing material for the IR655 flight crew on 3 July 1988.

2.7.4 Although there were no set procedures for the handling of the communications, information from Iran Air pilots and flight operations staff in Tehran indicated that at take-off the likely VHF selections were: Bandar Abbas tower (118.1 MHz) and Bandar Abbas approach (124.2 MHz) on VHF no. 1 and the company frequency (131.8 MHz) and 121.5 MHz on VHF no. 2. Tehran ACC (133.4 MHz) would have replaced Bandar Abbas tower on VHF no. 1 after take-off. The call made by IR655 to Tehran ACC whilst under the control of Bandar Abbas approach was not a required procedure but was common practice by flight crews. It was not apparent whether this call would have been made on VHF no. 1, thus accepting a brief interruption of guard of the approach frequency, or on VHF no. 2 which would not have allowed guard of 121.5 MHz for a brief period. The flight remained under the control of Bandar Abbas approach from 0649:18 to 0654:11. The communication between IR655 and Tehran ACC took place between 0650:54 and 0651:30. The available information was not sufficient to determine which radio set was used for each transmission.

2.8 USS Vincennes

2.8.1 USS Vincennes joined the United States Joint Task Force Middle East in late May 1988. In this capacity USS Vincennes was directly involved in hostile activities for the first time on 3 July 1988.

2.8.2 Aircraft tracks in real time together with the civil ATS route structure and major airports in the Gulf area were displayed on two of the four AEGIS large screen displays in the Combat Information Centre. The area covered by the displays, and hence the degree of magnification of the projected pictures, could be varied by the operators as required by circumstances.

2.8.3 Information on civil flight schedules was available in the Combat Information Centre. However, it was pointed out that such information was, at best, of limited value in determining expected time of overflight. In the absence of flight plan and flight progress information, a realistic traffic picture could not be established and positive aircraft identification could not be obtained on that basis.

2.8.4 There was no co-ordination between United States warships and the civil ATS units responsible for the provision of air traffic services within the various flight information regions in the Gulf area. Such co-ordination would have enabled or at least facilitated identification of civil flight operations. The United States warships were not provided with equipment for VHF communications other than on the international air distress frequency 121.5 MHz. Thus, they could not monitor civil ATC frequencies for flight identification purposes.

2.8.5 In the process of determination of civil versus military and friendly versus hostile aircraft, a number of parameters were being taken into account. These were in order of importance:

- flight profile (speed range, rate of climb/descent, rate of turn, altitude);
- emissions from fire control radar, aircraft weather radar and radio altimeter;
- radio communications established; and
- IFF mode 3 (SSR mode A) responses.

2.8.6 With respect to warship radar surveillance of a given area of operation, it was normal practice to have more than one warship scanning the airspace. On 3 July 1988 USS Vincennes, USS Montgomery and USS Sides were in the north-western part of the Strait of Hormuz. While USS Montgomery was not able to cover the area, the other two warships monitored the radar track of IR655.

2.9 Electronic emissions and their detection

2.9.1 Aircraft weather radar. According to the United States report the warships had the capability to detect emissions from the type of weather radar carried by IR655. The report stated that no such emissions were detected by USS Vincennes, USS Montgomery or USS Sides. Information from Iran Air flight crews indicated that it would be reasonable to assume that in the weather conditions prevailing at the time of flight IR655, the flight crew would not have been operating the airborne weather radar.

2.9.2 Radio altimeters. IR655 was equipped with two radio altimeters. There was no indication of unserviceability on departure from Bandar Abbas. The radio altimeter installation on the Airbus A300 provided altitude information to the ground proximity warning system (GPWS) and both radio altimeters operated continuously during flight. The power supplies for the radio altimeters were controlled by the no. 1 and 2 radio master supply switches and there were no ON/OFF selectors for the radio altimeters on the flight deck. However, it was stated that radio altimeter emissions were not detected by the warships. According to the United States report there were no electronic emissions other than IFF mode 3.

2.9.3 Illumination with weapons fire control radar. The United States notice current on 3 July 1988, as well as previous issues, stressed that the illumination of a United States warship with a weapons fire control radar would be viewed with suspicion and could result in immediate defensive reaction. No United States warship was illuminated with a weapons fire control radar during the flight of IR655.

2.9.4 United States warships expected no reaction from a civil flight illuminated by fire control radar since civil aircraft did not carry detection equipment. IR655 was so illuminated by the USS Sides at approximately 0650 hours and by USS Vincennes prior to missile launch. There was no reaction from the contact (IR655) to either of these illuminations.

2.10 Analysis of the challenges made to IR655

2.10.1 A total of eleven challenges were broadcast by United States warships between 0649:39 and 0654:47 with respect to the radar contact (IR655). Seven challenges were made by USS Vincennes on the military air distress frequency 243 MHz. Three challenges were made by USS Vincennes and one by USS Sides on the international air distress frequency 121.5 MHz.

2.10.2 Military air distress frequency 243 MHz. A recording of communications on 243 MHz on 3 July 1988 was available from the Emirates ACC (Abu Dhabi). A transcript and recording was also available from USS Vincennes. There were seven challenges made to the radar contact (IR655) by USS Vincennes at 0649:39 - 0650:06, 0650:30 - 0650:49, 0651:11 - 0651:33, 0652:00 - 0652:21, 0652:44 - 0653:04, 0653:48 - 0654:10 and 0654:34 - 0654:47 hours. Except for the Italian warship Espero, no other stations reported having heard or recorded communications on 243 MHz at the time of flight IR655.

2.10.3 As civil aircraft did not carry radio equipment capable of being tuned to 243 MHz, these transmissions had no relevance as challenges to a civil aircraft.

2.10.4 Immediately prior to the challenges to IR655, between 0648:25 and 0649:28 hours, USS Vincennes was in radio communications with an Iranian P3 patrol aircraft 64 NM to the west. From 0656:15 hours onwards USS Vincennes challenged an Iranian C-130 aircraft.

2.10.5 International air distress frequency 121.5 MHz. A transcript and recording of messages broadcast on the international air distress frequency 121.5 MHz was available from the British warship HMS Beaver and from USS Vincennes.

2.10.6 Personnel at Dubai approach control had listened to their recording of 121.5 MHz for the period 0645 to 0715 hours on 3 July 1988, and reported that there were no messages recorded. The tape was not available. An operator of an oil company radio station located 40 NM south of Dubai reported having heard challenges on 121.5 MHz at about the time of flight IR655 and having recorded the last two or three messages. Requests to verify this report on site by interviewing the operator were denied. No other stations reported having heard or recorded transmissions on 121.5 MHz at that time.

2.10.7 The recording of frequency 121.5 MHz at Bandar Abbas ATC did not contain any communications from 0640 until 0656:43 hours when the latter part of a challenge was recorded. This recording corresponded to a challenge broadcast by USS Vincennes to another unidentified contact (military C-130) approximately two minutes after the destruction of flight IR655.

2.10.8 There were four challenges broadcast to IR655 on 121.5 MHz at 0650:02 - 0650:22, 0651:09 - 0651:43, 0652:33 - 0653:03 and 0653:25 - 0653:43 hours. The first three challenges were made by USS Vincennes, except that at the end of the second challenge when USS Vincennes transmitted "... request you alter course immediately over", USS Sides instantly added "to 270 immediately". The fourth challenge was made by USS Sides.

2.10.9 The challenges commenced approximately three minutes after take-off of IR655 from Bandar Abbas. By that time the flight crew would have completed their immediate after take-off actions. On reaching 1000 ft altitude the flight would have commenced flap retraction and transition from initial climb to enroute climb followed by the after take-off checks. During this time the call was made to the Iran Air office at Bandar Abbas with a departure message. From 0649:18 to 0649:43 hours the flight was in contact with Bandar Abbas approach. The flight crew would also have been preparing forward estimates for transmission to Tehran ACC. The contact with Tehran ACC took place from 0650:54 to 0651:30 hours. Further communication with Bandar Abbas approach with the MOBET position report and receiving instruction to change to Tehran ACC took place between 0654:00 and 0654:11 hours. It appeared that the first, third and fourth challenges made on 121.5 MHz were not co-incident with routine communications by the crew.

2.10.10 Information contained in the challenges on 121.5 MHz. It was relevant to examine whether the flight crew would have been able to readily identify themselves as the subject of the challenges on 121.5 MHz. The Iran Air flight crews were well versed with the use of English which was required by the Iranian Civil Aviation Authority. The majority of transmissions between IR655 and Bandar Abbas TWR/APP and Tehran ACC were conducted in English.

2.10.11 In accordance with the standard format of challenges United States warships should address unidentified aircraft as "unidentified aircraft on course ... , speed ... , altitude ... ". The standard format of warnings referred to the position of the warship as "bearing ... range ... from you". However, the information given in the transmissions from which an airline pilot would have to identify his particular flight varied from one transmission to the next (Table 1).

2.10.12 Course information. The course was given in degrees true and could be expected to be accurate. With a magnetic variation of one degree east in the area concerned, that course would correspond closely to the magnetic track of the aircraft. Although the course given may differ somewhat from the heading of the aircraft due to drift correction for cross-wind component, such difference was probably insignificant on flight IR655 in view of the estimated wind. The flight crew had heading and course information presented in degrees magnetic. Thus the course given could have been recognizable by the flight crew of IR655.

2.10.13 Speed information. The speed given in the transmissions was ground speed derived from radar information. Subject to the conditions of altitude, temperature and wind, ground speed could have been considerably different from indicated air speed (IAS) at which flight crews operated their aircraft.

2.10.14 The Airbus A300 could be expected to be climbing at 250 kt IAS up to FL100. In view of the high temperatures and the slight tailwind, as estimated from the available meteorological information, the ground speed in the phase up to FL100 at 250 kt IAS would have been over 300 kt. The speed given by USS Vincennes was 316, 350 and 360 kt. During the short period of climb above FL100 IAS would have been increased to 300 kt. The ground speed would have been of the order of 380 kt and this was recorded in USS Vincennes. Although the ground speed from radar data seemed accurate, it was apparent that at low altitude and at high temperature, the ground speed may not be readily recognizable to the pilot.

2.10.15 Altitude information. Altitude information based on SSR Mode C could be expected to be useful in establishing an association with the challenge. Such altitude information was given in the second and the third challenges on 121.5 MHz.

2.10.16 Bearing and range information. An airline pilot could not normally be expected to see and identify the source of the challenge, since this would depend on the altitude, visibility, and attitude of the aircraft. There may also be several other ships in the area not associated with the challenge. Therefore, bearing and range from the aircraft to the warship would only convey the immediacy of the problem, and would be of little or no assistance to civil flight crews in establishing whether their flight was the subject of the challenge. In addition, a range expressed in yards (fourth challenge) would be confusing.

2.10.17 Geographical co-ordinates. The first challenge issued to the unidentified aircraft (IR655) included aircraft position in geographical co-ordinates. Although it may be necessary to use geographical co-ordinates in an area where no other references are available, the transmission and interpretation of such position information was time consuming and error prone, even in aircraft equipped with navigational equipment that could display such information. Thus, geographical co-ordinates were not a practical method of establishing identification.

2.10.18 SSR code. Only the fourth challenge, issued by USS Sides, included the SSR code displayed by IR655. This code being unique to a particular flight, recorded on the flight log and indicated on the SSR selector box, could be expected to be immediately recognizable to the flight crew.

2.10.19 There was no response to the four challenges made on frequency 121.5 MHz, either by radio or by a change of course. This indicated that the flight crew of IR655 either was not monitoring frequency 121.5 MHz in the early stages of flight, or did not identify their flight as being challenged.

2.11 Information available on USS Vincennes and action taken

2.11.1 The surface action involving USS Vincennes and small gunboats coincided with the perceived aerial threat. Intelligence information available to the United States Joint Task Force Middle East indicated the deployment of Iranian F-14 fighters to Bandar Abbas against the background of expected heightened hostile activities around 4 July. Furthermore, the possibility of Iranian air support in the surface engagements with United States warships could not be excluded in view of precedent albeit not with F-14 type fighter aeroplanes. Also, the actual take-off time from the joint civil/military aerodrome differed from the scheduled departure time of flight IR655 listed in the commercial schedule information available on the ship. The radar contact was briefly associated with an unrelated IFF mode 2 response. This information led to an initial identification of the aircraft (IR655) as a hostile F-14.

2.11.2 This was reinforced by the lack of response to the challenges and warnings on frequencies 121.5 MHz and 243 MHz. Electronic emissions of weather radar and radio altimeters were not detected by the United States warships and the radar contact was tracked on a course slightly diverging from the centerline of airway A59. Upon consultation, the Commander, Joint Task Force Middle East concurred with engagement of the target, in the event of lack of response to additional radio warnings.

2.11.3 All seven challenges issued by USS Vincennes on 243 MHz were addressed to Iranian aircraft, Iranian fighter or Iranian F-14. The third and fourth challenges contained the word fighter and the fifth challenge F-14. USS Vincennes also issued three challenges on the emergency frequency 121.5 MHz addressed to unidentified aircraft. There appeared to have been an emphasis on challenges on 243 MHz by USS Vincennes consistent with the perceived threat of possible F-14 activities.

2.11.4 Reports of changes in flight profile from climb to descent and acceleration were heard in the Combat Information Centre of USS Vincennes, as recalled by a number of personnel in the Combat Information Centre of USS Vincennes. The international air distress (IAD) operator and the military air distress (MAD) operator, who also was the automatic detection and tracking operator (49ADT), recalled perceiving from the AEGIS system the aircraft in a descending and accelerating profile towards the warships as announced in the Combat Information Centre. Nonetheless the 49ADT-MAD operator at 0652:00 and

0653:48 hours, and the IAD operator at 0652:33 hours issued warnings to the contact (IR655) containing correct AEGIS system information.

2.11.5 Considering itself and USS Montgomery under aggression, USS Vincennes took the ultimate decision to launch missiles against the perceived hostile target at 0654:22 hours.

2.11.6 The United States report stated that the data recorded from the AEGIS system of USS Vincennes was correct and consistent with the actual flight profile of IR655. However, a number of operators misread the displays and wrongly interpreted the information. The report described in detail recollections by operators on USS Vincennes and the circumstances in which the unidentified aircraft (IR655) was associated with an IFF mode 2 code, rapidly decreasing altitude and increasing speed, and thus evaluated as a hostile military aircraft. The United States report and the endorsements by the Chairman, Joint Chiefs of Staff and the Commander in Chief, United States Central Command are appended.

2.11.7 Positions of USS Vincennes and IR655. The position of USS Vincennes at the time of missile launch based on the AEGIS-system data was given as 26 30 47 N, 056 00 57 E and that of flight IR655 as 26 40 06 N, 056 02 41 E. At missile intercept the position of USS Vincennes was given as 26 30 51 N, 056 01 04 E and that of flight IR655 as 26 38 22 N, 056 01 24 E. Thus the position of IR655 at missile intercept would be approximately 10 NM south-southwest of MOBET and approximately 3.7 NM west of the centreline of airway A59, and the position of USS Vincennes approximately 17 NM south of MOBET. USS Montgomery had observed the flash of missile impact and the descent of the aircraft towards the sea in a flat spin with one wing and the tail section missing. The wreckage impact point on the surface of the sea was given as 26 37 45 N, 056 01 E, i.e. some 11 NM south-southwest of MOBET.

2.11.8 The climb profile of IR655 (Figure 1) based on AEGIS-system data from USS Vincennes shows IR655 at 12000 ft at approximately 0653:50 which corresponds to the position report at 0654:00 from IR655 to Bandar Abbas APP "MOBET out of FL120". However, based on the positions given by USS Vincennes, IR655 passed MOBET at approximately 0653:10, thus indicating that the position report by IR655 was given some 5 NM after MOBET.

2.11.9 Most of the recovered bodies and floating parts of the aircraft were found in an area around 26 43 N, 056 02 E. Taking into account an estimated 3 kt tidal flow towards the west as given by USS Vincennes, this would indicate a position of impact with the sea in an area some 5 NM south-southwest of MOBET.

2.12 Information available on USS Sides and action taken

2.12.1 USS Sides did not issue challenges on 243 MHz. At the end of the second challenge when USS Vincennes transmitted on 121.5 MHz "request you alter course immediately", USS Sides instantly added "to 270 immediately". The fourth and last challenge on 121.5 MHz was issued by USS Sides and was addressed to "unidentified aircraft squawking 6760 mode 3". This was the SSR code displayed by IR655.

2.12.2 Several operators on USS Sides recalled having seen only IFF mode 3 codes between 0647 and 0654 hours, and no IFF mode 2 codes. Two operators recalled that the unidentified aircraft was evaluated as a commercial flight at 0651 hours and so reported to the tactical action officer, who did not recall having heard this report. According to the United States report there was at 0653 hours growing excitement and shouting in the Combat Information Centre of USS Sides about a commercial flight. Also the Commanding Officer of USS Sides recalled having evaluated at 0653 hours the unidentified aircraft as a non-threat to USS Sides based on the closest point of approach, his knowledge of F-14 anti-surface warfare capability, lack of electronic signature and lack of precedent, noting altitude 11000 ft, and having shifted his attention to the Iranian P3 some 60 - 70 NM to the west.

TABLE 1: CHALLENGES TRANSMITTED ON 121.5 MHz TO IR655 BY US WARSHIPS

TRANSMISSION	CALL SIGN	INFORMATION					REQUEST	OTHER INFORMATION
		Course	Speed	Altitude	Bearing	Range		
US PROCEDURE Challenge or Warning	Unidentified Aircraft	Course	Speed	Altitude	Bearing	Range	Establish communications; Alter course to --	-
Actual Transmissions 1 Vincennes (0650:02)	Unidentified Aircraft	Course	Speed	-	-	-	Remain clear	Geographical position co-ordinates
2 Vincennes (0651:09)	Unidentified Aircraft	Course	Speed	Altitude	Bearing	Range (NM)	Remain clear; Alter course to 270	-
3 Vincennes (0652:33)	Unidentified Aircraft	Course	Speed	Altitude	Bearing	Range (NM)	Remain clear	-
4 Sides (0653:25)	Unidentified Aircraft	-	-	-	Bearing	Range (Yards)	Alter course to 270	SSR code 6760

FIGURE 1: Flight profile of IR655
FIGURE 1: Profil du Vol IR655
FIGURA 1: Perfil de vuelo del IR655
Рис. 1. Профиль полета самолета авиакомпании "Иран Эр", выполнявшего рейс 655

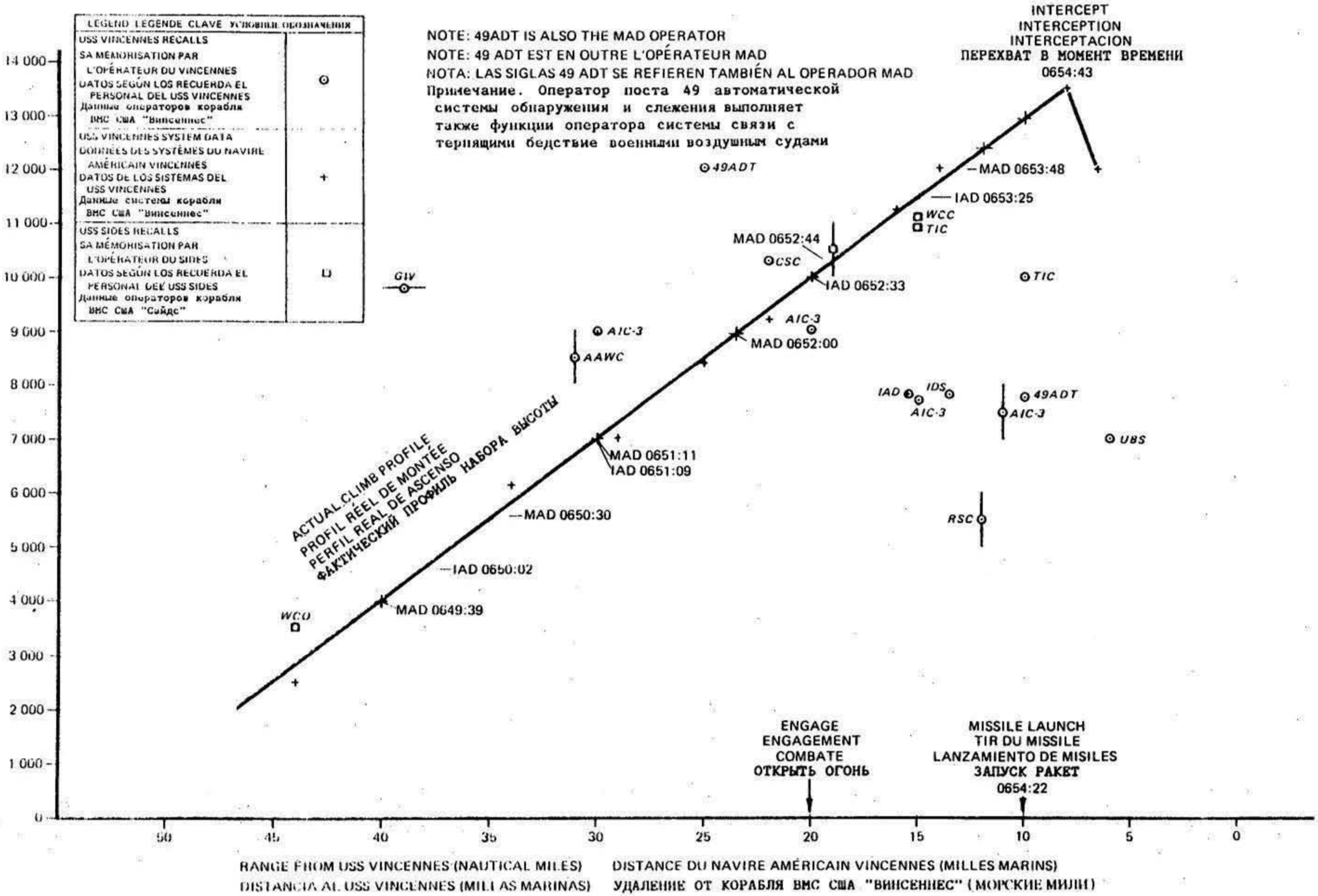
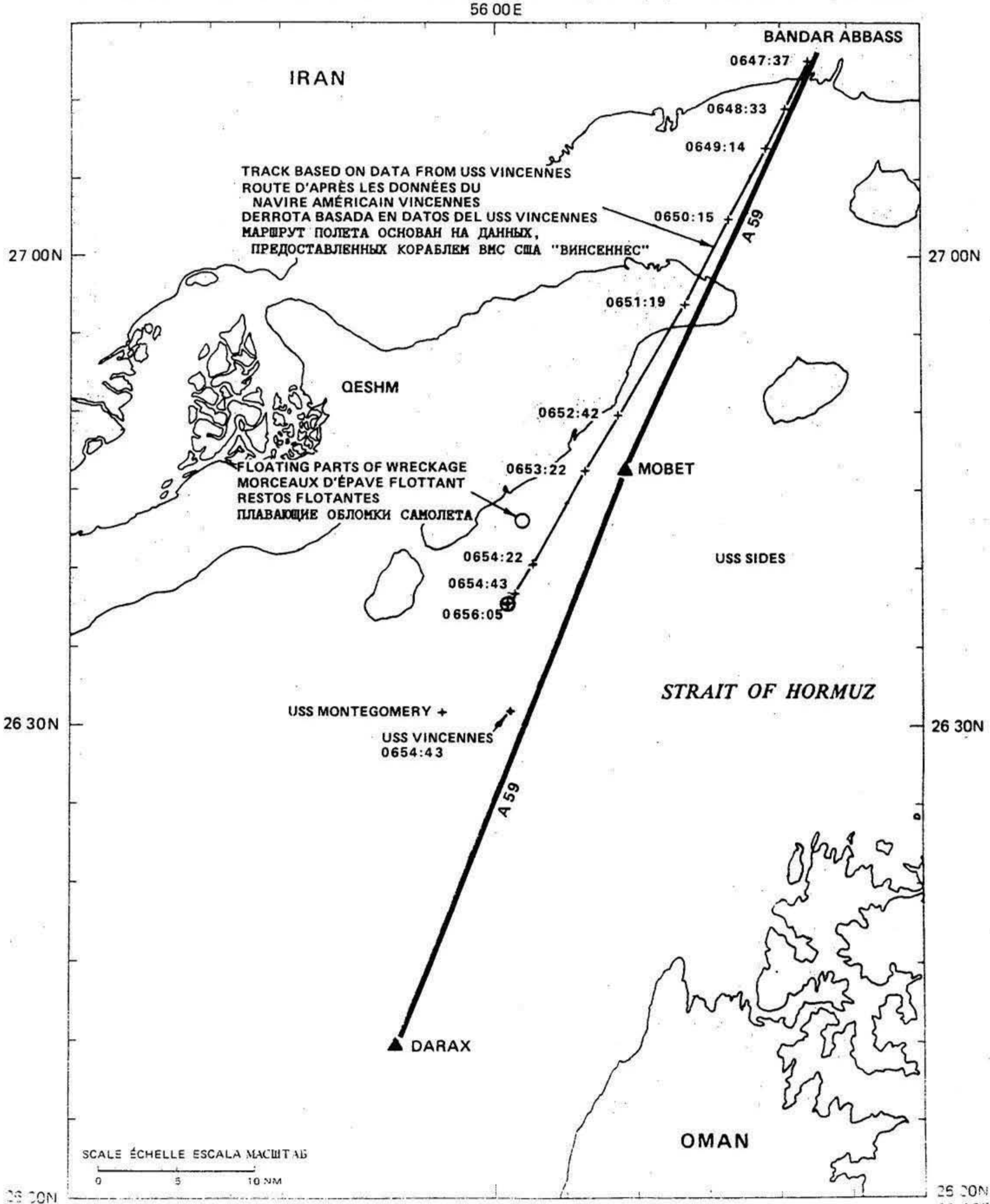


FIGURE 2: Track of IR655
FIGURE 2: Route d'IR655
FIGURA 2: Derrota del IR655
Рис. 2. Маршрут полета самолета авиакомпании "Иран Эр", выполнявшего рейс 655



3. CONCLUSIONS

3.1 Findings

3.1.1 The flight crew of flight IR655 was properly certificated and qualified for the scheduled international passenger flight in accordance with existing regulations. There was no indication that the flight crew may not have been physically or psychologically fit.

3.1.2 The aircraft was properly certificated, equipped and maintained in accordance with existing regulations and approved procedures. The aircraft was serviceable when dispatched from Bandar Abbas.

3.1.3 There was no indication of failure during flight in the equipment of the aircraft including the communications and navigation equipment.

3.1.4 The wreckage including the digital flight data recorder and the cockpit voice recorder had not been recovered by 16 October 1988.

3.1.5 On 3 July 1988 the Bandar Abbas VORTAC was operating normally, although its flight check had expired on 21 May 1988. A flight check carried out on 30 July 1988 found the facility operational without discrepancy.

3.1.6 On 3 July 1988 no "red alert" status was in effect and the ATC units at Tehran and Bandar Abbas were unaware of any activities at sea.

3.1.7 Flight IR655 departed Bandar Abbas airport terminal 20 minutes after the scheduled time.

3.1.8 The flight crew had correctly selected SSR mode A code 6760. SSR mode C (automatic pressure altitude transmission) was functioning.

3.1.9 After take-off the aircraft climbed straight ahead enroute and the climb profile was normal. It followed airway A59 and remained well within its lateral limits. The use of FL140 or FL160 was normal for flights on airways A59 and A59W from Bandar Abbas to Dubai.

3.1.10 The aircraft weather radar was probably not operated during the flight nor would normal procedures have required its operation in the prevailing weather conditions. The radio altimeters were probably functioning throughout the flight.

3.1.11 No electronic emissions from the aircraft, other than SSR responses, were detected by United States warships.

3.1.12 The flight crew carried out normal VHF communications with ATC units concerned.

3.1.13 Apart from the capability to communicate on the emergency frequency 121.5 MHz, United States warships were not equipped to monitor civil ATC frequencies for flight identification purposes.

3.1.14 The flight crew was aware of the Iran Air company instruction to monitor frequency 121.5 MHz at all times while operating in the Gulf area.

3.1.15 Four challenges addressed to an unidentified aircraft (IR655) were transmitted by United States warships on frequency 121.5 MHz (three from USS Vincennes and one from USS Sides).

3.1.16 There was no response to the four challenges made on 121.5 MHz, either by radio or by a change of course. This indicated that the flight crew of IR655 either was not monitoring 121.5 MHz in the early stages of flight, or did not identify their flight as being challenged.

3.1.17 The aircraft was not equipped to receive communications on the military air distress frequency 243 MHz.

3.1.18 The civil ATS route structure and major airports in the Gulf area were displayed on AEGIS large screen displays in the Combat Information Centre. The information did not include all types of promulgated airspace, in particular airway widths, low-level helicopter routes, standard departure and arrival routes and airspace restrictions. The information displayed together with aircraft tracks in real time appeared adequate for the projection of a two-dimensional air traffic situation. However, the absence of altitude information on the large screen displays did not allow ready assessment of flight profiles in three dimensions.

3.1.19 Information on civil flight schedules was available in the Combat Information Centre of USS Vincennes. However, in the form presented, it was of extremely limited value for the determination of estimated time of overflight of individual aircraft. Flight plan information and flight progress data, including information on assigned SSR mode A codes, were not available to assist in flight identification.

3.1.20 There was no co-ordination between United States warships and the civil ATS units responsible for the provision of air traffic services within the various flight information regions in the Gulf area.

3.1.21 Iran Air flight crews were well versed with the use of English and the majority of communications between IR655 and Bandar Abbas TWR/APP and Tehran ACC were conducted in that language.

3.1.22 The contents of the challenges and warnings issued to IR655 on 121.5 MHz varied from one transmission to the next. It is uncertain whether the flight crew would have been able to rapidly and reliably identify their flight as the subject of these challenges and warnings. Although course information given could have been recognizable to the flight crew of IR655, speed information given on the basis of ground speed may not have been recognizable by the pilot. Bearing and range information to the warship was of little relevance to the pilot. Position information in geographical co-ordinates was not a practical method to establish identification. The SSR mode A code displayed by IR655 could have been immediately recognizable to the flight crew, but was given only in the final challenge.

3.1.23 The initial assessment by USS Vincennes that the radar contact (IR655) may have been hostile, was based on:

a) the fact that the flight had taken off from a joint civil/military aerodrome;

b) the availability of intelligence information on Iranian F-14 deployment to Bandar Abbas and the expectation of hostile activity;

c) the possibility of Iranian use of air support in the surface engagements with United States warships;

d) the association of the radar contact with an unrelated IFF mode 2 response; and

e) the appearance of an unidentified radar contact that could not be related to a scheduled time of departure of a civil flight.

3.1.24 The continued assessment as a hostile military aircraft by USS Vincennes and the failure to identify it as a civil flight were based on the following:

a) the radar contact had already been identified and labelled as an F-14;

b) the lack of response from the contact to the challenges and warnings on frequencies 121.5 MHz and 243 MHz;

c) no detection of civil weather radar and radio altimeter emissions from the contact;

d) reports by some personnel on USS Vincennes of changes in flight profile (descent and acceleration) which gave the appearance of manoeuvering into an attack profile; and

e) the radar contact was tracked straight towards USS Montgomery and USS Vincennes on a course slightly diverging from the centreline of airway A59.

3.1.25 Reports of changes in flight profile from climb to descent and acceleration were heard in the Combat Information Centre of USS Vincennes, as recalled by a number of crew members including the operators who at that time issued the challenges on 121.5 MHz and 243 MHz containing correct AEGIS system information.

3.1.26 USS Vincennes AEGIS system contained and displayed correctly the IFF mode and code, and the altitude and speed information of the contact (IR655). The AEGIS system recorded a flight profile consistent with a normal climb profile of an Airbus A300.

3.2 Causes

3.2.1 The aircraft was perceived as a military aircraft with hostile intentions and was destroyed by two surface-to-air missiles.

3.2.2 The reasons for misidentification of the aircraft are detailed in the findings (paragraphs 3.1.23 and 3.1.24).

4. SAFETY RECOMMENDATIONS

4.1 In areas where military activities potentially hazardous to civil flight operations aircraft take place, optimum functioning of civil/military co-ordination should be pursued. When such military activities involve States not responsible for the provision of air traffic services in the area concerned, civil/military co-ordination will need to include such States. To this end:

a) Military forces should, initially through their appropriate State authorities, liaise with States and ATS units in the area concerned.

b) Military forces should be fully informed on the extent of all promulgated routes, types of airspace, and relevant regulations and restrictions.

c) Advance information on scheduled civil flights should be made available to military units including the allocated SSR mode A codes when available.

d) Direct communications between military units and the appropriate ATS units, not using regular ATC or the emergency frequencies, should be established for the exchange of real time flight progress information, delays and information on non-scheduled flights.

e) Military units should be equipped to monitor appropriate ATC frequencies to enable them to identify radar contacts without communication.

f) If challenges by military units on the emergency frequency 121.5 MHz become inevitable, these should follow an agreed message format with content operationally meaningful to civil pilots.

g) In areas where such military activities occur, information necessary for the safety, regularity and efficiency of air navigation should be promulgated in a suitable form. The information should contain the type of challenges that might be transmitted, and should include instructions to pilots of civil aircraft to monitor the emergency frequency 121.5 MHz.

h) To assist identification by electronic emissions, pilots of civil aircraft should ensure continuous operation of airborne weather radars and radio altimeters.

ICAO Note.— The appendices were not reproduced.

ICAO Ref.: 143/88

No. 4

Boeing 737-200, ET-AJA, accident at Bahar Dar, Ethiopia on 15 September 1988. Report released by the Civil Aviation Authority, Ethiopia.

SUMMARY

The airplane was taking-off from Bahar Dar with 98 pasengers and six crew members on board. Shortly after getting airborne it encountered a flock of birds (pigeons) a large number which was ingested into both engines resulting in severe surges and power loss. The two engines subsequently stopped almost simultaneously as the crew was trying to return to the airport. Unable to reach the runway, the airplane was crash landed in an open field about five miles South West of the runway.

Out of the 104 persons on board 35 were killed and 27 were seriously injured. The airplane was demolished in the process of the crash landing and post crash fire.

The investigation concludes that the accident occurred because the airplane could not be safely returned to the runway after the internal distruction and subsequent failure of both engines during take-off arrising from a multiple bird ingestion.

ETHIOPIAN AIRLINES BOEING 737 AIRPLANE ACCIDENT AT BAHAR DAR ON SEPTEMBER 15, 1988.

1. FACTUAL INFORMATION.

1.1. History of theFlight.

On September 15, 1988, Ethiopian Airlines flight, number ET-604, a Boeing 737-200, Ethiopian registration ET-AJA, departed Addis Ababa at 08:46 hours[1] on a scheduled domestic flight between Addis Ababa and Asmara, Ethiopia, with an intermediate stop in Bahar Dar. The flight between Addis Ababa and Bahar Dar was reported to be a normal operation.

On the flight leg from Bahar Dar to Asmara the crew consisted of the captain, the copilot, and four flight attendants. There were a total of 104 persons aboard.

At 09:50, the engines were started normally and the airplane was taxied to its take-off position. During this time the flight crew performed the standard engine start, pre-take-off and take-off check list items. The flight crew reported that in order to gain additional thrust they elected not to use engine bleed air during take-off. The auxiliary power unit was operating throughout the flight. The captain allowed the copilot to conduct the take-off. The flaps were set for take-off at position one (1 degree).

The flight crew reported, and it was confirmed by the digital flight data recorder (DFDR), that the airplane accelerated at a normal rate during the take-off roll and passed V_1 (take-off-reject) speed. As the airplane passed V_1 and very near V_R (rotation speed) the flight crew saw a "flock" of pigeons "camouflaged" with the colour of the runway lifting up from the left side. At this time the captain took over control from the copilot and pulled up. From the CVR and DFDR it was learnt that almost immediately after rotation, the airplane struck the flock of pigeons at an air speed of 146 knots and altitude of 5,730 feet above mean sea level (msl[2].) The crew also

[1] Times in this report are universal standard time.

[2] All altitude references were obtained from the DFDR. (Pressure altitude).

reported hearing loud bangs from outside the airplane. The captain then called for "gear up" and the copilot complied. Within the background sounds recorded by the cockpit voice recorder (CVR) area microphone, a "thud"[3] could be heard at a point in the take-off roll that was consistent with the description of the initial bird strike in the pilots' reports. The captain reported that shortly after the bird strike, approximately 100 to 200 ft. above the ground, both engines started backfiring (stalling). At this time, the flight crew reported that they experienced a considerable power loss and the airplane started mushing down at which time the captain "fire walled" the thrust levers. The engines reportedly responded and the airplane began to gain some altituae. The gain in altitude encouraged the captain to make a right turn away from Lake Tana for the right hand down wind leg and back to the take-off runway for landing.

The flight recorder data also indicated that during the initial 32 seconds after the thud, the airplane had gained altitude from 5,730 feet to 6,020 feet and had accelerated from 146 knots to 154 knots.

The crew report further indicated that both engines continued to surge (back fire) and the exhaust gas temperature guages (EGT) were reading at the top extreme, and the engine pressure ratio (EPR) guage readings were fluctuating at about 1.6. During this time, the captain reported that the he reduced engine thrust to prolong the operational life of the engines. The frequency of the surges decreased with engines power reduction as seen on the CVR sound spectral analysis at this time. The flight recorder data showed that at about 0:32 the airplane began to enter into an approxiamte 90 degree right turn which continued until about 0:59 where it completed its turn. During the turn, the airplane's altitude remained constant at 6,020 feet, while its airspeed increased from 154 knots to 162 knots. The airplane began another right turn at 1:18 and began to gain altitude to 6,410 feet at a constant 162 knots airspeed until 1:23. The airplane completed this turn and entered the

[3] This thud or "bang" was interpreted as the point of initial bird strike and defined as time 0:0 (0 min. 0 sec.) from which all times in this report will be referenced. The bird strike first appears at 2:24 on the CVR Transcript, which is provided in the Appendix to this report, and at approximately 5:20 or frame 83, in the DFDR data.

down wind leg portion of the return to runway 04 at about 1:48. The altitude just after 1:48 remained at 6,410 feet while the airspeed increased to 173 knots. At 1:48 the ground proximity warning system (GPWS) activated. At about 2:23, the captain announced "Look out for the field not to overshoot". At 3:06 the captain again instructed the copilot, to keep looking out for the runway. At this time the airplane's airspeed was 190 knots and its altitude was 7,100 feet. At 3:18 the captain announced "we have lost one engine". The captain later stated that first the Number 1 engine was "lost". All surging sounds stopped by approximately 3:24. At 3:28, the copilot announced, the "other one has quit". At this time the airplane's altitude was 7,100 feet and its air speed was 183 knots.

Shortly after the surging stopped, a pulse interpreted as the bus transfer of electrical power, was heard in both the area microphone and radio channels. The CVR and DFDR recording ended sixteen seconds after the engine surging sounds ceased.

Based on the captain's and the copilot's statements, after the loss of thrust from both engines, the copilot pointed out to the captain a small cleared area slightly ahead and on the right side of the airplane. Then the captain made the turn toward the cleared area to make an emergency gear up (belly) landing with the flaps still at position 1. (The turn to cleared area was confirmed by the flight recorder data). The copilot then made the announcement of the impending impact and gave instructions on emergency evacuation to the passengers and cabin crew. The captain continued to fly the airplane without any change of configuration and made a positive belly landing.

After the airplane came to a complete stop the copilot was able to open the side window and escape from the wreckage but the captain, due to an injury sustained on his right leg, managed to untangle himself and sit on the cockpit window rim. At this time he observed that the wrecked fuselage was on fire and had separated from the cockpit. After the copilot assisted the captain to get down from the cockpit window they were able to direct the rescue operation in which the surviving passengers and local villagers participated.

1.2. Injuries to Persons.

Injuries	Crew	Passengers	Others	Total
Fatal	0	35	0	35
Serious	6	21	0	27
Minor/None	0	42	0	42
Total	6	98	0	104

1.3. Damage to Aircraft.

The airplane was destroyed.

1.4. Other Damage.

None reported.

1.5. Personnel Information.

The crew consisted of a captain, a copilot, and four flight attendants. The flight crew was properly licensed by the Ethiopian Civil Aviation Authority and was qualified to conduct the flight under Ethiopian Civil Aviation requirements. Both pilots had adequate rest prior to the flight.

1.5.1. Pilot-In-Command.

Captain aged 45, held an Ethiopian Airline Transport Licence (No. AA-92) with pilot-in-command rating on the B-737. He was last medically checked by a CAA designated doctor on April 12, 1988 and was pronounced fit for duty. His Instrument and Proficiency checks were valid up to March 3, 1989.

His total flight experience was 19,936 hours including 4,520 hours of flight engineer time on turbine engined aircraft.

His flight experience on the Boeing 737 was 449 hours of which 257 hours were command time.

His most recent flight time record (all command time on B-737) was as follows:

Last 90 days	*137:51 hours*
Last 30 days	*66:33 hours*
Last 7 days	*21:13 hours*
Last 24 hours	*3:53 hours*

1.5.2. ***Second In-Command.***

Captain , aged 30, held a valid Ethiopian Airline Transport Licence (No. AA-151) with co-pilot rating on the B-737. He was last medically checked by a CAA designated doctor on June 26, 1988 and was pronounced fit for duty.

His Proficiency and Instrument checks were valid up to December 8, 1988.

His total flight experience was 9447 hours including 763 hours of flight engineer experience on a turbine engined aircraft.

His most recent flight record, all of which was co-pilot time on the B-737, was as follows:

Last 90 days	*153:45 hours*
Last 30 days	*57:20 hours*
Last 7 days	*15:30 hours*
Last 24 hours	*2:08 hours*

1.5.3. ***Flight Attendants.***

a) ***Lead Attendant*** *aged 35 was employed by Ethiopian Airlines as of March 23, 1974. She was trained and qualified to act as a flight attendant on all jet aircraft operated by Ethiopian Airlines including the B-737.*

b) aged 26 was employed by Ethiopian Airlines as of April 24, 1984. She was trained and qualified to act as a flight attendant on all jet aircraft operated by Ethiopian Airlines, including the B-737.

c) aged 22 years, was employed by Ethiopian Airlines as of December 14, 1987. She was trained and qualified to act as a flight attendant on the B-707/720, B727 and B-737.

d) aged 21 years, was employed by Ethiopian Airlines as of Dec. 14, 1987. She was trained and qualified to act as a flight attendant on the B-707, B727 and B-737.

1.6. Aircraft Information.

1.6.1. General Airplane Information.

The airplane, manufacturer's S/N 23914, was a Boeing 737-200 manufactured by Boeing Commercial Airplane's USA and delivered to Ethiopian Airlines on Oct. 29, 1987.

The airframe had accrued 1377 hours total time and 1870 cycles at the time of the accident.

The airplane was equipped with two Pratt & Whitney JT8D-17A turbofan engines which are rated at 16,000 lbs. take-off thrust at sea level standard day conditions. The table below, provides relevant data concerning each engine.

	Engine Left.	Engine Right.
Serial No.	P-709525B	P-709523B
Date Installed	13-11-87	Prior to OCt. 29, 1987.
Total Time (hrs)	1,313:36	1,377:33
Total Cycles	1,704	1,870

The take-off weight of the airplane was 47,700 Kilograms and its center of gravity (CG) was 17.5 percent mean aerodynamic chord (MAC). Both were within acceptable limits. At the ramp, the airplane contained 10,500 Kilograms of fuel.

The airplane was maintained by Ethiopian Airlines in accordance with a maintenance program approved by the Ethiopian CAA. There was no history of any significant technical defect, system or component malfunction found in the technical records of the airplane.

1.7. Meteorological Information.

Wind	-	360/8 knts.
Visibility	-	More than 10 km.
Cloud	-	1 cb 800 m to NE 5 cu 800 m
Temp/Dp	-	24°/15°
QNH	-	1020.2 mb (30.12 ins)
QFE	-	818.1 mb

Rain in sight to NE & East.

1.8. Aids to Navigation.

Not relevant.

1.9. Communications .

There were no communication difficulties between the airplane and Bahar Dar Control Tower.

1.10. Aerodrome Information.

Bahar Dar Airport is located at the southern edge of Lake Tana (11° 35' N & 37° 39'E).

It has a single paved runway oriented 22/04. The Take-off Distance Available (TODA) for Runway 04 was 3560M and 3400M for Runway 22. Landing Distance Available (LDA) was 3000M in both directions.

1.11. Cockpit Voice and Flight Recorders.

The airplane was equipped with a Sunstrand Model AV557C cockpit voice recorder (CVR) Serial No. 11072 and a Fairchild F800 digital flight data recorder (DFDR). Serial No. 1269.

Four separate microphone tracks are recorded on the cockpit voice recorder. One micrphone track records the conversations and various sounds that are heard in the cockpit. The remaining three tracks record radio communications that are heard by the crew. The recording was evaluated audibly and also traced on an oscillograph with time codes. The cockpit conversation from the time of initial bird strike until the recorders lost electrical power, was read out and transcribed at the Audio Laboratory of the National Transportation Safety Board, Washington,D.C. The Recording quality was considered good. The cockpit conversations and control tower transmissions were translated from Amharic to English by the Ethiopian Civil Aviation Authority's Investigator In-Charge of this accident and the Deputy General Manager of Flight Operations of Ethiopian Airlines. A copy of the recorded cockpit conversation is provided as an Appendix 2 to the report.

The DFDR data was read, tabulated, and plotted at the Washington, D.C. Flight Data Recorder Laboratory of the National Transportation Safety Board. The recorded parameters were altitude, airspeed, heading, vertical G, time and microphone key clicks. Microphone key clicks were not tabulated or plotted since the bus transfer pulse near the end of the flight was clearly apparent in both the CVR and DFDR information. The bus transfer pulse was used to provide an accurate time correlation between the CVR and the DFDR.

The flight path of the airplane from take-off until the accident, based on appropriate data that were extracted from the DFDR, CVR and control tower transmissions were plotted on a map of the Bahar Dar airport vicinity. The method used to plot the course was to identify the average airspeed and calculate the distance traveled for every 4 second increment of the flight. The individual aistances were scaled to the map ana individually linked heel to toe using the heading for each 4 second increment, and assuming no wind. After the course was markea out the entire path was shifted based upon the reported prevailing wina at the time of the accident. Magnetic to true North correction at Bahar Dar is negligible. A copy of this map is providea as Appendix 2 to this report.

1.12. <u>Wreckage and Impact Information.</u>

The wreckage was located about 10 km South-West of Bahar Dar Airport. During the ground slide of approx. 1,500m the left engine and several smaller parts broke off and remained some distance behind the main wreckage. Near the end of the ground slide, the cockpit part broke off and came to rest about 70m behind the main wreckage. The rest of the wreckage, namely the fuselage, both wings, the right engine and empanage swiveled about 90° to the left before coming to rest. Fire broke out and subsequently consumed the wreckage with the exception of the empanage which survived impact and fire damage.

The right engine which remained attached to the wing exhibited excessive heat damage. Externally, the left engine exhibited significant amount of ground impact damage but less visible evidence of ground or fuel-fed-fire. Most of the engine accessories including the entire main accessory gearbox and all of the engine accessories that were installed on the accessory gear box were separated from the left engine.

The left engine's fan inlet case and the fan inlet guide vanes were intact, and were not visibly damaged. The front and rear fan cases and the fan exit case were also intact. The bottom portion of the outer fan front discharge duct, between the discharge duct's "E" and the "F" flanges, was torn open. All of the remaining fan ducts that were installed to the rear of the rear outer fan discharge duct "H" flange were separated including the outer portion of the turbine exhaust case and the fan exhaust outer duct.

Nearly all of the left engine's front compressor drive turbine blade and vane airfoils from stages two through four were burned away to their root platforms, except for some 4th stage turbine vane airfoil stubs.

The lower portion of the right engine was partially submerged in water. This engine was also subjected to a pool fire at the accident site, thus, it was extensively damaged both by impact and the subsequent ground fire. The non-aluminum external cases which consisted of the inlet case, the front and rear fan cases, the intermediate case, and the exhaust case were damaged by impact, exposure to fire and resulting corrosion. All of the aluminum external cases (outer ducts) were melted away except for the very bottom approximately 60 degree arc segment of the engine.

The right engine's main accessory gearbox, the various accessory gearbox mounted accessories and most of the airplane equipment that is normally mounted on the engine were separated from their installed positions.

1.13. Medical and Pathological Information.

From the reports issued by the medical doctor in charge of the rescue effort it was established that the majority of fatal and serious injuries were incurred due to impact. Among the survivors only one person was treated for burns while 12 charred bodies were discovered. Due to lack of the necessary facilities it was not possible to conduct pathological and forensic examination, hence the possible effect of toxic gases could not be determined.

1.14. Fire.

Major part of the airplane was consumed by the resulting ground fire fed by fuel carried on board. The ground being swampy and wet contributed to the slow progress of the fire which provided adequate time for those passengers with minor or no injuries to escape safely from the burning wreckage. The fuselage and wings continued to burn for several hours. None of the mechanized fire fighting equipment at the airport could reach the scene due to lack of any access road and the swampy nature of the terrain. However, a team of fire fighting and rescue personnel from the airport eventually reached the scene carrying portable fire extinguishers, and took part in the rescue operation.

1.15. Survival Aspects.

The accident was partially survivable. However, post mortem examination of the victims, particularly those seated in the forward section *of the cabin revealed multiple fractures and head injuries.*

1.16. Tests and Research - Engine Disassembly and Examination.

1.16.1. Left Engine S/N P-709525B.

The 1st stage compressor rotor blade airfoils of the front compressor group exhibited dented and curled leading edges that were distributed over a span from slightly inboard of the part-span shroud location to the blade airfoil tip. The first stage front compressor rotor had 18 fan blades with soft body damage, including three with leading edge material tear out. This damage was evident in the outer 6.5 inches of the blade airfoil span.

The 2nd stage front compressor rotor had 21 blade airfoils with moderate nicks and gauges that were generally located near the leading edge tip. No other significant bird impact or soft object related damage was evident throughout the front compressor. The concave side of one 6th stage compressor blade had minor damage to its leading edge. The trailing edges of all of the 6th stage compressor blade exhibited a significant amount of minor nicks and dents on their concave sides. The blade tips were not visibly damaged.

All of the 7th stage compressor blade airfoil tip trailing edges were curled and had received extensive hard object impact damage; the impact damage was concentrated at the tip area, with minor damage between the midspan and the platform. Eighteen 8th stage compressor blade airfoils were missing from the rear compressor front hub (stage 8) disk slots. The remainder of the 8th stage blade airfoils were broken at their platforms. In some instances, a fractured surface was visible, in other instances, the 8th stage blade airfoil metal surfaces were smeared due to secondary damage. Forty-four 9th stage compressor blade airfoils and thirty-one 10th stage compressor blade airfoils were missing from their respective compressor disk slots. The *remainder of the 9th and 10th stage compressor blade airfoils were broken at their platforms.*

Twenty-one 11th stage compressor rotor blade airfoils were missing from their 11th stage compressor disk slots. The fractured surfaces of the 11th stage compressor rotor blade airfoils generally exhibited metal smear.

All of the 12th stage rear compressor rotor blade airfoils remained in their respective compressor disk slots. One 13th stage compressor blade was missing from its 13th stage disk slot. All of the 12th and 13th stage rear compressor blade airfoils were severely battered.

All of the remaining attached 11th and 12th stage, and nearly all of the remaining attached 13th stage rear compressor rotor blade airfoils were bent over in the direction opposite to compressor rotor rotation.

The leading edges of the 7th stage compressor startor vanes were object damaged.

The 8th stage compressor stator front outer shroud was penetrated. The front outer shroud of the 9th stage compressor stator assembly was bulged, however, the shrouds were not penetrated. The front outer shroud of the 10th and the 11th stage compressor stators were bulged and were penetrated in several locations. The leading and trailing edges of all of the vane airfoils in the 12th stage compressor stator had impact damage.

The combustion chambers were intact, however, there was some metallic slag from debris that had passed downstream from the rear compressor.

The first stage turbine vanes of the turbine nozzle group were heavily damaged due to thermal distress. All of the *leading edges of the turbine vane airfoils were extensively heat distressed. The trailing edges of most of the 1st stage turbine vane airfoils were dented and burned.*

All of the sixty-four 1st stage rear compressor drive turbine blade airfoils were burned off at about 50 percent of their individual span heights.

All of the 2nd, 3rd, and 4th stage front compressor drive turbine blade airfoils were overheated to the extent that they had melted, thus, leaving only blade airfoil "stub" sections/platforms attached to their respective disk slots. All of the 2nd and 3rd stage front compressor drive turbine vane airfoils were melted, except for the vane outer shrouds. These outer shrouds remained in their installed positions in the rear turbine case. The outer portions of all of the front compressor drive 4th stage turbine vane airfoils, were approximately one to three inches in length. These airfoils remained in their installed positions in the turbine rear case.

Bird impact smears were found on the fan inlet guide vane hub between fan inlet guide vanes numbers four and five and between vanes numbers 16 and 17. Bird matter had collected and adhered to the underside of all of the port-span shrouds of the 1st stage compressor rotor (fan blades). Bird matter was observed in the fan discharge area of the front compressor for the Number 1 engine, in the inlet guide vanes, the intermediate case area, and on the full circumference of the outer rear fan discharge duct's inside wall.

Ultraviolet light inspection showed the presence of bird matter over most of the annulus of both the bypass duct and the primary flow path. The bird matter was visible as a yellow green glow under ultraviolet light as well as being visible as streaking under white light. There was also a slight build-up of bird matter on the leading edge surface such as struts, etc.

In addition, ultraviolet light examinations were made on the stator vanes and rotor blades of stages one through three. These examinations showed the presence of an almost uniform deposit of bird matter over the full circumference of the engine gas path.

Bird matter streaking was also observed in the rear compressor bleed cavities as observed through the bleed parts. Bird remains were not detected on any of the rear compressor blade airfoils or vanes.

After the diffuser case fairings were removed from the case, bird matter was observed under the fairings and on the exterior of the case, primarily on the upper half.

1.16.2. *Right Engine S/N P-709523B.*

The airfoil sections of ten of the twenty-seven 1st stage compressor rotor (fan) blades were severely bent by soft body impact typical of multiple bird impact. The 2nd stage fan rotor was intact and was not visibly damaged; except for several adjacent fan blades which had a significant "S" bend in their airfoil sections. The 3rd stage blades exhibited some minor airfoil trailing edge tip curl. The 4th, 5th, and 6th stage front compressor rotor blades were intact and were not damaged.

The trailing edges of the 7th stage rear compressor rotor blade airfoils had relatively light impact damage. All of the 8th stage rear compressor rotor blades were either fractured at the platform or were missing from their respective compressor disk slots. The blades were missing from twenty-nine and forty-six slots in the 8th stage compressor disk and the 9th stage compressor disk, respectively. A blade was missing from one 10th and one 11th stage compressor disk slot.

Damage to the 12th and 13th compressor rotors blades was about the same as that which occurred on the 11th stage compressor rotor blades. Nearly all of the 13th stage rear compressor rotor blade airfoils were bent over nearly 90 degrees in the direction opposite to compressor rotor rotation. The blade airfoils were severely battered.

Except for two blades, all of the remaining attached 10th stage, sixty-nine of the 11th stage and nearly all of the 13th stage rear compressor rotor blade airfoils were bent over in the direction opposite to compressor rotor rotation.

All of the rear compressor 7th, 8th, 9th, 11th, and 12th stage compressor stator vanes were intact. The leading edges of the rear compressor 7th stage stator vane airfoils were not damaged or thermally distressed, however, severe 7th stage vane airfoil trailing edge mechanical and thermal distress was observed. All of the rear compressor's 8th, 9th, 11th, and 12th stage compressor stator vane airfoils were severely battered and torn on both their leading edges and trailing edges, and exhibited battered outer shrouds, which were also bulged and dented. The vane airfoil damage was predominantly located on the outer 50 percent of the individual blade's airfoil span. The 8th, 10th and 11th stage compressor outer shrouds were punctured and penetrated. The remaining outer shrouds were battered, bulged and dented, however, they were not penetrated.

Seven vanes were missing from the 10th stage rear compressor stator. All of the remaining 10th stage rear compressor stator vane airfoils were battered and torn on both their leading edges and their trailing edges.

The 13th stage rear compressor stator vane airfoil trailing edges were not damaged.

The nine combustion chambers and the first stage nozzle guide vane transition duct were heat damaged. Molten/re-solidified metal splatter adhered to the domes of all of the combustion chambers.

The first stage nozzle guide vanes of the turbine nozzle showed evidence of over-temperature distress, primarily to the coatings on these parts. All of the vanes were intact.

All of the blade airfoils for the rear compressor drive turbine were broken or burned and melted away at approximately their 50 percent span locations, such that the outer portions of all of these blades were missing.

The front compressor drive turbine experienced severe over-temperature thermal damage. All of the 2nd and 3rd stage turbine blade airfoils for the front compressor drive turbine were burned and broken at their approximate 50 percent span locations. All of the 2nd and 3rd stage turbine vanes were broken at their outer shrouds; however, the inboard portions of these vanes were either missing or were found with other parts at the bottom of the nozzle case.

Ground fire exposure partially destroyed the physical evidence of bird matter within the engine. In spite of the fire damage exposure that the engine received, it was still possible to observe staining of both the metal and fiberglass (diffuser fairing) components, by employing visual and ultra-violet light techniques.

Bird matter was visually observed within the fan discharge area and the rear compressor front bleed manifold assembly, however, no bird matter residue build-up adhered to these components.

1.16.3. **Metallurgical Evaluations.**

A random number of representative blades from the 7th through the 13th stages of the rear compressors and a representative number of blades from the front and rear compressor drive turbines of the left and the right engines were forwarded to Pratt & Whitney Materials Engineering Research Laboratory for detailed evaluation. The evaluations included binocular examinations, chemical and metallographic analysis and peak operational metal temperature evaluations.

All of the fractured rear compressor blades from both engines generally featured transverse airfoil fractures and/or parallel directed cracks. Most of the rear compressor blade airfoils exhibited fatigue, which progressed from multiple origins. The remaining rear compressor blade airfoil fracture surfaces were heavily battered, deformed and smeared.

The turbine blade airfoils from the front and rear compressor drive turbines of both engines were severely thermally distressed. The turbine blade airfoil fracture surfaces, generally, were typical of rapid tensile or impact fractures. Metallographic examination of selected 1st and 4th stage turbine blades showed that these blades experienced metal temperatures of 2300 degrees fahrenheit or higher.

1.17. **Aircraft/Engine Performance.**

The airplane manufacturer estimated that based on the accident airplane's flight path, the engines were producing a total of approximately 12,000 pounds of effective thrust. This thrust was being developed while the engines were surging, during the time period from about 30 seconds to approximately three minutes after rotation.

The engine manufacturer was requested to cevelop an analytical evaluation to provide an assessment of the higest surge free thrust level that an engine with operational performcnce deterioration and first stage fan damage comparable to the accident airplane's engines coula produce. The evaluation basically showed that the nominal estimated compressor efficiency loss for the left and right engines was 13 percent ana 27 percent respectively. Estimated flow capcity loss for the left and right engines were 9 percent and 18 percent respectively.

The evaluation also suggested that a power reduction to about 140 lbs/sec. airflow for the left engine and 115 lbs/sec. airflow for the right engine would be necessary to clear the surge. Engine power for these airflows would be approximately 60 percent of take-off thrust for the left engine and 30 percent of take-off thrust for the right engine.

1.17.1. **Bird Characteristics.**

The engine examinations, as well as the crew reports, suggestea that a large number of birds were ingested during the event. The ingested bird matter had collected and adhered to the underside of all the portspan shrouds of the 1st stage compressor rotor fan blades. This bird matter was analyzed by an ornitologist from the National Museum of Natural History of the Smithsonian Institution, Washington, D.C. The species of the bird matter was identified as a speckled pigeon (Columba guinea). The estimated weight of these birds was between 10 to 12 ounces.

The coloring of these birds is primarily grey or silvergrey with chesnut or purple shoulders.

These birds are mainly, perhaps entirely, a ground feeder and feed largely on seeds, including cultivatea grains. They are fond of groundnuts when these are available on or near the surface after harvesting. These birds are usually found in pairs, small parties or singly but large numbers may aggregate at good feeding grounds. These birds sometimes form large and cohesive flocks when not breeding. The bird's flight is direct and fairly fast with strong wing beats. The bird also walks and runs nimbly on the ground.[6]

1.18. Federal Aviation Administration Engine Bird Certification Requirements.

The Pratt & Whitney JT8D-17A turbofan engines were type certified by the United States Government Federal Aviation Administration (FAA) in accordance with the following:

(1) The JT8D-17A is a derivative engine with a fan similar to the JT8D-1 orginally tested in 1962 per Civil Aviation Regulations (CAR) Part 13.200 thus, no new bird ingestion test was required. The tests run in 1962 and described in Report PWA 2130 consisted of one 4 oz. bird dropped in at take-off, five 4 oz. birds dropped in at take-off, and one 2 lb. seagull shot in at 160 mph.

(2) The JT8D-17A engine model was type certificated on January 26, 1982.

(3) The FAA bird ingestion certification requirements in effect for new engines on the above date were from Federal Aviation Regulations (FAR) Part 33.77 Amendment 6. For JT8D size engine it would have required three 1.5 lb. birds ingested at take-off conditions and one 4 lb. bird ingested at maximum cruise conditions.

[6] The above bird characteristics reference material was obtained from Pigeons and Doves of the World by Derek Goodwin, published by the Trustee of the British Museum (Natural History) London: 1967.

The current FAA turbine engine bird ingestion certification standard for new technology turbofan/turbojet engines is contained under FAR 33.77, foreign object ingestion. Compliance with this regulation as specified in the standard is demonstrated by engine test where one 4 lb. bird (if it can enter inlet) is ingested at maximum climb or liftoff speed of typical airplane with the engine operating at the maximum cruise or take-off rating (depending if the engine has inlet guide vanes or not and aimed at a critical area.) The 4 lb. bird ingestion may not cause the engine to catch fire, release hazardous fragments through the engine case, generate loads greater than ultimate loads specified in the FAR or lose the capability of being shutdown. The engine test must also demonstrate the ingestion of from one up to eight 1½ lb. birds (depending on inlet area) at intial climb speed with the engine operating at the take-off rating in rapid sequence to simulate a flock encounter and aimed at selected critical areas. The 1½ lb. bird ingestion may not cause more than a sustained 25 percent power or thrust loss, require the engine to be shut down within 5 minutes from time of ingestion or result in a potentially hazardous condition. If the 1½ lb. bird will not pass the inlet guide vanes into the rotor, ingestion of from one up to sixteen 3 ounce birds (depending on inlet area) will replace the 1½ lb. bird.

1.19. *Overview Evaluation of Bird Hazard.*

As demonstrated by this accident, the collision between birds and an aircraft particularly the ingestion of birds into turbine engines is a serious safety hazard. Bird strikes also result in considerable economic loss for additional repair and lost operational time to aircraft operations each year. Analysis of data developed by the FAA through their various bird ingestion investigation programs indicate that 77 to 84 percent of commerical engine bird strikes occur during take-off, landing and taxi operations; thus, demonstrating that the primary bird hazard exists on and in the immediate vicinity of commercial airports.

In response to a National Transportation Safety Board recommendation to review the technical adequacy of the then current FAR bird ingestion certification standards, the FAA initiated studies in 1981 to obtain service data on turbine engine bird ingestions.[7] These studies attempt to provide number, weight, and type of birds ingested by selected commercial engines in worldwide service, damage analysis, and a definition of the airport bird threat. The initial 2-year data census was conducted between 1981 and 1983, where the population of biras being ingested by wide-bodied airplane engines was identified. The results of, this stuay was published in the FAA report, "A Study of Bira Ingestions into Large, High Bypass Ratio Turbine Aircraft Engines, DOT/FAA/CT-84/13, September 1984."

To expand the information, parallel, 2-year studies were initiated in 1987. Both studies concentrated on the service experience of the two engine models in use on the Boeing 737. These studies is providing a comparison between the new generation CFM 56-3 high bypass engine and the older JT8D low bypass engine installed on the same airplane configuration. The FAA has contracted with the respective engine manufacturers to provide service data and analysis on their particular engines. The stuay period was completed in October 1989.

The JT8D engine models, as used on the B737-200 airplane, have experienced numerous incidents of bird ingestions. These incidents have included bird ingestions into multiple engines and multiple bird ingestions into a single engine. Data relating to these experiences have been tabulated and previously reported to the FAA under the B737 study described above. Preliminary analysis of these data gathered

[7] The FAA's latest bird ingestion study consists of a 2-year data collection begun in January 1989 involving a contemporary commercial transport fleet operating worldwide. This current study will include high bypass turbofan engines certified to the current FAA bird ingestion standards and which are installed on B747, B757, B767, MD-11, DC-10, A300, A310, and A320 airplanes. The FAA is contracting with the engine manufacturers, Pratt & Whitney, Rolls Rayce, and General Electric to collect and report these data. In addition a second study is tracking representative, small inlet area turbine engines used in business executive, and commuter aircraft, since FAR bird ingestion standards cover all sizes of turbine engines. This study is concentrating on the Garrett TFE 731 and TPE 331, the Lycoming ALF502, and the Pratt & Whitney of Canada JT150 engines. FAA contracts have been awarded to each engine manufacturer to conduct the service data gathering on its respective engines. This study was scheduled to be completed in May 1989.

during 1987 through 1988 shows that 2.0 percent of all the bird ingestions reported for the B737-100/-200 fleet involved multiple engines, ana 6.6 percent involved were multiple bird ingestion into a single engine.

2. ANALYSIS.

The analysis of this accident focuses on the flight crew coordination, condition and capabilities, the airplane's flight path, the maintenance of the airplane, the conaition of the engines, the bird hazard aspects to the engines and the airport environs, the digital flight data and cockpit voice recorders, the airplane/engine performance and an analytical assessment of engine surge mechanisms.

2.1. General.

The pilots were properly trained and licensed to conauct the flight in accordance with applicable Ethiopian Civil Aviation regulations and there was no evidence of medical problems which would have aaversely affected the flight crew's ability to conduct the flight. It was also established that crew had received the requirea duty break before the accident.

Analysis of the flight crew's action as chosen suggested that their performance was reasonable ana prudent based on the performance of the air and all information available to them at the time.

The airplane was maintained in accordance with approved maintenance program and there was no eviaence of pre-existing airplane structural, systems or engine malfunctions which could have affected the flight prior to the bird strike event.

2.2. Cockpit Voice Recorder (CVR).

In summary the evaluation and analysis of the cockpit voice recorder transmissions revealed that:

1) *The bira strike event could be identified among the background sounds recorded by the CVR.*

2) *Sounds believed to be surges from the engines could be heard from the cockpit area microphone.*

3) *About 500 surges from each engine were heard on the cockpit area microphone recorded track of the CVR after the bird strike; these surges continued for 3 minutes and 24 seconds.*

4) *The surges of one of the engines provided a pulse on the recorded radio track of the CVR.*

5) *The surge rate determined by the pulse rate on the radio track was approximately 2.5 surges per second. The rate reduced to as low as approximately 1.7 surges per second for 13 seconds during a period in the cockpit conversation concerned with engine power and high EGT.*

6) *Both engines stopped operating within 11 seconds of one another.*

An anomaly was noted in the cockpit voice recorder transmissions in that, "thump" sounds of slightly different character could be heard within the communication radio channel. These "thumps" were recorded at the same base frequency as the surge of one of the engines that was heard on the area microphone track. The "thumps" were apparent whether or not radio conversation was taking place or the microphone key was depressed. After some consideration, these "thump" sounds were interpreted as a pulse leak into the radio channel due to one of the engine's surging based on the following:

The "thump" sounds started at approximately the same time as the audible engine surging sounds after initial bird impact and continued until the radio transmission referred to between 3:07 and 3:20. At the end of this transmission, these thumps in the radio channel had ceased and the surging sound in the area microphone channel was no longer evident. Having established that the radio track "thumps" were associated with the surging of only one engine, the surging frequency of that engine was determined to be approximately 2.5 surges per second except for a 13 second period between 1:25 and 1:38 dur-

ing which the frequency was reduced to as low as approximately 1.7 surges per second. During that 13 second period cockpit discussion centered around reducing engine power due to high EGT. It was not possible to determine which of the two engines that was surging, produced the impulse in the radio track.

2.3. Digital Flight Data Recorder (DFDR).

In summary, on analysis of the flight data obtained from the DFDR indicated that, following the bird ingestion event, the airplane gained altitude and airspeed until the loss of engine operation. Therefore, it can be concluded that the airplane had sufficient power to maintain a positive rate of climb, and increasing airspeed until both engines ceased to operate. It was also noted that the flight data was in general agreement with eye witness reports, terrain avoidance discussion within the cockpit, and the final resting place of the airplane.

2.4. Bird Hazard Evaluation.

It is known that single engines of similar models as those used on this type of airplane have experienced some degree of power loss due to bird ingestions; however, the magnitude and character of the resultant damage that occurred in this accident has never been observed prior to this accident. Thus, the circumstances of this accident demonstrated that the number of birds that were ingested by both engines was well in excess of both the Federal Aviation Administration type certificate requirements that were in effect at the time that this model engine was type certificated and the current requirements for new technology turbine engines. The observation of the amount of secondary damage within the rear compresssors of both engines suggested that the continued operation of the engines with the observed level of fan damage was unique.

Previous engine examinations as documented under the FAA study indicated that a relationship exists between "soft-body" damage and the number and sizes of birds that were ingested. For the engine conditions present during the accident flight, data collected under the FAA study indicated that the variation in damage to the fan blades for any one bird ingestion event could vary from two blades that were severely curled at their leading edge tips, to no visible damage if the bird was broken up by an inlet guide vane (IGV).[8]

Additionally, ingestion of a bird or birds through the inner section of the fan path inboard of the port span shrouds would not be expected to cause damage, due to the increased stiffness of the fan blades as a result of their increased curvature in this section. The passage of the bird through two fan stages generally results in a reduction of the bird mass in such a way that no secondary bird caused core damage is experienced.

The FAA data reported that an average of 35.8 percent of the total number of reported bird strikes for the B737-100/-200 series airplanes resulted in some degree of fan/engine damage significant power loss due to bird ingestion was reported for 5 percent of the total number of bird strikes.

2.5. <u>Engine Bird Ingestion Density Estimate.</u>

Based on a normal spatial density of birds in flight, it was assumed these birds would be randomly ingested over the face of the engines. Under this condition, it would be conservative to assume that at least one half of the ingested birds caused no engine damage.

Using the previous experience of documented blade damage for the reported size range of the ingested bird, it was possible to determine damage patterns on the fan rotors which could be correlated to the quantity of ingested birds wich caused this damage. This determination provided a quantity of damage producing birds of 7 to 8 in the left engine and 5 to 6 in the right engine. In this accident, by applying a conservative 50 percent damage expectation for a random

[8] It is also interesting to note that the FAA study reported primary soft body damage which resulted in transverse fan blade fracture. Of all the reported B737-100/-200 bird ingestions, 1.9 percent of these ingestions resulted in a blade airfoil transverse fracture.

ingestion event, it can be postulated that the estimated number of birds that were ingested by the left engine was 14 to 16, while the right engine ingested between 10 to 12 birds.

Previous documented experience with the JT8D size engine model has shown that no more than 3 birds of the reported size range have been ingested at any one time. This comparative experience demonstrated that the number of birds encountered in this accident was unique to the documented experience.

Estimating the number of birds which may have entered an aircraft engine during a bird flock encounter is sometimes difficult. Not all birds entering the engine will cause visible damage to the engine. In those cases where the number of birds entering the engine is not clear it is sometimes possible to estimate the number of birds entering the engine by observing and recording bird impact on those areas of the aircraft that have a direct frontal exposure. Appropriate areas of frontal exposure would be the wing leading edge, the horizontal stabilizer, and the engine inlet lip on the same side of the aircraft as the engine in question. It would be preferable to use a surface on a plane as close as possible to that of the engine.

As a second method of determining the quantity of birds ingested, a determination was made of the number of visible bird strikes on the airplane. Examination of the airplane's leading edge surfaces that remained intact after the post crash fire, revealed a density of bird caused dents to the left hand horizontal stabilizer equal to four birds within the inlet diameter of the left engine. This linear flock density was then converted to an area density which gave an estimate of expected engine ingestions at 9 to 16 birds. This correlates well with the previous estimate for the left engine of 14 to 16.

2.6. Analysis of Airport Hazard.

Airport observers had noted the presence of pigeons in large flocks on the ground and feeding alongside the runway (seed grass) during the day immediately preceding the accident and shortly afterwards.

This knowledge of the bird hazard was made known to all airmen by virtue of an Ethiopian Civil Aviation Authority NOTAM series C #077 dated September 5, 1988. It was also noted that the birds had become acclimated to the airport and were actively feeding in seed grass alongside the runway. The grass was about 6 to 18 inches in height and was clumped such that the birds could move freely about. The Bahar Dar airport has a low utilization rate. since there are only 2 commercial jet flight operations a week. The day before the accident, it was reported that a commercial jet was warned from landing because the birds could not be moved away from the runway.

In the days immediately after the accident, it was observed that the birds could be frightened by a vehicle approach, but would only move 100 to 200 yards away from the visible hazard. On the day of the accident, it was reported that a vehicle preceded the airplane down the runway so as to scare the dirds off the runway. It was then necessary for the vehicle to stand clear of the runway while the aircraft took-off but the birds that were scared away could have returned by then.

2.7. Airplane/Engine Performance Evuluation.

Evaluations of the engine surge mechanisms indicated that the engines could have been cleared of front compressor and fan surges by retardation of the power levers to a point where the operating lines dropped below the surge lines. However, this may have required power lever retardation to the extent that the engines would not be capable of developing sufficient thrust to sustain further flight.

Based on the circumstances of this accident, it is apparent that a reduction in engine power level will reduce the severity of engine surging and will prolong the engine's useful operational life, or will possibly completely eliminate the surging, depending on the degree of engine damage. Thus, it is apparent that the decision to lower power level during take-off, to reduce engine surging, would depend on the altitude gain, airspeed, terrain and weather conditions.

Since each foreign object damage event will yield a different amount and type of engine damage, it would be impossible to provide flight crews with an input (i.e., EPR setting), which would bring them "safely home" in every instance. In addition, the airplane manufacturer believes that the large number of possible circumstances surrounding the accident scenario do not allow for the writing of a procedure which would result in the best course of action in all circumstances.

2.8. Analytical assessment of Engine Surge Mechanism.

An analytical assessment was conducted by the engine manufacturer of the possible mechanisms which may have produced the engine surges encountered by the accident airplane's two JT8D-17A engines.

Two mechanisms to produce the surges were hypothesized utilizing the degree of fan damage that was observed on the two engines as a result of the ingestion of a large number of birds. The engine manufacturer did not have any analytical means to determine which of the two postulated surge mechanisms may have caused the surges.

Fan damage would be expected to result in substantial losses in fan efficiency and fan flow capacity. To validate this assumption, the engine manufacturer determined fan efficiency and flow capacity losses by using a data base which consisted of measured efficiency and flow capacity losses that were obtained during a series of engine tests on a PW2037 engine with various degrees of fan damage due to bird ingestion. For purposes of this study, both flow capacity and efficiency loss were assumed the same as the PW2037 data base for an equivalently damaged fan. In this instance, the measured efficiency and flow capacity losses were correlated with the estimated percentage of blockage of the fan flow passage area due to bent fan blade leading edges. For this study, the blockage of the fan flow passage area was considered to be oriented perpendicular to the blade chord. By using the measured efficiency and flow capacity loss test data and empirically extrapolating these data, the actual degree of fan blade deformation that was sustained by the accident airplane's engines may have been simulated.

It was further rationalized by the engine manufacturer that the effects of blockage of the airfoil passage area on fan flow capacity would be similar on either single stage fans like the PW2037 or the two stage JT8D fan. The engine manufacturer recognized that the effects on efficiency may be somewhat different on a two stage fan; however, the engine manufacturer believes that the damage of the first stage fan would degrade the performance of the second stage fan such that the overall efficiency effects might be similar.

Nominal estimated fan efficiency loss for the left and right engines were 13 percent and 27 percent respectively. In addition, the estimated flow capacity loss for the left and right were 9 percent and 18 percent respectively.

It should be noted that these estimates may contain substantial errors, since a fan damage event will result in a unique fan damage pattern. Therefore, it is apparent that using foreign object damage data from one event, and comparing these data to another unique event can produce significant errors. In addition, the adjustments for design differences between the compared engines may not have been adequate. It is believed that the engine manufacturer has accounted for the extremes of these errors by presenting a "Range of Estimate" band for the estimated fan operating line. This band is presented as a shaded area on Curve No. 332317 (Appendix 3) discussed later.

2.8.1. Mechanism A.

Losses in fan flow capacity result in a significant rematch of the front compressor's operating line toward surge. This can most easily be visualized by the following reasoning. The fan and the front compressor are installed on the same shaft and are jointly driven by the front compressor drive turbine; however, only the air passing through the front compressor passes through the front compressor drive turbine. The fan air is bypassed around the core engine. A reduction in fan flow capacity will result in less power absorption by the fan. If it were assumed there were no changes in the core engine operation, the front compressor drive turbine would produce more power than would be absorbed by the front compressor and the fan. This excess power that is being developed by the front compressor drive turbine would result in a thermodynamic rematch of the core engine. One effect is the pressure ratio (operating line) of the front compressor will increase to compensate for the fan loss. Conversely, a loss in fan efficiency will result in a greater demand by the fan leaving less energy available for the front compressor and therefore a somewhat offsetting lowering of the operating line.

The estimated flow capacity and efficiency losses for the left and right engines were input into a thermodynamic model of the -17A engine. Curve No. 332317, Appendix 3 show the results. The thermodynamic model contains a full representation of the JT8D-17A engine including compressor and turbine representations that allow thermodynamically correct, off design matching including the ability to accommodate a 27 point loss of fan efficiency. The fan model representation is such that the fan airflow is directed outboard of the fan/front compressor airflow splitter, thus bypassing the front compressor; while the fan airflow that is directed inboard of the flow splitter is modeled as part of the front compressor. For this study only the fan outboard airflow characteristics were changed since fan efficiency changes as an efficiency reduction to the fan map values, while the flow capacity loss changes as a percentage reduction of outboard directed fan air flow for a given front compressor rotor speed.

The normal undamaged fan, and front compressor operating and surge lines, and the estimated range of the operating and surge lines for the damaged fans of the left and right engines are provided on Curve No. 332317, Appendix 3 respectively. The normal undamaged engine front compressor surge and operating lines are well defined based on the engine manufacturer's production and experimental engine test data. A range is shown for the damaged fan operating line due to the uncertainty of predicting the operating line. Lines of constant EPR settings are also indicated.

These curves indicated that surging would be predicted for both engines, using the highest operating line estimate, as the damaged fan's operating line intersects the surge line of the damaged fan. This intersection would be above 1.6 EPR for the left engine and at lower EPR for the right engine.

2.8.2. **Mechanism B.**

This mechanism differs from mechanism A only in the cause of the work transfer to the front compressor. For this surge mechanism, it is assumed the fan damage is sufficient to cause the fan to stall. Fan stall will result in a collapse in fan flow and work requirement; thus, shifting the fan work requirement to the front compressor. As a result, the increased front compressor work requirement will increase the compressor's operating line to the point of surge.

In either case (Mechanism A or Mechanism B), the subsequent events would be expected to be the same.

If a fan stall initiated the front compressor surging, as presented in mechanism B, causing the operational problem, a larger reduction in power would probably have been required to completely clear the fan stall.

The front compressor operating line plots (Curve No. 332317) demonstrated that a power reduction to about 140 lbs/sec. airflow for the left engine and 115 lbs/sec. airflow for the right engine, would probably have been sufficient to clear the surge lines. This is an area for both engines where the front compressor would be estimated to be free of surge based on the analysis. Engine power for these airflows would be approximately 60 percent of take-off thrust for the left and 30 percent of take-off thrust for the right engine.

Following the bird encounter and resulting fan damage, the engine power lever was initially advanced to levels higher than normal take-off settings (based on the pilots statement) and maintained at a high power level (based on analysis of the CVR) while the engines surged continuously for approximately 3½ minutes and approximately 500 times each. This continuous surging apparently caused the fatigue failures in the rear compressor. The fatigue failures subsequently led to secondary compressor and turbine damage, rapid disintegration of the rear compressor gas path, and loss of the rear compressor's capability to pump air which then led to turbine over-temperature, melting, and destruction.

It was estimated that turbine destruction and the subsequent loss of all thrust occurred within a few seconds of the time after the rear compressor blade fractures began to occur. Fatigued rear compressor airfoils have been previously observed on JT8D engines that were subjected to repeated surging. In such instances the JT8D Engine Manual (Sections 72-36-32 and 72-36-33) requires inspection of 8th stage and 9th stage blade airfoils for fatigue cracks.

Therefore, based on the above evaluations, it can be concluded that the engines could have been cleared of front compressor and fan surges by retardation of the power levers to a point where the operating lines dropped below the surge lines. Once surging is eliminated, this would also eliminate the excitation which can cause the rear compressor blade fatigue cracking and failure.

An engine computer simulation and analysis of the post surge depressurization (blowdown) was used to estimate air temperatures in the combustion and turbine sections of the accident airplane's engines during the bird ingestion caused surge events. The repetitive surging was estimated to produce a maximum average rear compressor drive turbine inlet temperature of 2145 degrees Fahrenheit (1880 degrees Fahrenheit is normal), front compressor drive turbine inlet temperature of 1945 degrees Fahrenheit (1425 Degrees Fahrenheit is normal), and exhaust gas temperature of 1575 degrees (1005 degrees Fahrenheit is normal).

Appendix 4 is a graphic presentation which depicts surge initiation at 0.01 sec. and temperatures which begin to rise shortly thereafter and continue past 0.06 second at which time all available oxygen within the combustion section at surge initiation has been consumed. At approximately this time, the compressor begins flowing significant airflow, reducing the air temperature to the orginal levels. On the basis of the observed surge frequency of approximately 2.5 times per second per engine based on the cockpit voice recorder, the elevated air temperature period is less than 20 percent of the surge cycle while normal air temperatures exist for the remaining time. The air temperatures summarized earlier represent the average integrated value over the approximate 3½ minutes of repetitive surging. Failure of the rear compressor section following this repetitive surging would result in a severe reduction of engine airflow and an increase of air temperature that would exceed the melting point of the turbine airfoil material.

First and fourth stage turbine blade fracture segments from the accident airplane's engines were metallographically examined to determine the metal temperature.

The engine manufacturer's turbine blade material specification data reported that the melting range is on the order of 2300 Degrees Fahrenheit.

The estimated stress rupture data for the first stage turbine blades, even assuming zero cooling airflow rather than the normal 0.6 percent cooling airflow, indicated that the blades would have an estimated several hours of life at the estimated turbine inlet temperature of 2145 Degrees Fahrenheit. Inlet temperatures would have to be on the order of 2500 Degrees Fahrenheit or higher to attain a 2300 Degrees Fahrenheit metal temperature and essentially zero life.

The evidence is even more compelling for the fourth stage turbine blades. It is estimated that turbine inlet temperatures would have to be well in excess of 3500 degree Fahrenheit in order to produce metal turbine blade material exposure temperatures at the 2300 degree Fahrenheit range. Therefore, based on the above discussion, it can be concluded that the cause of the turbine melting and failures that occurred to the accident airplane's engines was the result of the cessation of airflow. The cessation of airflow was due to rear compressor destruction which was caused by the repetitive surging. In this instance, continuing fuel introduction into the combustion section without the corresponding airflow from the rear compressor would result in an unstable combustion pattern in the combustion section. The unstable combustion pattern would result in a flame front which would continue to migrate into the turbine area due to the reduced airflow. This situation would continue until the rear compressor drive turbine (N2) rotor ceased to operate. This would then cut the fuel supply provided by the N2 driven fuel pump and fuel control unit.

2.9. Findings and Conclusions.

(1) The airplane accelerated at a normal rate during its take-off roll.

(2) The airplane encountered a flock of speckled pigeons (columba guinea) immediately after rotation.

(3) The left engine ingested an estimated 14 to 16 speckled pigeons which weighed an estimated 10 to 12 ounces each while the right engine ingested an estimated 10 to 12 pigeons.

(4) The number of birds that were ingested by both engines was well in excess of both the Federal Aviation Administration type certificate requirements that were in effect at the time that this model engine was type certificated as well as the current requirements for new technology turbofan engines.

(5) Except for a brief power reduction the flight crew essentially maintained the engines at full power thrust lever setting during the entire flight.

(6) Both of the engines individually experienced about 500 surges that continued for 3 minutes and 24 seconds.

(7) As a result of the bird ingestions and the subsequent compressor surging, it was analytically assessed that the nominal estimated fan efficiency loss for the left and right engines were 13 percent and 27 percent respectively. In addition, the estimated flow capacity losses for the left and right engines were 9 percent and 18 percent respectively.

(8) The analytical assessment also suggested that a power reduction to about 140 lbs/sec. airflow for the left engine and 115 lbs/sec. airflow for the right engine would be necessary to clear the surges. This vales are equivalent to 60% of take-off thrust for the left engine and 30% of take-off thrust for the right engine.

(9) The turbine melting and failures that were observed on the accident airplane's engines resulted from the cessation of airflow due to rear compressor destruction that was caused by the repetitive surges.

3. CAUSE.

The accident occurred because the airplane could not be safely retuned to the runway after the internal destruction and subsequent failure of both engines to operate arrising from multiple bird ingestion by both engines during take-off.

*ICAO Note.— Names of personnel were deleted.

ICAO Ref.: 245/88

No. 5

Boeing 707-338C Combi, 5X-UBC, accident at Fiumicina Airport, Rome, Italy on 16 October 1988. Report released by the Ministry of Transport, Italy.

PREFACE

On the 16th of October 1988 at 23.30 GMT (00.30 local time of the 17th of October 1988), Uganda Airlines' 338-C (Combi Version) Boeing 707, Registration Letters 5X - UBC, crashed during an approach manoeuvre on the extension of Runway 34L in the proximity of Rome's Fiumicino Airport.

With telex number 44/172011 dated 18th October 1988 followed by Ministerial Decree No. 165/44 dated 18th January 1989, the Italian Ministry of Transport appointed the Board Members listed hereunder, to conduct the Inquiry into the afore mentioned accident:*

This Inquiry was conducted in accordance with Article No. 827 of the Air Navigation Laws, based on Decree Number 165/44 issued by the Italian Ministry of Transport on the 18th of January 1989.

Investigations and Evaluations were made in order to determine the cause of the accident and enlightening evidence on the accident was acquired during the course of the Inquiry.

The Results of the Inquiry transcribed herein, are in the prescribed format in accordance with the ICAO Manual 6920/AN/855/IV, 1970 Edition.

**ICAO Note.*— The lists of board members and parties who participated in the inquiry were not reproduced.

1.1 HISTORY OF THE FLIGHT

On the 16th of October 1988, Uganda Airlines' Flight UGA 774/775 scheduled to fly the Route EBB-ROM-LON-EBB, rerouted their flight plan to EBB-LON-ROM-EBB. The Carrier was a Boeing 707/338-C, Registration Letters 5X-UBC.

At LON/GATWICK, the crew carried out the normal pre-flight operations and obtained all the meteorological information for the flight to Rome. The aircraft Took-Off from Gatwick at 21:10 GMT with 7 crew members, 45 passengers (43 adults and 2 infants), 28.624 Kg. of cargo and luggage and 20.910 Kg. of fuel.

After a regular flight, at 22:33:37 GMT the crew established their first contact with Rome Control on Frequency 124.8, advising that they were at FL 370 in the direction ELB/VOR and requesting the latest meteorological conditions at Fiumicino Airport.

Rome Control informed the crew that Runway 16L was in use and that at that moment, the RVR conditions were, point Alfa 2000 metres, point Bravo 1500 metres and point Charlie 200 metres. Since 21:20 GMT, the weather reports showed fluctuating fog-banks and light winds at the airport, with consequent considerable and sudden changes of the RVR values on the runways and a lowering of the ceiling.

The aircraft was cleared to begin its descent along the ELBA/GROSSETO/TARQUINIA Route and the crew was instructed to contact Approach Control on Frequency 125.5. The aircraft was then cleared for a further descent to 4000 feet and for an ILS Approach on Runway 16L.

In the meantime, visibility was deteriorating and when the pilot confirmed that he had intercepted the localiser and the aircraft was at 9 nautical miles from touchdown point, Rome ACC informed him of the new RVR values for Runway 16L (Point Alfa 400 metres, Point Bravo 1000 metres, Point Charlie 350 metres) and instructed him to contact Fiumicino Tower on Frequency 118.7 for authorisation to land.

Due to a sudden decrease in visibility, the aircraft missed the approach and the crew informed the Tower at 23:05:42 GMT, that they were effecting a Go-Around. The Tower instructed them to switch back to the Approach Frequency 125.5 after having performed the Standard Missed Approach Procedure.

After having received the new RVR values for the various runways, the crew attempted a second approach on Runway 25 which for the same reason as above, was also negative.

The Captain contacted Approach Control again and requested the meteorological conditions for Ciampino Airport (which at that time registered a visibility of 5 Km. with mist) and asked if any improvements were forseen for Runway 16L at Fiumicino. The Controller advised him of the meteorological conditions at Ciampino and specified that at that moment at Fiumicino, only Runway 34L registered 1600 metres, 2000 metres and 175 metres respectively at points Alfa, Charlie and Bravo, the Captain then requested Radar Vectoring for Runway 34L.

Therefore, the aircraft was assisted by Rome Radar up to the time it intercepted the 349° Radial of Ostia/VOR to carry out the subsequent VOR/DME procedure for Runway 34L. Once again the pilot was given the RVR values for Runway 34L (Point Alfa 1600 metres, Point Bravo 2000 metres and Point Charlie 150 metres) and was instructed to contact Fiumicino Tower when estabilised on the 349° radial.

At 23:28:55 GMT, the crew confirmed with the Tower that they were estabilised on the localiser for Runway 34L, they were authorised to land and informed of the latest meteorological conditions (visibility 1500 mt. and no wind on Runway 34L).

After approximately 30 seconds, the Captain who at that moment was PF, decided to turn over the controls to the First Officer in order to look outside to locate the Visual Runway Markings and intended taking control again before landing.

Upon confirmation from the First Officer that he had assumed control, the Captain requested an Altitude Reading and while the First Officer was answering "1500 feet maintain...", the Ground Proximity Warning System activated "PULL-UP" an impact "TAKE-OFF CONFIGURATION WARNING" then two more impacts which were recorded by the C.V.R..

The first impact occurred in dense fog with the roof of a house 9.52 metres high (11.4 metres s.l.) situated in a flat, residential area in the vicinity of the Fiumicino boat canal approximately 1300 metres from the threshold of Runway 34L and about 100 metres to the right with respect to the runway extension's Centre Line.

After the initial impact, the aircraft struck three more buildings, broke into various sections and caught fire.

1.2 INJURIES TO PEOPLE

TYPE OF INJURIES	CREW	PASSENGERS	OTHERS	TOTAL
FATAL :	7	26	-	33
SERIOUS:	-	16	-	16
MINOR/NONE:	-	3	-	3

1.3 DAMAGE TO THE AIRCRAFT

The aircraft was completely destroyed in the impact with the ground and by the subsequent fire.

1.4 OTHER DAMAGE

The following damage was caused by the aircraft during the final part of its flight:

- Three buildings were damaged.
- A building under construction was completely destroyed.
- Sections of fences and a S.I.P. telegraph pole were knocked down.
- ENEL electricity cables were severed.
- Several trees along Via Portuense were damaged.
- Several EUROPCAR cars in an open parking lot were more or less seriously damaged because they were either struck by parts of the aircraft or because of fire caused by fuel spilt from a section of the RH wing that had detached during the impact.

1.5 PERSONNEL INFORMATION

CAPTAIN:	
BORN IN:	KAMPALA, UGANDA
DATE OF BIRTH:	7th MARCH 1945
AIRLINE PILOT LICENCE NUMBER:	1798

ICAO Note.— List of the pilot's flights to the Rome/Fiumicino Airport was not reproduced.

LAST MEDICAL CHECK-UP	1ST JUNE 1988
MEDICAL CHECK-UP VALID UNTIL:	31ST DECEMBER 1988
TOTAL NUMBER OF FLIGHT HOURS:	8365
TOTAL NUMBER OF FLIGHT HOURS AS CAPTAIN DURING THE LAST SIX MONTHS:	162 hours 30 minutes
LAST IN-FLIGHT CHECK:	2ND DECEMBER 1987

FIRST OFFICER:	
BORN IN:	KAKUMIRO, UGANDA
DATE OF BIRTH:	7th JUNE 1955
AIRLINE PILOT LICENCE NUMBER:	X-135 AP
RATING FOR BOEING 707 OBTAINED IN:	1984
LAST MEDICAL CHECK-UP	11Th JULY 1988
MEDICAL CHECK-UP VALID UNTIL:	11TH JANUARY 1989
TOTAL NUMBER OF FLIGHT HOURS:	2202
TOTAL NUMBER OF FLIGHT HOURS AS FIRST OFFICER DURING THE LAST SIX MONTHS:	151
LAST IN-FLIGHT CHECK:	6TH MAY 1988

FLIGHT ENGINEER:	
BORN IN:	KEBALE, UGANDA
DATE OF BIRTH:	22ND OCTOBER 1950
LICENCE NUMBER:	U00504
LICENCE VALID UNTIL:	3RD DECEMBER 1988
LAST MEDICAL CHECK-UP	25TH NOVEMBER 1987
MEDICAL CHECK-UP VALID UNTIL:	11TH JANUARY 1989
TOTAL NUMBER OF FLIGHT HOURS UP TO THE 25TH OF NOVEMBER 1987:	4000
TOTAL NUMBER OF FLIGHT HOURS DURING THE LAST TWELVE MONTHS:	334

ICAO Note.— List of the co-pilot's flights to the Rome/Fiumicino Airport was not reproduced.

1.6 INFORMATION ON THE AIRCRAFT

AIRCRAFT TYPE:	BOEING 707-338 C COMBI
CATEGORY:	TPP (PASSENGER TRANSPORT) TPM (CARGO)
SERIAL NUMBER:	19630
DATE OF MANUFACTURE:	25TH SEPTEMBER 1968
PREVIOUS OWNER:	BRITISH CALEDONIAN AIRWAYS LTD.
PREVIOUS REGISTRATION LETTERS:	G-BDSJ
OWNER AT TIME OF ACCIDENT:	UGANDA AIRLINES CORPORATION
AIRCRAFT REGISTERED IN UGANDA ON:	5TH OCTOBER 1981
REGISTRATION LETTERS:	*5X-UBC*
CERTIFICATE OF AIRWORTHINESS NUMBER:	111
ISSUED BY:	THE DIRECTORATE OF CIVIL AVIATION OF UGANDA
DATE OF ISSUE:	30TH OCTOBER 1981
DATE OF LAST C OF A RENEWAL:	6TH SEPTEMBER 1988
AIRCRAFT FLIGHT HOURS AT LAST C OF A RENEWAL:	57.776
LAST C OF A VALID UNTIL:	21ST AUGUST 1989
DURING THE RENEWAL OF THE C OF A. THE DIRECTORATE OF,CIVIL AVIATION OF UGANDA DECLARED THAT THE MAINTENANCE, MODIFICATIONS AND MANDATORY DIRECTIVES AND BULLETINS HAD BEEN COMPLIED WITH IN ACCORDANCE WITH THEIR REGULATIONS.	

ENGINES: PRATT AND WHITNEY TYPE JT 3D - 3B		
POSITION	SERIAL NBR.	TOTAL NUMBER OF HOURS FROM MANUFACTURE TO LAST TAKE-OFF
1	P 645125 BAB	51.087
2	P 645040 BAB	8.058 HOURS SINCE OVERHAUL (TOTAL HOURS UNKNOWN)
3	P 645053 BAB	58.287
4	P 645770 BAB	48.400

AIRFRAME: 58.098 TOTAL HOURS	
NUMBER OF FLIGHTS:	17.363
LAST INSPECTION "A" (110 HOUR INSPECTION)	CARRIED OUT AT 58.047 HOURS
LAST INSPECTION "B" (550 HOUR INSPECTION)	CARRIED OUT TOGETHER WITH THE LAST INSPECTION "C". EXTENSION TO 58.199 HOURS RECORDED IN THE TECHNICAL LOG ON THE 13TH OCTOBER 1988.
LAST INSPECTION "C" (1700 HOUR INSPECTION)	CARRIED OUT AT 57.512 HOURS, BY ETHIOPIAN AIRLINES ON 26TH MAY 1988 AS PER WORK SHEET.
LAST INSPECTION "D" (14.000 HOUR INSPECTION)	CARRIED OUT AT 55.748 HOURS, BY ETHIOPIAN AIRLINES IN APRIL 1987 AS PER WORK SHEET.
THE ORIGINAL AND THE COPIES OF THE TECHNICAL LOG RELATIVE TO THE LAST FLIGHT BEFORE THE ACCIDENT, WERE ALL ON BOARD THE AIRCRAFT AT THE TIME OF THE ACCIDENT AND WERE NEVER RECOVERED.	

AVIONICS

The aircraft's NAV/COM Instrumentation was tested with positive results on the 7th of September 1988 by Uganda's Directorate of Civil Aviation.

No malfunctions concerning the flight prior to the accident, were recorded in the Flight Engineer's Instrument Log.

In the aircraft log book under "Allowed Deferred Defects", the Altitude Alert was recorded as being inoperative since the 28th of May 1988. However, since the Minimum Equipment List was not recovered from the wreck and in spite of repeated requests from the Board of Inquiry, the Ugandan Authorities were unable to produce a copy, it was impossible to verify if the above mentioned failure was allowable by the prescribed standards of the Ugandan C.A.A..

(a) Radio-Altimeter

The Radio-Altimeter consisted of a Receiver-Transmitter System, Type 860F-1 522-3698-003, Serial Number 10510 and relative Indicator, manufactured by the Company COLLINS.

The Receiver-Transmitter System transmits data to the Indicator and the Ground Proximity Warning Computer.

As confirmed by Uganda Airlines, the Acoustic Warning System was unservicable.

(b) Ground Proximity Warning System

The SUNSTRAND Ground Proximity Warning System manufactured under licence by SMITHS, consists of a Ground Proximity Warning Computer, Smiths Part Number 965-0376-084, Serial Number 064. For purposes of technical information, copies of pages from the Maintenance Manual and a General Information Letter are attached.

The G.P.W.S. was bench tested on the 5th of April 1988 by Ethiopian Airlines.

From the Cockpit Voice Recordings it is assumed that the G.P.W.S. activated in mode 5 during the Approach on Runway 16L and most probably in mode 1 before impact.

(c) Altimeters

The KOLLSMAN Altimeters, Part Numbers A4186910021 and A4186910024 and the HONEYWELL ADC, Part Number HG18OU711 are pneumatically connected as shown in the attached diagram.

The ADCs incorporate barometric capsules which transmit data to the Altimeters, which when operating normally, display the data. The Altimeters also incorporate barometric capsules and their data is compared with the data transmitted by the ADC, and in the event there is a discrepancy of about 150 feet, the data from the Altimeter prevails and the pilot is advised by a Baro Flag.

The complete documentation containing proof of the tests conducted on the static system and the relative components, as required by the Airworthiness Authorities in compliance with the F.A.R., was not found.

AIRCRAFT LOAD CONDITIONS

The aircraft's last Weight and Balance Report was unavailable and therefore, it was not possible to verify if the following figures shown in the Weight and Balance Sheet compiled before Take-Off, were correct:

ZERO FUEL WEIGHT:	96.484 KG. (MAX. ALLOWABLE 104.326 KG.)
TAKE-OFF FUEL:	20.910 KG.
TAKE-OFF WEIGHT:	117.394 KG. (MAX. ALLOWABLE 123.857 KG.)

A fragment of the Fuel Log compiled by the Flight Engineer (this document was badly damaged in the accident), shows the Ramp Weight as 52.000 lbs. (23.608 Kg.).

It is therefore assumed, that the aircraft's Take-Off Weight was approximately 119,500 Kg, less than the Maximum Allowable Take-Off Weight.

On the basis of the instrument readings and the amount of fuel used after the Cockpit Voice Recording of 19.000 lbs at about eleven minutes before impact, it is assumed that at the time of the accident, there was approximately 12.000 lbs of fuel on board and therefore the total weight of the aircraft at that time, was estimated as 101.600 Kg., versus the Maximum Landing Weight of 112.037 Kg.

In view of the above and considering the aircraft's load condition as per the weight and balance sheet compiled before Take-Off, the aircraft was within the allowable limits both during Take-Off as well as Landing.

1.7 METEOROLOGICAL INFORMATION

In the standard procedure, the weather forecasts are recorded ten minutes before the relative bulletin is issued and must give the various meteorological parameters, which are valid for the entire airport area and the outside of the airport as well.

The accident occurred at 23:30 GMT during the period of time between the bulletins issued at 23:20 GMT and 23:50 GMT on the 16th of October 1988. For a detailed description of the weather conditions at the time of the accident, refer to Part II of this Report.

1.8 AIDS TO NAVIGATION

(a) The Radio Assistance available at Fiumicino Airport is as follows:

RUNWAY 16R	ILS/VOR + DME/NDB + DME
RUNWAY 16L	ILS/VOR + DME/NDB + DME
RUNWAY 25	ILS/VOR + DME/NDB + DME
RUNWAY 34R	ILS
RUNWAY 34L	VOR + DME/NDB + DME
RUNWAY 07	VOR + DME
RUNWAY 16R/L	LO

The following Table shows a summarised description of the lighting systems installed:

RUNWAY	APPROACH SYSTEM	LIGHTING		RUNWAY LIGHTING			
		INTST.	VASIS	THR	TDZ	RWY	TWY
07	SALS	VRB	-	X	-	X	X
25	CALV1 + EFAS	VRB	-	X	-	X	X
16R	CALV1 + EFAS	VRB	-	X	-	-	X
34L	SALS	VRB	T 3	X	-	-	X
16L	CALV2 + EFAS	VRB	-	X	X	-	X
34R	CALV2 + EFAS	VRB	-	X	X	-	X
NOTE: THE INFORMATION ON THE OBSTACLE LIGHTS IS INCOMPLETE							

(b) All the illuminated radio assistance systems available at the aiport were operating with the exception of the following equipment:

VASIS RUNWAY 34L :	OPERATIVE BUT AWAITING FLIGHT TESTING (NOTAM 1A 4842-88)
RUNWAY CENTRE LINE :	INOPERATIVE (NOTAM 1A 2712-87)

(c) The process used in Air Traffic Control of tracking a target with a radar, evaluates the kinematic parameters (position, speed, acceleration) of each aircraft in the area concerned, with the purpose of following the flight evolution and predicting the future positions of the aircraft, in order to enable the Operators to trace the flight path on their PPI monitors as accurately as possible.

The Multi-Radar Tracking Systems at Fiumicino, Monte Codi, Poggio Leccata and Monte Stella, are integrated with Ciampino's ATCAS CRAV System.

In the ATCAS Multi-Radar System, the tracking function supplied by a Data Processing Centre, operates by using signals coming from sensors that see the same target in simultaneously covered areas and by means of a single reference system, is able to show the tracks of all the aircraft covered by the individual radars, as if one single radar was covering a great area and was able to see all the targets.

The tracking process initiates a new track, every time three plots are detected thrice in succession, with the same SSR Code, Mode A and are correlative in every position.

The track is visualised every four seconds, regardless of the frequency of the actual signal.

For the Approach (Position TNR/ARR, Frequency 125,5 Mhz), the Controller of the ATCAS Radar at Ciampino, obviously used the information furnished by this system.

Therefore, the Board of Inquiry thought fit to acquire all the recordings of the ATCAS System as well as those relative to the Fiumicino Sensors which were nearest to the area of the Last Approach, the technical characteristics of which are as follows: *

1.9 COMMUNICATIONS

The exactness of the transcriptions, of the Ground/Air/Ground Comunications between the crew of Uganda Airlines' Flight Number UGA 775 and the Air Traffic Controllers on duty at the time, as well as the telephone conversations between the Controllers, was verified.

Particular attention was paid to the examination of the following:

- Excerpts of the Ground/Air/Ground Communications on Frequency 135.450 MHz, between Milan ACC and Flight Number UGA 775.
- Excerpts of the Ground/Air/Ground Communications on Frequencies 124.8 and 125.5 MHz, between Rome ACC and Flight Number UGA 775.

*ICAO Note.— The technical characteristics of the radars were not reproduced.

- Excerpts of the Ground/Air/Ground Communications on Frequency 118.7 MHz, between Fiumicino Tower and Flight Number UGA 775.
- Excerpts of telephone conversations between:

  Rome ACC and Fiumicino Tower.

  Fiumicino Tower and the Air Traffic Control.

  Fiumicino Tower and the Fire Department (Radio telephone).

All the tape recordings and relative excerpts are being held in the records of Rome's Flight Safety Department and are available for consultation.

1.10 AERODROME INFORMATION

The accident occurred just outside the airport perimeter.

The airport installations relative to Navigation and Approach are sufficiently dealt with in paragraph 1.8 "Aids to Navigation".

Numerous luminous sources of varying nature were noticed along the Approach Path of Runway 34L.

In view of the above, the direction of the aircraft's flight path was photographed from the top of the building where the first impact occurred and are filed in the records of Rome's Flight Safety Department.

1.11 FLIGHT RECORDERS

The aircraft was equipped with a Flight Data Recorder and a Cockpit Voice Recorder, both of which were recovered from the wreckage on the same day of the accident and confiscated by the Judicial Authorities, pending the investigation and laboratory tests.

(i) Flight Data Recorder

Manufacturer: PENNY AND GILES

Length of Tape: 25 hours

Recordable Parameters: Eight.

The Flight Data Recorder had probably been inoperative for some time. See attached Report from the Aircraft Accident Investigation Branch.

(ii) Cockpit Voice Recorder

Type: C.V.R. Model A100 manufactured by Fairchild Industrial Products.

On the 27th of October 1988 at Farnborough, in the presence of members of the Board of Inquiry and an expert appointed by the Italian Magistracy, the tape was removed from the C.V.R. by technicians of the Aircraft Accident Investigation Branch.

The quality of the recording is sufficiently good and continues up to the last few moments of the flight.

The recorded conversations were transcribed in order to identify the acoustic warnings and their timings. The conversations between the crew members were carried out entirely in the English language.

The acoustic warning "WHOOP WHOOP PULL-UP" is clearly distinguishable about 1.5 seconds before the first impact.

1.12 WRECKAGE AND IMPACT INFORMATION

Pieces of the wreckage, which detached from the aircraft towards the end of it's flight path, were scattered over an area between the point of the first impact with the roof of a house 9.52 metres high (11.4 metres s.l.), situated in a flat residential area in the vicinity of the Fiumicino boat canal about 1300 metres from the threshold of Runway 34L and the point at which Engine Number Two was found, at about 900 metres from the threshold of Runway 34L.

Small fragments of metal honeycomb were found in the vicinity of the first impact. Two tyre skid marks were visible on the roof of the house and some of the roof tiling had chipped off, which realistically indicates that the RH Main Landing Gear and Engine Number Three touched the building. The skid marks were at an angle of approximately 13 degrees northwards.

At a location of approximately 85 metres from the first impact, at a height of about 2.5 metres, the RH Wing Tip hit the second building and debris was strewn from this point up to the Europcar Parking Lot.

A building under construction, located immediately before the Europcar Parking Lot was presumably hit by the under section of the fuselage. This impact caused the lower section of the baggage compartment to open and part of the cargo consisting of sheets of printed paper was scattered around.

In this area, approximately 3 metres of the RH Wing in the vicinity of a fuel tank for engine numbers three and four, as well as the rear section of the fuselage including the horizontal and vertical tailplanes, detached themselves from the rest of the aircraft.

The greater part of the aircraft, very much inlined to the right, continued onwards, flew beyond Via Portuense and hit the ground with the forward section of the fuselage in the vicinity of the cockpit, which detached itself from the rest of the aircraft and came to a stop at about 60 metres from the road. The remainder of the fuselage together with about 10 metres of the inner section of the RH Wing and the whole LH Wing, continued on, banging along the ground in an almost circular fashion, losing other pieces and parts of cargo and came to a stop at approximately 150 feet from the cockpit. Engine Numbers One and Two detached from the LH Wing and came to a stop quite a few dozens of metres away. One of the Main Landing Gears was found immediately after Via Portuense and the other in the vicinity of the main section of the wreckage. The Nose Landing Gear was found at approximately 10 metres before the cockpit.

The largest part of the wreckage was seriously damaged by the fire caused by the fuel in the wing tanks. Only a limited section on the RH side of the rear fuselage between fuselage stations 960 and 1180, did not catch fire since it was partially detached from the rest of the wreck, and some rows of seats still attached to the seat rails, were found on the inside.

All the cargo and other debris from various parts of the aircraft were strewn around, particularly in the area between Via Portuense and the main section of the wreckage.

Condition of Instruments and Controls on board the wreckage

As previously mentioned, the cockpit had detached itself from the rest of the aircraft. It was seriously damaged by the impact, but had not caught fire. The cabin floor was in a practically upright position.

For the most part, the instrument panels were not visible, since the mass of the wreckage had bent them inwards. However, the Central Panel and a section of the Flight Engineer's panel were clearly visible. Subsequently, the panels were so positioned, as to be visible.

A diagram of the instrument panels is enclosed herein, the "Xs" indicate instruments that had either exited their housings or were completely illegible.

The following photographs are filed in the records and are available for consultation:

- Overhead Panel (Photograph Numbers 14C, 15C and 17C refer).
- Electronic Controls Forward Panel and Central Panel (Photograph Numbers 5C, 6C and 11C refer).
- Electronic Controls Rear Panel (Photograph Number 13B refers).
- Control Pedestal (Photograph Number 21B refers).
- Flight Engineer's Lower Panel (Photograph Numbers 9B, 10B and 11B refer).

- Flight Engineer's Upper Panel (Photograph Numbers 2B and 8B refer).
- CM 2 Panel (Photograph Numbers 24B and 25B refer).
- CM 1 Panel (Photograph Numbers 1C and 4C refer).
- CM 1 LH Panel (Photograph Number 22B refers).
- Radio Altimeter and Other Instruments (Photograph Number 12C refers).

The following tables show the principal instruments, their readings and the positions of the relative controls. Number one indicates the captain's side and number two indicates the co-pilot's side: *

1.13 MEDICAL AND PATHOLOGICAL INFORMATION

No elements, leading to a hypothesis that any of the crew members, were not in the required mental and physical conditions at the time of the accident, or that any such factor could have contributed to causing the accident, emerged from the Coroner's Report of the post-mortem examinations.

In sustainment of the above and in compliance with the current I.C.A.O. Regulations, the results of the last medical check-ups conducted on the crew members were examined and showed that all of them had been judged fit to fly.

Besides the seven crew members, twenty-six passengers perished in the accident. All the deaths were more or less instantaneous and were caused by severe multiple injuries

*ICAO Note.— The tables were not reproduced.

to the body, with the exception of three of the victims that expired after being hospitalised. One due to severe head injuries and the other two due to complications deriving from second and third degree burns.

Although many of the bodies showed considerable signs of burns, the toxicological examinations revealed an absence of carbon-monoxide leading to the conclusion, that there was no fire on board the aircraft before the impact with the ground and that the burns on the victims occurred after their expiry or whilst they were taking their dying breath.

1.14 FIRE

From the results of investigations carried out and from the testimony of witnesses, no elements emerged to indicate that there was a fire on board the aircraft before its impact with the buildings.

The first signs of fire were in the area where the RH wing detached when it hit the building under construction, near the Europcar Parking Lot.

At the moment of this impact, the fuel in the wing caught fire and spilt into the surrounding area, giving rise to numerous small fires that were fed by the fuel in the parked cars.

At 23:31:13 GMT, Fiumicino Tower tried in vain to make contact with Flight UGA 775 and at 23:32:58 GMT, reported a state of emergency to the Fire Brigade and the Port Authorities. At 23:35:20 GMT the Air Traffic Control's Central Office and the Airport's First Aid Department were informed of the possibility of an accident.

At 23:36:50 GMT, the Airport State Police informed the Tower that one of their cars was in the area of Via Portuense outside the airport perimeter, on the extension of Runway 34L, where the presumed accident had occurred.

The fire-fighting vehicles, which were the first to arrive in the area of the threshold of Runway 34L, were unable to locate the Ugandan aircraft because of the extremely poor visibility conditions and proceeded outside the airport perimeter, through gate numbers 1 and 2, into the area of the extension of Runway 34L and reached the vicinity of the Europcar Parking Lot, approximately eight minutes after the first alert.

The fire-fighting operations were conducted with the following equipment available on the airport:

7 Heavy Duty Vehicles of which:	-	6 PERLINI-BARIBBI Hydrofoam Vehicles with a capacity of 10.000 litres of water + AFFF.
	-	1 PERLINI Vehicle with a capacity of 8.000 litres of water + AFFF.
5 Rapid Intervention Vehicles of which:	-	4 UNIMOG Vehicles equipped with dual extinguishers, one with a capacity of 450 litres of water + AFFF and the other with a capacity of 480 Kg. of chemical powder.
	-	1 BARIBBI Vehicle with dual extinguishers.

Other Supporting Equipment

In addition to the above, the following equipment together with 65 fire-men, arrived from the city:

- seven fire engines equipped with water tanks
- four tank-trucks equipped with pumps
- six motor vehicles with special equipment

- an ambulance
- a ladder truck
- a truck crane.

Five minutes after the first alert, the Tower informed the First Aid Department that the area of the accident was outside the airport perimeter and at 23:46:00 GMT, a Doctor arrived with an ambulance on the scene of the accident.

At 23:47:00 GMT, the first ambulance left for the hospital.

At 23:48:00 GMT, the Rome Airport's Operational Safety Supervisor arrived at the scene of the accident with three ambulances, sanitary material and emergency lighting equipment.

At 24:10:00 GMT the first ambulances arrived from the city and at 24:30:00 GMT, all the survivors had been despatched to hospitals.

1.15 SURVIVAL ASPECTS

As shown in the post-mortem reports, all the deaths were more or less instantaneous and were caused by severe multiple injuries to the body, with the exception of three of the victims that expired after being hospitalised. One due to severe head injuries and the other two due to complications deriving from second and third degree burns.

Although the immediate arrival of the Rescue Teams on the scene of the accident was hampered by extremely poor visibility conditions, it can objectively be stated that this factor did not have negative repercussions on the possibility of survival, as confirmed by the above mentioned reasons.

With regards to elements effecting serviceability, no specific evaluations could be made, due to the condition of the wreckage after the fire had been extinguished.

1.16 TESTS AND RESEARCH

The Board of Inquiry had laboratory analyses carried out on the Altimeters and A.D.Cs at the facilities of the respective manufacturers, for the purpose of verifying the proper functioning of these instruments and the eventual possibility of an indication of malfunction at the time of the impact.

For the same reason a study was conducted using the information contained in the tapes of the Cockpit Voice Recorder and the Radar.

The results of the above mentioned tests have been filed in the records of Rome's Flight Safety Department, are available for consultation and are discussed in "PART II - ANALYSIS".

ANALYSIS

1. INTRODUCTION

Although this investigation was conducted in compliance with the relative I.C.A.O. Manual (Doc. 6920/AN/855/IV, 1970 Edition), the fact that the Flight Data Recorder had been inoperative for an unknown period of time and the consequent lack of data, obliged the Board of Inquiry to base their reconstruction of the final phase of flight UGA 775, essentially on the Cockpit Voice Recordings, Ground - Air -Ground Communications, Radar Recordings and Laboratory Analyses carried out on the Altimeters and A.D.Cs at the facilities of the respective manufacturers.
Due to the circumstances of the accident, the Board of Inquiry focused their attention primarily on the following:

(a) The weather conditions at Fiumicino Airport at the time of the accident and the information and assistance provided to the crew.

(b) Flight UGA 775 crew's operational performance during the three Landing Approaches at Fiumicino Airport.

(c) Proper functioning of the aircraft's Altimeters.

2. WEATHER CONDITIONS

With regards to ground reports at Fiumicino Airport between 18:20 and 18:50 GMT on the 16th of October 1988, an examination of the weather reports revealed the first significant decrease in general visibility from 3000 metres to 1600 metres. A tendency of a further reduction in general visibility to 1000 metres and a ceiling of 600 feet was recorded at 19:50 GMT.

For the first time at 21:20 GMT, the weather report showed the presence of fog-banks, a light easterly wind and a ceiling of 300 feet. From this moment onwards, the weather reports showed fluctuating fog-banks at the airport, with consequent considerable and unexpected changes of the RVR values on the various runways and a reduction of the general visibility to approximately 300 metres. The ceiling lowered simultaneously, although it climbed back to 500 feet at 23:20 GMT.

The QNH value remained more or less constant and from 1022 HPA recorded at 21.20 GMT, it dropped to 1021 HPA at 22:20 GMT and maintained this value for several hours later.

Under these circumstances, the Board of Inquiry considers the weather reports to have had little bearing on information useful to the pilot and in order to determine the minimum operational values, the only valid element in the weather report, usable by the pilot, was to be sought in the RVR values available at that time.

With regards to the weather conditions at the time of the accident (23:30 GMT (00:30 LOCAL TIME)) the METAR and MET-REPORTS of 23:20 GMT and 23:50 GMT respectively, show that in the time period between these two reports, the weather conditions changed from a prevalence of fog-banks with consequent very variable visibility to irradiation fog with homogeneously reduced visibility.

3. INFORMATION AND ASSISTANCE PROVIDED TO THE CREW

On the whole, the weather reports provided to the crew were in compliance with the current International Regulations, although some straying from the established standards gave rise to specific recommendations from the Board of Inquiry. In fact, after confirmation from the crew of flight UGA 775 (22:36:50 GMT) of their awareness of the weather conditions at Fiumicino Airport, Rome Radar gave them RVR values (RVR Recordings refer) that corresponded to the weather conditions at the time during their landing attempts on Runways 16L and 25 respectively. Even during the third Approach (based on a VOR/DME procedure), Rome Radar gave the pilot the RVR values relative to Runway 34L.

In view of the above, the Board of Inquiry considered that, the use of the RVR data for Runway 34L at Fiumicino being limited to Take-Off operations only, as per the AIP Italia, Part MET 0.10 Paragraph 7.2.14.1, was an incorrect application of the afore mentioned I.C.A.O. Regulations which also permits the use of RVR data for landing operations conducted with non precision instruments.

An examination of the RVR Recordings, showed that during this Approach, the Air Traffic Controller provided the pilot with weather conditions that were less favourable than the actual situation (Point Bravo on Runway 34L, 175 metres instead of the actual 2000 metres).

However, at 23:26:04 GMT, just before confirmation from the pilot of being estabilished on the 349° radial of Ostia VOR (9 DME), ACC Rome gave the pilot the following RVR values for Runway 34L: Point Alfa 1600 metres, Point Bravo 2000 metres, Point Charlie 150 metres (which corresponded to the relative recordings) and instructed him to contact Fiumicino Tower, who while authorising the landing of the aircraft (23:28:55 GMT) and providing RVR values (Point Alfa 1500 metres), erroneously used the term "visibility" (normally used with general visibility values) instead of RVR.

With regards to the radar assistance provided to the Ugandan crew, the Board of Inquiry established that the procedures for the initial approach as well as the two radar assisted approaches, were in compliance with the prescribed regulations.

The approach to Runway 34L was regular in the downwind and base legs. The radar vectoring supplied had the aircraft intercepting the 349° radial of Ostia VOR at approximately 9 DME, and the crew confirmed being estabilished on the same radial. The assistance of Rome Radar ceased at 7 miles from touchdown point and Flight UGA 775 was instructed to contact Fiumicino Tower. At approximately 4.5 miles from touchdown (6 DME), in compliance with the prescribed procedures, the aircraft descended from 1500 feet and continued descending beyond the M.D.A. (420 feet) without any confirmed evidence that the crew had located the runway visual markings.

With regards to the radar vectoring supplied, the Board of Inquiry observed that it had the aircraft intercept the final radial two miles nearer to touchdown point, with respect to the prescribed instrumental procedures.

4. FLIGHT MANAGEMENT

A general evaluation regarding the attitude of Flight UGA 775 during the initial approach procedure, as well as the three intermediate approach procedures at Fiumicino airport, shows a repetitive straying from the required standard procedures.

There appears to have been a serious lack of crew coordination, whereby each crew member acted independently without being adequately supervised by the captain. Documentation acquired by the Board of Inquiry, shows a lack of organisation and proper training of the crew and the carrier's Operational Manual appears to be inadequate with respect to the international standards, especially with regards to the specific duties of the crew members during the various phases of flight and standard call-outs.

In fact, an examination of the Radar and Cockpit Voice Recordings revealed that during the precision approach on Runway 16L, the captain decided to attempt the landing in spite of being aware that the RVR values were below their landing minima. M.D.A. The approach on Runway 25, was carried out with the crew being unable to find the proper procedural chart and the aircraft descended below M.D.A., before effecting a go-around.

Even the flight preparation did not appear to be sufficiently adequate since the captain decided to attempt a third approach without being certain of the specific instrumental procedures to follow and under the circumstances, seemed to have adopted the least suitable one.

Because of the existing elements of doubt on the visibility conditions, the landing attempt on Runway 34L should have been avoided and the alternative airport Ciampino, for which a visibility of 5 Km was given, should have been used instead.

The Approach to Runway 34L was undertaken in meteorological conditions that were just barely compatible with a positive outcome and in any case , below the Jeppesen minima adopted by the Company (1600 metres with respect to the prescribed 1800 metres), with a further deterioration in visibility to 1500 metres, during the phase of authorisation to land.

The evidence collected shows a remarkable delay in preparing the configuration of the aircraft as required for the Approach and Landing on Runway 34L, with consequent excessive speed (over 30/40 Kts) with regards to the standard requirements.

A detailed examination of the flight attitude from the initial phase of the third Approach, shows that during the radar vectoring, at approximately 10 n.m. south of the Landing Strip, the captain briefed the crew synthetically on essential data of the standard VOR/DME procedure for Runway 34L, which is as follows:

- 11 n.m. DME 2500 ft.
- Descent and Maintain 1500 ft up to 6 n.m. DME
- Further Descent up to M.D.A. of 420 ft.

The co-pilot was carrying out the functions of PNF and therefore required to call out the respective Altitude Crossings.

Substantially, the captain requested radar vectoring from Air Traffic Control and implicitly accepted a straying from the prescribed instrumental procedures and in fact, the aircraft stabilised at 349° of the Ostia VOR radial at only 9 n.m. DME and 2300 feet. The next Descent to 1500 feet was accomplished in the vicinity of 6 miles DME, after which as foreseen in the procedure, the crew continued a constant descent to M.D.A. The co-pilot only called out the 1500 feet altitude crossing.

After this crossing, the radar recordings show a flight path coherent with the nominal descent path as foreseen in the procedures. even though as previously emphasized. there was a delay in the preparation of the correct configuration of the aircraft. At approximately 2 n.m. VOR/DME, the captain decided to turn over the controls of the aircraft to the Co-pilot. In this delicate phase, close to the M.D.A., strayal from the required operational standards was most evident. In fact up to this moment, the captain who had carried out the functions of PF, asked the Co-pilot to take over the controls of the aircraft, with the intention of resuming command as soon as he had located the Runway Visual Markings.

From this new assignment of crew duties, it is not clear which of the two pilots was responsable for the Instrument Readings and consequent altitude call-outs while approaching M.D.A..

Together with this exchange of duties on board the aircraft, the radar recordings show an accentuated inclination in the aircraft's path and an increase of approximately 1500 ft/min in the Rate of Descent which just before the crash, activated the Ground Proximity Warning System in the SINK-RATE fashion.

The captain's request for altitude readings and the co-pilot's obviously erroneous reply (1500 maintain, etc.) 1.5 seconds before the activation of the G.P.W.S., evidences the fact that none of the crew members were monitoring the Altitude Readings just before impact.

It is the Board of Inquiry's belief that, the captain had not located the Runway Visual Markings (seeing that he had not resumed command as intended).

Nevertheless, they noticed numerous luminous sources along the final approach to

Runway 34L, which in similar situations could create difficulty in singling out and recognising the specific visual aids on the ground (ALS, etc.).

In conclusion, the Board of Inquiry feels that it cannot be excluded that one of the reasons that induced the crew to attempt the third approach, was that they saw the luminous sources on the airport area below, whilst overflying the landing strips after the aborted attempts on Runways 16L and 25, as reported to the local ATC by the captain of Flight BM 1348, who declared that during the Approaches of Flight UGA 775, he was in the area awaiting clearance to land and could see the Runways of Fiumicino Airport clearly.

The difference between the reported visibility situation in Altitude and the one in proximity of the ground during the phases of descent, are naturally to be attributed to the difference in transparency of a stratus of fog when observed vertically (from above) with respect to when observed from the descent path.

5. TECHNICAL ASPECTS

Although the Flight Data Recorder was inoperative and had been so for an unknown period of time, and a copy of the Technical Log Sheet relative to the last flight was unavailable, the examination of the wreck, the testimony of witnesses and the Cockpit Voice Recordings did not evidence any technical problems relative to the airframe. the power-plant or the flight controls.

With regards to the Aircraft Maintenance, evidence was found on the following:

Calender delays in maintenance.

- Uncertainity as to the maintenance methods adopted.
- Uncertainity as to whether the maintenance personnel were certified or not.
- Non standard keeping of the prescribed records.

The last Weight and Balance Report on the aircraft, was unavailable to the Board of Inquiry and therefore they were unable to verify, whether correct data was used to calculate the aircraft's weight and balance before the last Take-Off. Furthermore, it was not possible to determine whether the Ugandan Civil Aviation Authorities had permitted the above mentioned delays in maintenance.

Although the instrumentation on board the aircraft was not of the latest type, the configuration was in compliance with the required international standards for that aircraft type. Moreover, the Radio Altimeter was equipped with a single Indicator situated on the central panel and was not duplicated on either of the pilot's panels. There was only one Visual Indicator for the Decision Height Warning, since the Acoustic Warning System was inoperative and had been declared so, by the previous owner at the time of purchase by Uganda Airlines.

Although this situation was accepted by the Ugandan Civil Aviation Authorities and is not incompatible with the Italian Regulations, it did not prove sufficiently suitable to the purpose of drawing the crew's attention, during the critical phase of the probably inadvertent crossing of the M.D.A..

Furthermore, the Co-pilot's obviously erroneous reply to the captain's request for an Altitude Reading a few moments prior to impact, induced the Board of Inquiry to have the respective manufacturers execute specific laboratory tests on the instruments. The results are as follows:

(a) The Altimeter on the pilot's side was probably operative until the moment of impact.

(b) No useful information emerged with regards to the Altimeter on the co-pilot's side.

(c) The Radio Altimeter was found inoperative due to a failure which, from an evaluation of the available information, originated in all probability from stress caused by the impact.

(d) There was no evidence of malfunction in the ADCs.

In parallel with the tests conducted on the instruments, the Board of Inquiry elaborated a study with the purpose of evidencing possible anomalies in the previously specified equipment.

Starting with information from the Cockpit Voice Recordings (Altitude Call-outs, Ground Proximity Warnings, Glide Indications, Markers, Etc.) and the Multi-Radar Tracking on recordings of the *Air Plot as well as Ground Speed Print Outs.*

The results of this study did not evidence any malfunction of the equipment that could have induced the co-pilot to call out an erroneous Altitude Reading.

Furthermore, in view of the information from the Radar and Cockpit Voice Recordings, the fact that both the VOR/NAV Instruments were found with erroneous radial selections, could reasonably be attributed to mechanical stress due to the impact.

CONCLUSIONS

1. FINDINGS

The following was verified by the Board of Inquiry:

(a) A copy of the aircraft's Certificate of Airworthiness, produced by the Ugandan Authorities, resulted valid.

(b) The crew possessed valid licences and necessary qualifications as prescribed, for piloting the aircraft.

(c) The Air Traffic Controllers on duty were properly qualified.

(d) The crew had had a sufficient period of rest.

(e) There is no evidence of technical problems concerning the airframe, powerplant, flight controls and on-board instrumentation, except as indicated in points (l) and (m).

(f) The Air/Ground/Air communications were carried out in a regular manner and without difficulty.

(g) The Navigation and Approach Systems in use at the Rome Fiumicino Airport, were available and in function, with the exception of the VASIS for Runway 34L which was awaiting flight testing and the runway centre line which was inoperative.

(h) Since the Flight Data Recorder had been unservicable for a period of time that was not possible to ascertain, it did not record the parameters of Flight UGA 775.

(i) The meteorological conditions at Fiumicino Airport at the time of the accident, were characterised by formations of fog-banks with unexpected changes in the horizontal visibility which maintained low values and were generally lower than the operators minima.

(l) The instrumentation on board was only just in compliance with the required international standards for the aircraft type. In particular the DH/MDH Acoustic Warning of the Radio Altimeter was inoperative since the time the aircraft was purchased by Uganda Airlines and only one visual warning indicator was installed on the central panel without being duplicated on either of the pilot's panels.

(m) The Altitude Alert had been inoperative for approximately four months. In spite of repeated requests from the Board of Inquiry, the Ugandan Authorities were unable to produce a copy of the Minimum Equipment List and therefore it was impossible to verify if the above mentioned failure was allowable by the prescribed standards of the Ugandan C.A.A..

(n) The maintenance procedures applied evidenced calender delays, uncertainity as to the maintenance methods adopted and uncertainity as to whether the maintenance personnel were certified or not

(o) There was a remarkable delay on the part of the crew, in preparing the aircraft's configuration for Landing on Runway 34L, with a consequent delay in the activation of the flaps and an excessive landing speed 30/40 Kts higher than the standard.

(p) At approximately 7 miles from touchdown the pilot confirmed to ACC Rome of being established on the 349° radial of Ostia VOR; at approximately 4.5 miles from touchdown and at an altitude of 1500 feet, the captain advised that approach was being continued and subsequently the aircraft proceeded to descend even beyond the M.D.A. (420 feet), without any confirmed evidence that the crew had located the necessary runway visual markings and with a complete absence of the indispensable altitude call-outs.

(q) At approximately 20 seconds before the accident in the proximity of the M.D.A., the captain turned over the controls of the aircraft to the Co-pilot, with the intention of locating the runway visual markings and resuming command as soon as he had achieved his purpose.

(r) The first impact occurred in dense fog with the roof of a house 9.52 metres high (11.4 metres s.l.) situated at approximately 1300 metres from the threshold of Runway 34L and about 100 metres to the right with respect to the runway extension's Centre Line.

(s) Of the 52 people aboard the aircraft 19 survived. For the others, including the crew members, death was more or less instantaneous due to severe multiple injuries to the body, with the exception of three of the victims that expired after being hospitalised. One due to severe head injuries and the other two due to complications deriving from second and third degree burns, caused by the fire that generated after the impact of the aircraft.

2. POSSIBLE CAUSES

The Board of Inquiry believes that the probable cause of the accident was the crew's lack of adequate preparation in the procedure for a Non Precision Approach on Runway 34L at Fiumicino Airport, especially in the matter of crew coordination and altitude call-outs and their continued descent beyond the M.D.A. without having located the runway visual markings.

Besides, the following factors may have contributed to the cause of the accident:

- Presumed mental and physical fatigue, accumulated by the crew during the two previous landing approaches, which were also carried out in an enviromental situation that was extremely unfavourable and operationally demanding.
- A configuration of the Altitude Instruments, which although sufficient for the approaches that were carried out, consisted of a single radio altimeter with the acoustic warning of the M.D.A. crossing inoperative.

The attention of the crew was excessively concentrated on the luminuous sources along Runway 34L, instead of on the instrument readings.

Furthermore, as integrally reported in Appendix 1, part of the Board of Inquiry as well as the representative of the Ugandan Civil Aviation Authorities, disassociated themselves from the majority, during the phase of indentifying the factors that may have contributed to causing the accident.

SAFETY RECOMMENDATIONS

1. TO THE COMPETENT AIRWORTHINESS AUTHORITIES

(a) It is strongly urged that proper control be exercised on Air Transport Operators to adopt correct training methods for their crews and especially with regards to the following factors:

- Favouring of aspects relative to operational safety rather than those of a commercial nature.
- Ensure that crew personnel, that have been improperly trained and/or have not undergone the required check-outs by the airline company, do not fly.

(b) The strictest vigilance on Air Transport Operators is urged. so that they:

- Respect maintenance expiry dates, even through the use of modern computerised instruments to keep records of the maintenance operations carried out and the ones to be carried out.

- Ensure that eventual malfunctions of operational instruments relative to Airworthiness, be rectified in the shortest possible time, even if temporarily considered acceptable.

(c) With regards to minimum on-board equipment, it is strongly urged that action be taken, to amend the current regulations so that the configuration of altitude equipment on commercial aircraft, include at least two radio altimeters and an acoustic warning of the DH/MDH crossing.

(d) It is recommended that action be taken, so that the installation on board commercial aircraft, of Flight Data Recorders equipped with proper warning systems of eventual malfunctions, becomes a mandatory requirement.

2. TO THE AIRLINE COMPANIES

(a) It is recommended that Company Operating Manuals, be properly updated in matters concerning crew co-ordination and altitude call-outs especially for non-precision approaches for which, the standard adopted by the major international companies are, that the PNF monitors the instruments until the landing and calls out the altitudes every 100 feet and at the M.D.A., while the PF looks outside to locate the visual runway references.

(b) It is recommended that flight crews be properly trained, in order to ensure that the following matters are complied with:

- Before each flight, all essential information regarding the infrastructures available at the airports of departure. arrival and alternative airports and the relative operational procedures, should be acquired.
- The Company's procedural minima with regards to the various landings along the route, should be rigorously respected.
- The incorporation of rules in the Company's Operating Manual that guarantee a change of course to an alternative airport, in the event of two missed approaches.
- The requirement of standard altitude call-outs, essential to operational safety during the various phases of flight, is strictly respected.

(c) It is recommended that maintenance operations not be deferred and that the methods used and the qualifications of the maintenance personnel be properly recorded.

3. TO THE DEPARTMENT OF AIR TRAFFIC CONTROL

(a) It is recommended that proper action be taken to ensure that the Air Traffic Controllers, while giving meteorological information, strictly keep to the use of standard phraseology.

(b) It is recommended that the directives published in the AIP-ITALIA, Part MET-010, paragraph 7.2.14.1, are updated to concord with the current I.C.A.O. Regulations.

(c) The promotion in every possible circumstance, of encounters between Air Traffic Controllers and Pilots is recommended, in order for them to develop a clearer understanding of their respective needs, with the purpose of constantly improving the current procedures and increasing the levels of operational safety.

(d) It is recommended that every possible initiative towards the improvement in handling situations of unusual operations and emergencies, is emphasized during the training of Air Traffic Personnel.

4. THE ITALIAN MINISTRY OF TRANSPORT

(a) It is recommended that proper action be taken, so that the competent departments ensure the application of the recommendations in I.C.A.O. Annex 14, paragraph 5.3.1, with regards to non-aeronautical luminous sources in the vicinity of airports.

(b) Whilst awaiting the adoption of the above recommendations, it is urged that the procedural charts for the Final Approach Leg, on Fiumicino's Runway 34L, be updated by emphasizing the possibility of potential confusion in differentiating the aeronautical lighting from the other luminuous sources in the area.

(c) It is urged that action be taken to ensure that the runway extensions are free of obstacles and easily accessible by rescue teams, thereby permitting a correct application of the recommendations in the I.C.A.O. Annex 14, paragraph 9.2.20.

(d) It is urged that action be taken to ensure that airport personnel responsable for alerts, co-ordination and intervention in situation of emergencies and/or accidents. undergo proper and continuous training to enable them to acquire familiarity with the airport infrastructures and the access to critical areas outside the airport.

(e) The creation of a properly equipped and supervised government department, with highly specialised and trained personnel that function exclusively as investigators during inquiries into accidents and near accidents of aircraft.

ICAO Note.— Names of personnel were deleted.

ICAO Ref.: 254/88

No. 6

Boeing 747-121, N739PA, accident at Lockerbie, Scotland on 21 December 1988. Report 2/90 released by the Air Accidents Investigation Branch, United Kingdom.

SYNOPSIS

The accident was notified to the Air Accidents Investigation Branch at 19.40 hrs on the 21 December 1988 and the investigation commenced that day. The members of the AAIB team are listed at Appendix A.

The aircraft, Flight PA103 from London Heathrow to New York, had been in level cruising flight at flight level 310 (31,000 feet) for approximately seven minutes when the last secondary radar return was received just before 19.03 hrs. The radar then showed multiple primary returns fanning out downwind. Major portions of the wreckage of the aircraft fell on the town of Lockerbie with other large parts landing in the countryside to the east of the town. Lighter debris from the aircraft was strewn along two trails, the longest of which extended some 130 kilometres to the east coast of England. Within a few days items of wreckage were retrieved upon which forensic scientists found conclusive evidence of a detonating high explosive. The airport security and criminal aspects of the accident are the subject of a separate investigation and are not covered in this report which concentrates on the technical aspects of the disintegration of the aircraft.

The report concludes that the detonation of an improvised explosive device led directly to the destruction of the aircraft with the loss of all 259 persons on board and 11 of the residents of the town of Lockerbie. Five recommendations are made of which four concern flight

recorders, including the funding of a study to devise methods of recording violent positive and negative pressure pulses associated with explosions. The final recommendation is that Airworthiness Authorities and aircraft manufacturers undertake a systematic study with a view to identifying measures that might mitigate the effects of explosive devices and improve the tolerance of the aircraft's structure and systems to explosive damage.

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 pasengers 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 turnround, 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.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	16	243	11
Serious	-	-	2
Minor/None	-	-	3

1.3 Damage to aircraft

The aircraft was destroyed

1.4 Other damage

The wings impacted at the southern edge of Lockerbie, producing a crater whose volume, calculated from a photogrammetric survey, was approximately 560 cubic metres. The weight of material displaced by the wing impact was estimated to be well in excess of 1500 tonnes. The wing impact created a fireball, setting fire to neighbouring houses and carrying aloft debris which was then blown downwind for several miles. It was subsequently established that domestic properties had been so seriously damaged as a result of fire and/or impact that 21 had to be demolished and an even greater number of homes required substantial repairs. Major portions of the aircraft, including the engines, also landed on the town of Lockerbie and other large parts, including the flight deck and forward fuselage section, landed in the countryside to the east of the town. Lighter debris from the aircraft was strewn as far as the east coast of England over a distance of 130 kilometres.

1.5 Personnel information

1.5.1 Commander: Male, aged 55 years

Licence: USA Airline Transport Pilot's Licence

Aircraft ratings: Boeing 747, Boeing 707, Boeing 720, Lockheed L1011 and Douglas DC3

Medical Certificate: Class 1,valid to April 1989, with the limitation that the holder shall wear lenses that correct for distant vision and possess glasses that correct for near vision

	Flying experience:	Total all types: 10,910 hours Total on type: 4,107 hours Total last 28 days: 82 hours
	Duty time:	Commensurate with company requirements
	Last base check: Last route check: Last emergencies check:	11 November 1988 30 June 1988 8 November 1988
1.5.2	Co-pilot:	Male, aged 52 years
	Licence:	USA Airline Transport Pilot's Licence
	Aircraft ratings:	Boeing 747, Boeing 707, Boeing 727
	Medical Certificate:	Class 1, valid to April 1989, with the limitation that the holder shall possess correcting glasses for near vision
	Flying experience:	Total all types: 11,855 hours Total on type: 5,517 hours Total last 28 days: 51 hours
	Duty time:	Commensurate with company requirements
	Last base check: Last route check: Last emergencies check:	30 November 1988 Not required 27 November 1988
1.5.3	Flight Engineer:	Male, aged 46 years
	Licence:	USA Flight Engineer's Licence
	Aircraft ratings:	Turbojet
	Medical certificate:	Class 2, valid to June 1989, with the limitation that the holder shall wear correcting glasses for near vision

Flying experience:	Total all types:	8,068 hours
	Total on type:	487 hours
	Total last 28 days:	53 hours

Duty time: Commensurate with company requirements

Last base check: 30 October 1988
Last route check: Not required
Last emergencies check: 27 October 1988

1.5.4 Flight Attendants: There were 13 Flight Attendants on the aircraft, all of whom met company proficiency and medical requirements

1.6 Aircraft information

1.6.1 Leading particulars

Aircraft type: Boeing 747-121

Constructor's serial number: 19646

Engines: 4 Pratt and Whitney JT9D-7A turbofan

1.6.2 General description

The Boeing 747 aircraft, registration N739PA, was a conventionally designed long range transport aeroplane. A diagram showing the general arrangement is shown at Appendix B, Figure B-1 together with the principal dimensions of the aircraft.

The fuselage of the aircraft type was of approximately circular section over most of its length, with the forward fuselage having a diameter of 21¼ feet where the cross-section was constant. The pressurised section of the fuselage (which included the forward and aft cargo holds) had an overall length of 190 feet, extending from the nose to a point just forward of the tailplane. In normal cruising flight the service pressure differential was at the miximum value of 8.9 pounds per square inch. The fuselage was of conventional skin, stringer and frame construction, riveted throughout, generally using countersunk flush riveting for the skin panels. The fuselage frames were spaced at 20 inch intervals and given the same numbers as their stations, defined in terms of the distance in inches from the datum point close to the nose of the aircraft [Appendix B, Figure B-2]. The skin panels were joined using vertical butt joints and horizontal lap joints. The horizontal lap joints used three rows of rivets together with a cold bonded adhesive.

Accommodation within the aircraft was predominately on the main deck, which extended throughout the whole length of the pressurised compartment. A separate upper deck was incorporated in the forward part of the aircraft. This upper deck was reached by means of a spiral staircase from the main deck and incorporated the flight crew compartment together with additional passenger accommodation. The cross-section of the forward fuselage differed considerably from the near circular section of the remainder of the aircraft, incorporating an additional smaller radius arc above the upper deck section joined to the main circular arc of the lower cabin portion by elements of straight fuselage frames and flat skin.

In order to preserve the correct shape of the aircraft under pressurisation loading, the straight portions of the fuselage frames in the region of the upper deck floor and above it were required to be much stiffer than the frame portions lower down in the aircraft. These straight sections were therefore of very much more substantial construction than most of the curved sections of frames lower down and further back in the fuselage. There was considerable variation in the gauge of the fuselage skin at various locations in the forward fuselage of the aircraft.

The fuselage structure of N739PA differed from that of the majority of Boeing 747 aircraft in that it had been modified to carry special purpose freight containers on the main deck, in place of seats. This was known as the Civil Reserve Air Fleet (CRAF) modification and enabled the aircraft to be quickly converted for carriage of military freight containers on the main deck during times of national emergency. The effect of this modification on the structure of the fuselage was mainly to replace the existing main deck floor beams with beams of more substantial cross-section than those generally found in passenger carrying Boeing 747 aircraft. A large side loading door, generally known as the CRAF door, was also incorporated on the left side of the main deck aft of the wing.

Below the main deck, in common with other Boeing 747 aircraft, were a number of additional compartments, the largest of which were the forward and aft freight holds used for the storage of cargo and baggage in standard air-transportable containers. These containers were placed within the aircraft hold by means of a freight handling system and were carried on a system of rails approximately 2 feet above the outer skin at the bottom of the aircraft, there being no continuous floor.

as such, below these baggage containers. The forward freight compartment had a length of approximately 40 feet and a depth of approximately 6 feet. The containers were loaded into the forward hold through a large cargo door on the right side of the aircraft.

1.6.3 Internal fuselage cavities

Because of the conventional skin, frame and stringer type of construction, common to all large public transport aircraft, the fuselage was effectively divided into a series of 'bays'. Each bay, comprising two adjacent fuselage frames and the structure between them, provided, in effect, a series of interlinking cavities bounded by the frames, floor beams, fuselage skins and cabin floor panels etc. The principal cavities thus formed were:

(i) A semi-circular cavity formed in between the fuselage frames in the lower lobe of the hull, i.e. from the crease beam (at cabin floor level) on one side down to the belly beneath the containers and up to the opposite crease beam, bounded by the fuselage skin on the outside and the containers/cargo liner on the inside [Appendix B, Figure B-3, detail A].

(ii) A horizontal cavity between the main cabin floor beams, the cabin floor panels and the cargo bay liner. This extended the full width of the fuselage and linked the upper ends of the lower lobe cavity [Appendix B, Figure B-3, detail B].

(iii) A narrow vertical cavity between the two containers [Appendix B, Figure B-3, detail C].

(iv) A further narrow cavity around the outside of the two containers, between the container skins and the cargo bay liner, communicating with the lower lobe cavity [Appendix B, Figure B-3, detail D].

(v) A continuation of the semi-circular cavity into the space behind the cabin wall liner [Appendix B, Figure B-3, detail E]. This space was restricted somewhat by the presence of the window assembly, but nevertheless provided a continuous cavity extending upwards to the level of the upper deck floor. Forward of station 740, this cavity was effectively terminated at its upper end by the presence of diaphragms which formed extensions of the upper deck floor panels; aft of station 740, the cavity communicated with the ceiling space and the cavity in the fuselage crown aft of the upper deck.

All of these cavities were repeated at each fuselage bay (formed between pairs of fuselage frames), and all of the cavities in a given bay were linked together, principally at the crease beam area [Appendix B, Figure B-3, region F]. Furthermore, each of the set of bay cavities was linked with the next by the longitudinal cavities formed between the cargo hold liner and the outer hull, just below the crease beam [Appendix B, Figure B-3, detail F]; i.e. this cavity formed a manifold linking together each of the bays within the cargo hold.

The main passenger cabin formed a large chamber which communicated directly with each of the sub floor bays, and also with the longitudinal manifold cavity, via the air conditioning and cabin/cargo bay de-pressurisation vent passages in the crease beam area. (It should be noted that a similar communication did not exist between the upper and lower cabins because there were no air conditioning/depressurisation passages to bypass the upper deck floor.)

1.6.4 Aircraft weight and centre of gravity

The aircraft was loaded within its permitted centre of gravity limits as follows:

Loading:	lb	kg
Operating empty weight	366,228	166,120
Additional crew	130	59
243 passengers (1)	40,324	18,291
Load in compartments:		
1	11,616	5,269
2	20,039	9,090
3	15,057	6,830
4	17,196	7,800
5	2,544	1,154
Total in compartments (2)	66,452	30,143
Total traffic load	106,776	48,434
Zero fuel weight	472,156	214,554
Fuel (Take-off)	239,997	108,862
Actual take-off weight(4)	713,002	323,416
Maximum take-off weight	733,992	332,937

Note 1: Calculated at standard weights and including cabin baggage.

Note 2: Despatch information stated that the cargo did not include dangerous goods, perishable cargo, live animals or known security exceptions.

1.6.5 Maintenance details

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:

DATE	SERVICE	HOURS	CYCLES
27 Sept 88	C Check (Interior upgrade)	71,502	16,347
2 Nov 88	B Service Check	71,919	16,406
27 Nov 88	Base 1	72,210	16,454
13 Dec 88	Base 2	72,374	16,481

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).

SB 53-2088	Frame to Tension Tie Joint Modification - BS760 to 780.
	Repetitive inspection IAW AD 84-19-01 last accomplished on 19 June 1985 at 60,153 hours TAT and 14,436 TAC.
SB 53-2200	Lower Cargo Doorway Lower Sill Truss and Latch Support Fitting Inspection Repair and Replacement.
	Repetitive inspection IAW AD 79-17-02 R2 last accomplished 2 November 1988 at 71,919 hours TAT and 16,406 TAC.
SB 53-2234	Fuselage - Auxiliary Structure - Main Deck Floor - BS 480 Floor Beam Upper Chord Modification.
	Repetitive inspection per SB 53A2263 IAW AD 86-23-06 last accomplished on 26 September 1987 at 67,376 hours TAT and 15,680 TAC.
SB 53-2237	Fuselage - Main Frame - BS 540 thru 760 and 1820 thru 1900 Frame Inspection and Reinforcement.
	Repetitive inspection IAW AD 86-18-01 last accomplished on 27 February 1987 at 67,088 hours TAT and 15,627 TAC.
SB 53-2267	Fuselage - Skin - Lower Body Longitudinal Skin Lap Joint and Adjacent Body Frame Inspection and Repair.
	Terminating modification accomplished 100% under wing-to-body fairings and approximately 80% in forward and aft fuselage sections on 26 September 1987 at 67,376 hours TAT and 15,680 TAC.
	Repetitive inspection of unmodified lap joints IAW AD 86-09-07 R1 last accomplished on 18 August 1988 at 71,043 hours TAT and 16,273 TAC.
SB 53A2303	Fuselage - Nose Section - station 400 to 520 Stringer 6 Skin Lap Splice Inspection, Repair and Modification.
	Repetitive inspection IAW AD 89-05-03 last accomplished on 26 September 1987 at 67,376 hours TAT and 15,680 TAC.

This documentation, when viewed together with the detailed content of the above service bulletins, shows the aircraft to have been in compliance with the requirements laid down in each of those bulletins. Some maintenance items were outstanding at the time the aircraft was despatched on the last flight, however, none of these items relate to the structure of the aircraft and none had any relevance to the accident.

1.7 *Meteorological Information*

1.7.1 General weather conditions

An aftercast of the general weather conditions in the area of Lockerbie at about 19.00 hrs was obtained from the Meteorological Office, Bracknell. The synoptic situation included a warm sector covering northern England and most of Scotland with a cold front some 200 nautical miles to the west of the area moving eastwards at about 35 knots. The weather consisted of intermittent rain or showers. The cloud consisted of 4 to 6 oktas of stratocumulus based at 2,200 feet with 2 oktas of altocumulus between 15,000 and 18,000 feet. Visibility was over 15 kilometers and the freezing level was at 8,500 feet with a sub-zero layer between 4,000 and 5,200 feet.

1.7.2 Winds

There was a weakening jet stream of around 115 knots above Flight Level 310. From examination of the wind profile (see below), there appeared to be insufficient shear both vertically and horizontally to produce any clear air turbulence but there may have been some light turbulence.

Flight Level	Wind
320	260°/115 knots
300	260°/ 90 knots
240	250°/ 80 knots
180	260°/ 60 knots
100	250°/ 60 knots
050	260°/ 40 knots
Surface	240°/ 15 to 20 gusting 25 to 30 knots

1.8 Aids to navigation

Not relevant.

1.9 Communications

The aircraft communicated normally on London Heathrow aerodrome, London control and Scottish control frequencies. Tape recordings and transcripts of all radio telephone (RTF) communications on these frequencies were available.

At 18.58 hrs the aircraft established two-way radio contact with Shanwick Oceanic Area Control on frequency 123.95 MHz. At 19.02:44 hrs the clearance delivery officer at Shanwick transmitted to the aircraft its oceanic route clearance. The aircraft did not acknowledge this message and made no subsequent transmission.

1.9.1 ATC recording replay

Scottish Air Traffic Control provided copy tapes with time injection for both Shanwick and Scottish ATC frequencies. The source of the time injection on the tapes was derived from the British Telecom "TIM" signal.

The tapes were replayed and the time signals corrected for errors at the time of the tape mounting.

1.9.2 Analysis of ATC tape recordings

From the cockpit voice recorder (CVR) tape it was known that Shanwick was transmitting Flight PA103's transatlantic clearance when the CVR stopped. By synchronising the Shanwick tape and the CVR it was possible to establish that a loud sound was heard on the CVR cockpit area microphone (CAM) channel at 19.02:50 hrs ±1 second.

As the Shanwick controller continued to transmit Flight PA103's clearance instructions through the initial destruction of the aircraft it would not have been possible for a distress call to be received from N739PA on the Shanwick frequency. The Scottish frequency tape recording was listened to from 19.02 hrs until 19.05 hrs for any unexplained sounds indicating an attempt at a distress call but none was heard.

A detailed examination and analysis of the ATC recording together with the flight recorder, radar, and seismic recordings is contained in Appendix C.

1.10 Aerodrome information

Not relevant

1.11 Flight recorders

The Digital Flight Data Recorder (DFDR) and the Cockpit Voice Recorder (CVR) were found close together at UK Ordnance Survey (OS) Grid Reference 146819, just to the east of Lockerbie, and recovered approximately 15 hours after the accident. Both recorders were taken directly to AAIB Farnborough for replay. Details of the examination and analysis of the flight recorders together with the radar, ATC and seismic recordings are contained in Appendix C.

1.11.1 Digital flight data recorder

The flight data recorder installation conformed to ARINC 573B standard with a Lockheed Model 209 DFDR receiving data from a Teledyne Controls Flight Data Acquisition Unit (FDAU). The system recorded 22 parameters and 27 discrete (event) parameters. The flight recorder control panel was located in the flight deck overhead panel. The FDAU was in the main equipment centre at the front end of the forward hold and the flight recorder was mounted in the aft equipment centre.

Decoding and reduction of the data from the accident flight showed that no abnormal behaviour of the data sensors had been recorded and that the recorder had simply stopped at 19.02:50 hrs ±1 second.

1.11.2 Cockpit voice recorder

The aircraft was equipped with a 30 minute duration 4 track Fairchild Model A100 CVR, and a Fairchild model A152 cockpit area microphone (CAM). The CVR control panel containing the CAM was located in the overhead panel on the flight deck and the recorder itself was mounted in the aft equipment centre.

The channel allocation was as follows:-

Channel 1	Flight Engineer's RTF.
Channel 2	Co-Pilot's RTF.
Channel 3	Pilot's RTF.
Channel 4	Cockpit Area Microphone.

The erase facility within the CVR was not functioning satisfactorily and low level communications from earlier recordings were audible on the RTF channels. The

CAM channel was particularly noisy, probably due to the combination of the inherently noisy flight deck of the B747-100 in the climb and distortion from the incomplete erasure of the previous recordings. On two occasions the crew had difficulty understanding ATC, possibly indicating high flight deck noise levels. There was a low frequency sound present at irregular intervals on the CAM track but the source of this sound could not be identified and could have been of either acoustic or electrical origin.

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.

1.12 Wreckage and impact information

1.12.1 General distribution of wreckage in the field

The complete wing primary structure, incorporating the centre section, impacted at the southern edge of Lockerbie. Major portions of the aircraft, including the engines, also landed in the town. Large portions of the aircraft fell in the countryside to the east of the town and lighter debris was strewn to the east as far as the North Sea. The wreckage was distributed in two trails which became known as the northern and southern trails respectively and these are shown in Appendix B, Figure B-4. A computer database of approximately 1200 significant items of wreckage was compiled and included a brief description of each item and the location where it was found

Appendix B, Figures B-5 to B-8 shows photographs of a model of the aircraft on which the fracture lines forming the boundaries of the separate items of structure have been marked. The model is colour coded to illustrate the way in which the wreckage was distributed between the town of Lockerbie and the northern and southern trails.

1.12.1.1 The crater

The aircraft wing impacted in the Sherwood Crescent area of the town leaving a crater approximately 47 metres (155 feet) long with a volume calculated to be 560 cubic metres.

The projected distance, measured parallel from one leading edge to the other wing tip, of the Boeing 747-100 was approximately 143 feet, whereas the span is known to be 196 feet. This suggests that impact took place with the wing structure yawed. Although the depth of the crater varied from one end to the other, its widest part was clearly towards the western end suggesting that the wing structure impacted whilst orientated with its root and centre section to the west.

The work carried out at the main crater was limited to assessing the general nature of its contents. The total absence of debris from the wing primary structure found remote from the crater confirmed the initial impression that the complete wing box structure had been present at the main impact.

The items of wreckage recovered from or near the crater are coloured grey on the model at Appendix B, Figures B-5 to B-8.

1.12.1.2 The Rosebank Crescent site

A 60 feet long section of fuselage between frame 1241 (the rear spar attachment) and frame 1960 (level with the rear edge of the CRAF cargo door) fell into a housing estate at Rosebank Crescent, just over 600 metres from the crater. This section of the fuselage was that situated immediately aft of the wing, and adjoined the wing and fuselage remains which produced the crater. It is colour coded yellow on the model at Appendix B, Figures B-5 to B-8. All fuselage skin structure above floor level was missing except for the following items:

Section containing 3 windows between door 4L and CRAF door;
The CRAF door itself (latched) apart from the top area containing the hinge;
Window belt containing 8 windows aft of 4R door aperture
Window belt containing 3 windows forward of 4R door aperture;
Door 4R.

Other items found in the wreckage included both body landing gears, the right wing landing gear, the left and right landing gear support beams and the cargo door (frames 1800-1920) which was latched. A number of pallets, luggage containers and their contents were also recovered from this site.

1.12.1.3 Forward fuselage and flight deck section.

The complete fuselage forward of approximately station 480 (left side) to station 380 (right side) and incorporating the flight deck and nose landing gear was found as a single piece [Appendix B, Figure B-9] in a field approximately 4 km miles east of Lockerbie at OS Grid Reference 174808. It was evident from the nature of the impact damage and the ground marks that it had fallen almost flat on its left side but with a slight nose-down attitude and with no discernible horizontal velocity. The impact had caused almost complete crushing of the structure on the left side. The radome and right nose landing gear door had detached in the air and were recovered in the southern trail.

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-eliptical 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.

The status of the controls and switches on the flight deck was consistent with normal operation in cruising flight. There were no indications that the crew had attempted to react to rapid decompression or loss of control or that any emergency preparations had been actioned prior to the catastrophic disintegration.

1.12.1.4 Northern trail

The northern trail was seen to be narrow and clearly defined, to emanate from a point very close to the main impact crater and to be orientated in a direction which agreed closely with the mean wind aftercast for the height band from sea level to 20,000 ft. Also at the western end of the northern trail were the lower rear fuselage at Rosebank Crescent, and the group of Nos. 1, 2 and 4 engines which fell in Lockerbie.

The trail contained items of structure distributed throughout its length, from the area slightly east of the crater, to a point approximately 16 km east, beyond which only items of low weight / high drag such as insulation, interior trim, paper etc, were found. For all practical purposes this trail ended at a range of 25 km.

The northern trail contained mainly wreckage from the rear fuselage, fin and the inner regions of both tailplanes together with structure and skin from the upper half of the fuselage forward to approximately the wing mid-chord position. A number of items from the wing were also found in the northern trail, including all 3 starboard Kreuger flaps, most of the remains of the port Kreuger flaps together with sections of their leading edge attachment structures, one portion of outboard aileron approximately 10 feet long, the aft ends of the flap-track fairings (one with a slide raft wrapped around it), and fragments of glass reinforced plastic honeycombe structure believed to be from the flap system, i.e. fore-flaps, aft-flaps, mid-flaps or adjacent fairings. In addition, a number of pieces of the engine cowlings and both HF antennae (situated projecting aft from the wing-tips) were found in this trail.

All items recovered from the northern trail, with the exception of the wing, engines, and lower rear fuselage in Rosebank Crescent, are coloured red on the model of the aircraft in Appendix B, Figures B-5 to B-8.

1.12.1.5 *Southern trail*

The southern trail was easily defined, except within 12 km of Lockerbie where it tended to merge with the northern trail. Further east, it extended across southern Scotland and northern England, essentially in a straight band as far as the North Sea. Most of the significant items of wreckage were found in this trail within a range of 30 km from the main impact crater. Items recovered from the southern trail are coloured green on the model of the aircraft at Appendix B, Figures B-5 to B-8.

The trail contained numerous large items from the forward fuselage. The flight deck and nose of the aircraft fell in the curved part of this trail close to Lockerbie. Fragments of the whole of the left tailplane and the outboard portion of the right tailplane were distributed almost entirely throughout the southern trail. Between 21 and 27 km east of the main impact point (either side of Langholm) substantial sections of tailplane skin were found, some bearing distinctive signs of contact with debris moving outwards and backwards relative to the fuselage. Also found in this area were numerous isolated sections of fuselage frame, clearly originating from the crown region above the forward upper deck.

1.12.1.6 Datum line

All grid references relating to items bearing actual explosive evidence, together with those attached to heavily distorted items found to originate immediately adjacent to them on the structure, were plotted on an Ordanance Survey (OS) chart. These references, 11 in total, were all found to be distributed evenly about about a mean line orientated 079°(Grid) within the southern trail and were spread over a distance of 12 km. The distance of each reference from the line was measured in a direction parallel to the aircraft's track and all were found to be within 500 metres of the line, with 50% of them being within 250 metres of the line. This line is referred to as the datum line and is shown in Appendix B, Figure B-4.

1.12.1.7 Distribution of wreckage within the southern trail

North of the datum line and parallel to it were drawn a series of lines at distances of 250, 300, 600 and 900 metres respectively from the line, again measured in a direction parallel to the aircraft's track. The positions on the aircraft structure of specific items of wreckage, for which grid references were known with a high degree of confidence, within the bands formed between these lines, are shown in Appendix B, Figures B-10 to 13. In addition, a separate assessment of the grid references of tailplane and elevator wreckage established that these items were distributed evenly about the 600 metre line.

1.12.1.8 Area between trails

Immediately east of the crater, the southern trail converged with the northern trail such that, to an easterly distance of approximately 5 km, considerable wreckage existed which could have formed part of either trail. Further east, between 6 and 11 km from the crater, a small number of sections and fragments of the fin had fallen outside the southern boundary of the northern trail. Beyond this a large area existed between the trails in which there was no wreckage.

1.12.2 Examination of wreckage at CAD Longtown

The debris from all areas was recovered by the Royal Air Force to the Army Central Ammunition Depot Longtown, about 20 miles from Lockerbie. Approximately 90% of the hull wreckage was successfully recovered, identified, and laid out on the floor in a two-dimensional reconstruction [Appendix B, Figure B-14]. Baggage container material was incorporated into a full three-dimensional reconstruction. Items of wreckage added to the reconstructions was given a reference number and recorded on a computer database together with a brief description of the item and the location where it was found.

1.12.2.1 Fuselage

The reconstruction revealed the presence of damage consistent with an explosion on the lower fuselage left side in the forward cargo bay area. A small region of structure bounded approximately by frames 700 & 720 and stringers 38L & 40L, had clearly been shattered and blasted through by material exhausting directly from an explosion centred immediately inboard of this location. The material from this area, hereafter referred to as the 'shatter zone', was mostly reduced to very small fragments, only a few of which were recovered, including a strip of two skins [Appendix B, Figure B-15] forming part of the lap joint at the stringer 39L position.

Surrounding the shatter zone were a series of much larger panels of torn fuselage 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 of the shatter zone, displayed evidence of more typical overload tearing, though some tears appeared to be rapid and, in the area below the missing panels, were multi-branched. These surrounding skin panels were moderately sooted in the regions adjacent to the shatter zone, but otherwise were lightly sooted or free of soot altogether. (Forensic analysis of the soot deposits on frame and skin material from this area confirmed the presence of explosive residues.) All of these skin panels had pulled away from the supporting structure and had been bent and torn in a manner which indicated that, as well as fracturing in the star burst pattern, they had also petalled outwards producing characteristic, tight curling of the sheet material.

Sections of frames 700 and 720 from the area of the explosion were also recovered and identified. Attached to frame 720 were the remnants of a section of the aluminium baggage container (side) guide rail, which was heavily distorted and displayed deep pitting together with very heavy sooting, indicating that it had been very close to the explosive charge. The pattern of distortion and damage on the frames and guide rail segment matched the overall pattern of damage observed on the skins.

The remainder of the structure forming the cargo deck and lower hull was, generally, more randomly distorted and did not display the clear indications of explosive processes which were evident on the skin panels and frames nearer the focus of the explosion. Nevertheless, the overall pattern of damage was consistent with the propagation of explosive pressure fronts away from the focal area inboard of the shatter zone. This was particularly evident in the fracture and bending characteristics of several of the fuselage frames ahead of, and behind station 700.

The whole of the two-dimensional fuselage reconstruction was examined for general evidence of the mode of disintegration and for signs of localised damage, including overpressure damage and pre-existing damage such as corrosion or fatigue. There was some evidence of corrosion and dis-bonding at the cold-bond lap joints in the fuselage. However, the corrosion was relatively light and would not have compromised significantly the static strength of the airframe. Certainly, there was no evidence to suggest that corrosion had affected the mode of disintegration, either in the area of the explosion or at areas more remote. Similarly, there were no indications of fatigue damage except for one very small region of fatigue, involving a single crack less than 3 inches long, which was remote from the bomb location. This crack was not in a critical area and had not coincided with a fracture path.

No evidence of overpressure fracture or distortion was found at the rear pressure bulkhead. Some suggestion of 'quilting' or 'pillowing' of skin panels between stringers and frames, indicative of localised overpressure, was evident on the skin panels attached to the larger segments of lower fuselage wreckage aft of the blast area. In addition, the mode of failure of the butt joint at station 520 suggested that there had been a rapid overpressure load in this area, causing the fastener heads to 'pop' in the region of stringers 13L to 16L, rather than producing shear in the fasteners. Further evidence of localised overpressure damage remote from the source of the explosion was found during the full three-dimensional reconstruction, detailed later in paragraph 1.12.3.2.

An attempt was made to analyse the fractures, to determine the direction and sequence of failure as the fractures propagated away from the region of the explosion. It was found that the directions of most of the fractures close to the explosion could be determined from an analysis of the fracture surfaces and other features, such as rivet and rivet hole distortions. However, it was apparent that beyond the boundary of the petalled region, the disintegration process had involved multiple fractures taking place simultaneously - extremely complex parallel processes which made the sequencing of events not amenable to conventional analysis.

1.12.2.2 Wing structure and adjacent fuselage area

On completion of the initial layout at Longtown it became evident that, in the area from station 1000 to approximately station 1240 the only identifiable fuselage structure consisted of elements of fuselage skin, stringers and frames from above the cabin window belts. The wreckage from in and around the crater was therefore sifted to establish more accurately what sections of the aircraft had produced the crater. All of the material was highly fragmented, but it was confirmed that the material comprised mostly wing structure, with a few fragments of fuselage sidewall and passenger seats. The badly burnt state of these fragments made it clear that they were recovered from the area of the main impact crater, the only scene of significant ground fire. Amongst these items a number of cabin window forgings were recovered with sections of thick horizontal panelling attached having a length equivalent to the normal window spacing/frame pitch. This arrangement, with skins of this thickness, is unique to the area from station 1100 to 1260. It is therefore reasonable to assume that these fragments formed parts of the missing cabin sides from station 1000 to station 1260, which must have remained attached to the wing centre section at the time of its impact. Because of the high degree of fragmentation and the relative insignificance of the wing in terms of the overall explosive damage pattern, a reconstruction of the wing material was not undertaken. The sections of the aircraft which went into the crater are colour coded grey in Appendix B, Figures B-5 to B-8.

1.12.2.3 Fin and aft section of fuselage

Examination of the structure of the fin revealed evidence of in-flight damage to the leading edge caused by the impact of structure or cabin contents. This damage was not severe or extensive and the general break-up of the fin did not suggest either a single readily defined loading direction, or break-up due to the effects of leading edge impact. A few items of fin debris were found between the northern and southern trails.

A number of sections of fuselage frame found in the northern trail exhibited evidence of plastic deformation of skin attachment cleats and tensile overload failure of the attachment rivets. This damage was consistent with that which would occur if the skin had been locally subjected to a high loading in a direction normal to its plane. Although this was suggestive of an internal overpressure condition, the rear fuselage revealed no other evidence to support this possibility. Examination of areas of the forward fuselage known to have been subjected to high blast overpressures revealed no comparable evidence of plastic deformation in the skin attachment cleats or rivets, most skin attachment failures appearing to have been rapid.

Calculations made on the effects of internal pressure generated by an open ended fuselage descending at the highest speed likely to have been experienced revealed that this could not generate an internal pressure approaching that necessary to cause failure in an intact cabin structure.

1.12.2.4 Baggage containers

During the wreckage recovery operation it became apparent that some items, identified as parts of baggage containers, exhibited damage consistent with being close to a detonating high explosive. It was therefore decided to segregate identifiable container parts and reconstruct any that showed evidence of explosive 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 forward and rear cargo hold containers was relatively straightforward as the rear cargo hold wreckage was almost entirely confined to Lockerbie, whilst that from the forward hold was scattered along the southern wreckage trail.

All immediately identifiable parts of the forward cargo containers were segregated into areas designated by their serial numbers and items not identified at that stage were collected into piles of similar parts for later assessment. As a result of this, two adjacent containers, one of metal construction the other fibreglass, were identified as exhibiting damage likely to have been caused by the explosion. Those parts which could be positively identified as being from these two containers were assembled onto one of three simple wooden frameworks, one each for the floor and superstructure of the metal container and one for the superstructure of the fibreglass container. From this it was positively determined that the explosion had occurred within the metal container (serial number AVE 4041 PA), the direct effects of this being evident also on the forward face of the adjacent fibreglass container (serial number AVN 7511 PA) and on the local airframe on the left side of the aircraft in the region of station 700. It was therefore confirmed that this metal container had been loaded in position 14L in agreement with the aircraft loading records. While this work was in progress a buckled section of the metal container skin was found by an AAIB Inspector to contain, trapped within its folds, an item which was subsequently identified by forensic scientists at the Royal Armaments Research and Development Establishment (RARDE) as belonging to a specific type of radio-cassette player and that this had been fitted with an improvised explosive device (IED).

The reconstruction of these containers and their relationship to the aircraft structure is described in detail in Appendix F. Examination of all other components of the remaining containers revealed only damage consistent with ejection into the high speed slipstream and/or ground impact, and that only one device had detonated within the containers on board the aircraft.

1.12.3 Fuselage three-dimensional reconstruction

1.12.3.1 The reconstruction

The two-dimensional reconstruction successfully established that there had been an explosion in the forward hold; its location was established and the general damage characteristics in the vicinity of the explosion were determined. However, the mechanisms by which the failure process developed from local damage in the immediate vicinity of the explosion to the complete structural break-up and separation of the whole forward section of the fuselage, could not be adequately investigated without recourse to a more elaborate reconstruction.

To facilitate this additional work, wreckage forming a 65 foot section of the fuselage (approximately 30 feet each side of the explosion) was transported to AAIB Farnborough, where it was attached to a specially designed framework to form a fully three-dimensional reconstruction [Appendix B, Figures B-16 and B-17] of the complete fuselage between stations 360 & 1000 (from the separated nose section back to the wing cut out). The support framework was designed to provide full and free access to all parts of the structure, both internally and externally. Because of height constraints, the reconstruction was carried out in two parts, with the structure divided along a horizontal line at approximately the upper cabin floor level. The previously reconstructed containers were also transported to AAIB Farnborough to allow correlation of evidence with, and partial incorporation into, the fuselage reconstruction.

Structure and skin panels were attached to the supporting framework by their last point of attachment, to provide a better appreciation of the modes and direction of curling, distortion, and ultimate separation. Thus, the panels of skin which had petalled back from the shatter zone were attached at their outer edges, so as to identify the bending modes of the panels, the extent of the petalled region, and also the size of the resulting aperture in the hull. In areas more remote from the explosion, the fracture and tear directions were used together with distortion and curling directions to determine the mode of separation, and thus the most appropriate point of attachment to the reconstruction. Cabin floor beam segments were supported on a steel mesh grid and a plot of the beam fractures is shown at Appendix B, Figure B-18.

The cargo container base elements were separated from the rest of the container reconstruction and transferred to the main wreckage reconstruction, where the re-assembled container base was positioned precisely onto the cargo deck. To assist in the correlation of the initial shatter zone and petalled-out regions with the position of the explosive device, the boundaries of the skin panel fractures were marked on a transparent plastic panel which was then attached to the reconstruction to provide a transparent pseudo-skin showing the positions of the skin tear lines. This provided a clear visual indication of the relationship between the skin panel fractures and the explosive damage to the container base, thus providing a more accurate indication of the location of the explosive device.

1.12.3.2 Summary of explosive features evident

The three-dimensional reconstruction provided additional information about the 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 two types of damage, i.e. the direct blast/tearing/petalling damage and the quite separate areas of 'pressure blow' damage at remote sites were evidently caused by separate mechanisms, though it was equally clear that each was caused by explosive processes, rather than more general disintegration.

The region of petalling was bounded (approximately) by frames 680 and 740, and extended from just below the window belt down nearly to the keel of the aircraft [Appendix B, Figure B-19, region A]. The resulting aperture measured approximately 17 feet by 5 feet. Three major fractures had propagated beyond the boundary of the petalled zone, clearly driven by a combination of hull pressurisation loading and the relatively long term (secondary) pressure pulse from the explosion. These fractures ran as follows:

(i) rearwards and downward in a stepped fashion, joining the stringer 38L lap joint at around station 840, running aft along stringer 38L to around station 920, then stepping down to stringer 39L and running aft to terminate at the wing box cut-out [Appendix B, Figure B-19, fracture 1].

(ii) downwards and forward to join the stringer 44L lap joint, then running forward along stringer 44L as far as station 480 [Appendix B, Figure B-19, fracture 2].

(iii) downwards and rearward, joining the butt line at station 740 to run under the fuselage and up the right side to a position approximately 18 inches above the cabin floor level [Appendix B, Figures B-19 and B-20, fracture 3].

The propagation of tears upwards from the shatter zone appeared to have taken the form of a series of parallel fractures running upwards together before turning towards each other and closing, forming large flaps of skin which appear to have separated relatively cleanly.

Regions of skin separation remote from the site of the explosion were evident in a number of areas. These principally were:

(i) A large section of upper fuselage skin extending from station 500 back to station 760, and from around stringers 15/19L up as far as stringer 5L [Appendix B, Figures B-19 and B-20, region B], and probably extending further up over the crown. This panel had separated initially at its lower forward edge as a result of a pressure blow type of impulse loading, which had popped the heads from the rivets at the butt joint on frame 500 and lifted the skin flap out into the airflow. The remainder of the panel had then torn away rearwards in the airflow.

A region of 'quilting' or 'pillowing', i.e. spherical bulging of skin panels between frames and stringers, was evident on these panels in the region between station 560 and 680, just below the level of the upper deck floor, indicative of high internal pressurisation loading [Appendix B, Figure B-19, region C].

(ii) A smaller section of skin between stations 500 and 580, bounded by stringers 27L and 34L [Appendix B, Figure B-19, region D], had also been 'blown' outwards at its forward edge and torn off the structure rearwards. A characteristic curling of the panel was evident, consistent with rapid, energetic separation from the structure.

(iii) A section of thick belly skin extending from station 560, stringers 40R to 44R, and tapering back to a point at stringer 45R/station720 [Appendix B, Figure B-19 and B-20, region E], had separated from the structure as a result of a very heavy 'pressure blow' load at its forward end which had popped the heads off a large number of substantial skin fasteners. The panel had then torn away rearwards from the structure, curling up tightly onto itself as it did so - indicating that considerable excess energy was involved in the separation process (over and above that needed simply to separate the skin material from its supporting structure).

(iv) A panel of skin on the right side of the aircraft, roughly opposite the explosion, had been torn off the frames, beginning at the top edge of the panel situated just below the window belt and tearing downwards towards the belly [Appendix B, Figure B-20, region F]. This panel was curled downwards in a manner which suggested significant excess energy.

Appendix B, Figure B-21 shows a plot of the fractures noted in the fuselage skins between stations 360 and 1000.

The cabin floor structure was badly disrupted, particularly in the general area above the explosion, where the floor beams had suffered localised upward loading sufficient to fracture them, and the floor panels were missing. Elsewhere, floor beam damage was mainly limited to fractures at the outer ends of the beams and at the centreline, leaving sections of separated floor structure comprising a number of half beams joined together by the Nomex honeycomb floor panels.

1.12.3.3 General damage features not directly associated with explosive forces.

A number of features appeared to be a part of the general structural break-up which followed on from the explosive damage, rather than being a part of the explosive damage process itself. This general break-up was complex and, to a certain extent, random. However, analysis of the fractures, surface scores, paint smears and other features enabled a number of discreet elements of the break-up process to be identified. These elements are summarised below.

(i) Buckling of the window belts on both sides of the aircraft was evident between stations 660 and 800. That on the left side appeared to be the result of in-plane bending in a nose up sense, followed by fracture. The belt on the right side had a large radius curve suggesting lateral deflection of the fuselage possibly accompanied by some longitudinal compression. This terminated in a peeling failure of the riveted joint at station 800.

(ii) On the left side three fractures, apparently resulting from in-plane bending/buckling distortion, had traversed the window belt [Appendix B, Figure B-21, detail G]. Of these, the forward two had broken through the window apertures and the aft fracture had exploited a rivet line at the region of reinforcement just forward of the L2 door aperture. On the right side, the window belt had peeled rearwards, after buckling had occurred, separating from the rest of the fuselage, following rivet failure, at the forward edge of the R2 door aperture.

(iii) All crown skins forward of frame 840 were badly distorted and a number of pieces were missing. It was clearly evident that the skin sections from this region had struck the empennage and/or other structure following separation.

(iv) The fuselage left side lower lobe from station 740 back to the wing box cut-out, and from the window level down to the cargo deck floor (the fracture line along stringer 38L), had peeled outwards, upwards and rearwards - separating from the rest of the fuselage at the window belt. The whole of this separated section had then continued to slide upwards and rearwards, over the fuselage, before being carried back in the slipstream and colliding with the outer leading edge of the right horizontal stabiliser, completely disrupting the outer half. A fragment of horizontal stabiliser spar cap was found embedded in the fuselage structure adjacent to the two vent valves, just below, and forward of, the L2 door [Appendix B, Figure B-22].

(v) A large, clear, imprint of semi-eliptical form was apparent on the lower right side at station 360 which had evidently been caused by the separating forward fuselage section striking the No 3 engine as it swung rearwards and to the right (confirmed by No 3 engine fan cowl damage).

1.12.3.4 Tailplane three-dimensional reconstruction

The tailplane structural design took the form of a forward and an aft torque box. The forward box was constructed from light gauge aluminium alloy sheet skins, supported by closely pitched, light gauge nose ribs but without lateral stringers. The aft torque box incorporated heavy gauge skin/stringer panels with more widely spaced ribs. The front spar web was of light gauge material. Leading edge impacts inflicted by debris would therefore have had the capacity to reduce the tailplane's structural integrity by passing through the light gauge skins and spar web into the interior of the aft torque box, damaging the shear connection between top and bottom skins in the process and thereby both removing the bending strength of the box and opening up the weakened structure to the direct effects of the airflow.

Examination of the rebuilt tailplane structure at AAIB Farnborough left little doubt that it had been destroyed by debris striking its leading edges. In addition, the presence on the skins of smear marks indicated that some unidentified soft debris had contacted those surfaces whilst moving with both longitudinal and lateral velocity components relative to the aircraft.

The reconstructed left tailplane [Appendix B, Figure B-23] showed evidence that disruption of the inboard leading edge, followed respectively by the forward torque box, front spar web and main torque box, occurred as a result of frontal impact by the base of a baggage container. Further outboard, a compact object appeared to have struck the underside of the leading edge and penetrated to the aft torque box. In both cases, the loss of the shear web of the front spar appeared to have permitted local bending failure of the remaining main torque box structure in a tip downwards sense, consistent with the normal load direction. For both events to have occured it would be reasonable to assume that the outboard damage preceded that occurring inboard.

The right tailplane exhibited massive leading edge impact damage on the outboard portion which also appeared to have progressed to disruption of the aft torsion box. A fragment of right tailplane spar cap was found embedded in the fuselage structure adjacent to the two vent valves, just below, and forward of, the L2 door and it is clear that this area of forward left fuselage had travelled over the top of the aircraft and contributed to the destruction of the outboard right tailplane.

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 similar deep, large circumference tip rub. These tip-rubs on the four engines were centred at slightly different clock positions around their respective fan cases.

The Pratt and Whitney specialists supplied information which was used to interpret the evidence found on the blades and fan cases including details of engine dynamic behaviour necessary to produce the tip rub evidence. This indicated that the depth and circumference of tip rubs noted would have required a marked nose down change of aircraft pitch attitude combined with a roll rate to the left.

Pratt and Whitney also advised that:

(i) Airflow disruption such as that presumed to have caused the shingling observed on No 2 engine fan blades was almost invariably the result of damage to the fan blade aerofoils, resulting from ingestion or blade failure.

(ii) Tip rubs of a depth and circumference noted on all four engines could be expected to reduce the fan rotational energy on each to a negligible value within approximately 5 seconds.

(iii) Airflow disruption sufficient to cause the extent of shingling noted on the fan blades of No 2 engine would also reduce the rotational fan energy to a negligible value within approximately 5 seconds.

1.13 Medical and pathological information

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 seated in the immediate vicinity of the explosion would have suffered some injury as a result of blast, this would have been of a secondary or tertiary nature.

Of the casualties from the aircraft, the majority were found in areas which indicated that they had been thrown from the fuselage during the disintegration. Although the pattern of distribution of bodies on the ground was not clear cut there was some correlation with seat allocation which suggested that the forward 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 hosereel. 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 1910 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 1¼ by ½ mile. The main concentration of the fire was in the southwest of the town around Sherwood Park and Sherwood Crescent. Appliances were in attendance at other fires in the town, particularly in Park Place and Rosebank Crescent. Water and electricity supplies were interrupted and water had to be brought into the town.

By 02.22 hrs on 22 December, all main seats of fire had been extinguished and the firemen were involved in turning over and damping down. At 04.42 hrs small fires were still occurring but had been confined to the Sherwood Crescent area.

1.15 Survival aspects

1.15.1 Survivability

The accident was not survivable.

1.15.2 Emergency services

A chronology of initial responses by the emergency services is listed below:-

Time	Event
19.03 hrs	Radio message from Police patrol in Lockerbie to Dumfries and Galloway Constabulary reporting an aircraft crash at Lockerbie.
19.04 hrs	Emergency call to Dumfries and Galloway Fire Brigade.
19.37 hrs	First ambulances leave for Dumfries and Galloway Royal Infirmary with injured town residents. (2- serious; 3- minor)
19.40 hrs	Sherwood Park and Sherwood Crescent residents evacuated to Lockerbie Town Hall.
20.25 hrs	Nose section of N739PA discovered at Tundergarth (approximately 4 km east of Lockerbie).

During the next few days a major emergency operation was mounted using the guidelines of the Dumfries and Galloway Regional Peacetime Emergency Plan. The Dumfries and Galloway Constabulary was reinforced by contingents from Strathclyde and Lothian & Borders Constabularies. Resources from HM Forces were made available and this support was subsequently authorised by the Ministry of Defence as Military Aid to the Civil Power. It included the provision of military personnel and a number of helicopters used mainly in the search for and recovery of aircraft wreckage. It was apparent at an early stage that there were no survivors from the aircraft and the search and recovery of bodies was mainly a Police task with military assistance.

Many other agencies were involved in the provision of welfare and support services for the residents of Lockerbie, relatives of the aircraft's occupants and personnel involved in the emergency operation.

1.16 Tests and research

An explosive detonation within a fuselage, in reasonably close proximity to the skin, will produce a high intensity spherically propagating shock wave which will expand outwards from the centre of detonation. On reaching the inner surface of the fuselage skin, energy will partially be absorbed in shattering, deforming and accelerating the skin and stringer material in its path. Much of the remaining energy will be transmitted, as a shock wave, through the skin and into the atmosphere but a significant amount of energy will be returned as a reflected shock wave, which will travel back into the fuselage interior where it will interact with the incident shock to produce Mach stem shocks - re-combination shock waves which can have pressures and velocities of propagation greater than the incident shock.

The Mach stem phenomenon is significant because it gives rise (for relatively small charge sizes) to a geometric limitation on the area of skin material which the incident shock wave can shatter, irrespective of charge size, thus providing a means of calculating the standoff distance of the explosive charge from the fuselage skin. Calculations suggest that a charge standoff distance of aproximately 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].

1.17 Additional information

1.17.1 Recorded radar information

Recorded radar information on the aircraft was available from from 4 radar sites. Initial analysis consisted of viewing the recorded information as it was shown to the controller on the radar screen from which it was clear that the flight had progressed in a normal manner until secondary surveillance radar (SSR) was lost.

The detailed analysis of the radar information concentrated on the break-up of the aircraft. The Royal Signals and Radar Establishment (RSRE) corrected the radar returns for fixed errors and converted the SSR returns to latitude and longitude so that an accurate time and position for the aircraft could be determined. The last secondary return from the aircraft was recorded at 19.02:46.9 hrs, identifying N739PA at Flight Level 310, and at the next radar return there is no SSR data, 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.

Each rotation of the radar head thereafter showed the number of returns increasing, with those first identified across track having slowed down very quickly and followed a track along the prevailing wind line. The radar evidence then indicated that a further break-up of the aircraft had occurred and formed a parallel wreckage trail to the north of the first. From the absence of any returns travelling along track it was concluded that the main wreckage was travelling almost vertically downwards for much of the time.

A detailed analysis of the recorded radar information, together with the radar, ATC and seismic recordings is contained in Appendix C.

1.17.2 Seismic data

The British Geological Survey has a number of seismic monitoring stations in Southern Scotland. Stations close to Lockerbie recorded a seismic event measuring 1.6 on the Richter scale and, with appropriate corrections for the times of the waves to reach the sensors, it was established that this occurred at 19.03:36.5 hrs ±1 second. A further check was made by triangulation techniques from the information recorded by the various sensors.

An analysis of the seismic recording, together with the radar, ATC and radar information is contained in Appendix C.

1.17.3 Trajectory analysis

A detailed trajectory analysis was carried out by Cranfield Institute of Technology in an effort to provide a sequence for the aircraft disintegration. This analysis comprised several separate processes, including individual trajectory calculations for a limited number of key items of wreckage and mathematical modelling of trajectory paths adopted by a series of hypothetical items of wreckage encompassing the drag/weight spectrum of the actual wreckage.

The work carried out at Cranfield enabled the reasons for the two separate trails to be established. The narrow northern trail was shown to be created by debris released from the aircraft in a vertical dive between 19,000 and 9,000 feet overhead Lockerbie. The southern trail, longer and straight for most of its length, appeared to have been created by wreckage released during the initial disintegration at altitude whilst the aircraft was in level flight. Those items falling closest to Lockerbie would have been those with higher density which would travel a significant distance along track before losing all along-track velocity, whilst only drifting a small distance downwind, owing to the high speed of their descent. The most westerly items thus showed the greatest such effect. The southern trail therefore had curved boundaries at its western end with the curvature becoming progressively less to the east until the wreckage essentially fell in a straight band. Thus wreckage in the southern trail positioned well to the east could be assumed to have retained negligible velocity along aircraft track after separation and the along-track distribution could be used to establish an approximate sequence of initial disintegration.

The analysis calculated impact speeds of 120 kts for the nose section weighing approximately 17,500 lb and 260 kts for the engines and pylons which each weighed about 13,500 lb. Based on the best available data at the time, the analysis showed that the wing (approximately 100,000 lb of structure containing an estimated 200,000 lb of fuel) could have impacted at a speed, in theory, as high as 650 kts if it had 'flown' in a streamlined attitude such that the drag coefficient was minimal. However, because small variations of wing incidence (and various amounts of attached fuselage) could have resulted in significant increases in drag coefficient, the analysis also recognized that the final impact speed of the wing could have been lower.

1.17.4 Space debris re-entry

Four items of space debris were known to have re-entered the Earth's atmosphere on 21 December 1988. Three of these items were fragments of debris which would not have survived re-entry, although their burn up in the upper atmosphere might have been visible from the Earth's surface. The fourth item landed in the USSR at 09.50 hrs UTC.

2 Analysis

2.1 Introduction

The airport security and criminal aspects of the destruction of Boeing 747 registration N739PA near Lockerbie on 21 December 1988 are the subjects of a separate investigation and are not covered in this report. This analysis discusses the technical aspects of the disintegration of the aircraft and considers possible ways of mitigating the effects of an explosion in the future.

2.2 Explosive destruction of the aircraft

The geographical position of the final secondary return at 19.02:46.9 hrs was calculated by RSRE to be OS Grid Reference 15257772, annotated Point A in Appendix B, Figure B-4, with an accuracy considered to be better than ±300 metres This return was received 3.1±1 seconds before the loud sound was recorded on the CVR at 19.02:50 hrs. By projecting from this position along the track of 321°(Grid) for 3.1±1 seconds at the groundspeed of 434 kts, the position of the aircraft was calculated to be OS Grid Reference 14827826, annotated Point B in Appendix B, Figure B-4, within an accuracy of ±525 metres. Based on the evidence of recorded data only, Point B therefore represents the geographical position of the aircraft at the moment the loud sound was recorded on the CVR.

The datum line. discussed at paragraph 1.12.1.6, was derived from a detailed analysis of the distribution of specific items of wreckage, including those exhibiting positive evidence of a detonating high performance plastic explosive. The scatter of these items about the datum line may have been due partly to velocities imparted by the force of the detonating explosive and partly by the difficulty experienced in pinpointing the location of the wreckage accurately in relatively featureless terrain and poor visibility. However, the random nature of the scatter created by these two effects would have tended to counteract one another, and a major error in any one of the eleven grid references would have had little overall effect on the whole line. There is, therefore, good reason to have confidence in the validity of the datum line.

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 westwards until it intersected the known radar track of the aircraft in order to derive the position of the aircraft along track at which the explosive items were released and therefore the position at which the IED had detonated. This position was OS grid reference 146786 and is annotated Point C in Appendix B, Figure B-4. Point C was well within the circle of accuracy (±525 metres) of the position 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.

2.3 Flight recorders

2.3.1 Digital flight data recordings

A working group of the European Organisation for Civil Aviation Electronics (EUROCAE) was, during the period of the investigation, formulating new standards (Minimum Operational Performance Requirement for Flight Data Recorder Systems, Ref:- ED55) for future generation flight recorders which would have permitted delays between parameter input and recording (buffering) of up to ½ second. These standards are intended to form the basis of new CAA specifications for flight recorders and may be adopted worldwide.

The analysis of the recording from the DFDR fitted to N739PA, which is detailed in Appendix C, showed that the recorded data simply stopped. Following careful examination and correlation of the various sources of recorded information, it was concluded that this occurred because the electrical power supply to the recorder had been interrupted at 19.02:50 hrs ±1 second. Only 17 bits of data were not recoverable (less that 23 milliseconds) and it was not possible to establish with any certainty if this data was from the accident flight or was old data from a previous recording.

The analysis of the final data recorded on the DFDR was possible because the system did not buffer the incoming data. Some existing recorders use a process whereby data is stored temporarily in a memory device (buffer) before recording. The data within this buffer is lost when power is removed from the recorder and in currently designed recorders this may mean that up to 1.2 seconds of final data contained within the buffer is lost. Due to the necessary processing of the signals prior to input to the recorder, additional delays of up to 300 milliseconds may be introduced. If the accident had occurred when the aircraft was over the sea, it is very probable that the relatively few small items of structure, luggage and clothing showing positive evidence of the detonation of an explosive device would not have been recovered. However, as flight recorders are fitted with underwater location beacons, there is a high probability that they would have been located and recovered. In such an event the final milliseconds of data contained on the DFDR could be vital to the successful determination of the cause of an accident whether due to an explosive device or other catastrophic failure. Whilst it may not be possible to reduce some of the delays external to the recorder, it is possible to reduce any data loss due to buffering of data within the data acquisition unit.

It is, therefore, recommended that manufacturers of existing recorders which use buffering techniques give consideration to making the buffers non-volatile, and hence recoverable after power loss. Although the recommendation on this aspect, made to the EUROCAE working group during the investigation, was incorporated into ED55, it is also recommended that Airworthiness Authorities reconsider the concept of allowing buffered data to be stored in a volatile memory.

2.3.2 Cockpit voice recorders

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 recommended during the investigation that the regulatory authorities consider requiring CVR systems to contain a short duration (i.e. no greater than 1 minute) back-up power supply.

2.3.3 Detection of explosive occurrences

In the aftermath of the Air India Boeing 747 accident (AI 182) in the North Atlantic on 23 June 1985, RARDE were asked informally by AAIB to examine means of differentiating, by recording violent cabin pressure pulses, between the detonation of an explosive device within the cabin (positive pulse) and a catastrophic structural failure (negative pulse). Following the Lockerbie disaster it was considered that this work should be raised to a formal research project. Therefore, in February 1989, it was recommended that the Department of Transport fund a study to devise methods of recording violent positive and negative pressure pulses, preferably utilising the aircraft's flight recorder systems. This recommendation was accepted.

Preliminary results from the trials indicate that, if a suitable sensor can be developed, its output will need to be recorded in real time and therefore it may require wiring to the CVR installation. This will further strengthen the requirement for battery back up of the CVR electrical power supply.

2.4 IED position within the aircraft

From the detailed examination of the reconstructed luggage containers, discussed at paragraph 1.12.2.4 and in Appendix F, it was evident that the IED had been located within a metal container (serial number AVE 4041 PA), near its aft outboard quarter as shown in Appendix F, Figure F-13. It was also clear that the container was loaded in position 14L of the forward hold which placed the explosive charge approximately 25 inches inboard from the fuselage skin at frame 700. There was no evidence to indicate that there was more than one explosive charge.

2.5 Engine evidence

To produce the fan blade tip rub damage noted on all engines by means of airflow inclined to the axes of the nacelles would have required a marked nose down change of aircraft pitch attitude combined with a roll rate to the left while all of the engines were attached to the wing.

The shingling damage noted on the fan blades of No 2 engine can only be attributed to airflow disturbance caused by ingestion related fan blade damage occurring when substantial power was being delivered. This is readily explained by the fact that No 2 engine intake is positioned some 27 feet aft and 30 feet outboard of the site of the explosion and that the interior of the intake exhibited a number of prominent paint smears and general foreign object damage. This damage included evidence of a strike by a cable similar to that forming part of the closure curtain of a typical baggage container. It is inconceivable that an independent blade failure could have occurred in the short time frame of this event. By similar reasoning, the absence of such shingling damage on blades of No 3 engine was a reliable indication that it suffered no ingestion until well into the accident sequence.

The combination of the position of the explosive device and the forward speed of the aircraft was such that significant sized debris resulting from the explosion would have been available to be ingested by No 2 engine within milliseconds of the explosion. In view of the fact that the tip rub damage observed on the fan case of No 2 engine is of similar magnitude to that observed on the other three engines it is reasonable to deduce that a manoeuvre of the aircraft occurred before most of the energy of the No 2 engine fan was lost due to the effect of ingestion (seen only in this engine). Since this shingling effect could only readily be produced as a by-product of ingestion whilst delivering considerable power, it is reasonable to assume that this was also occurring before loss of major fan energy due to tip rubbing took place. Hence both phenomena must have been occurring simultaneously, or nearly so, to produce the effects observed and must have occupied a time frame of substantially less than 5 seconds. The onset of this time period would have been the time at which debris from the explosion first inflicted damage to fan blades in No 3 engine and, since the fan is only approximately 40 feet from the location of the explosive device, this would have been an insignificant time interval after the explosion.

It was therefore concluded from this evidence that the wing with all of the engines attached had achieved a marked nose down and left roll attitude change well within 5 seconds of the explosion.

2.6 Detachment of forward fuselage

Examination of the three major structural elements either side of the region of station 800 on the right side of the fuselage makes it clear that to produce the curvature of the window belt and peeling of the riveted joint at the R2 door aperture requires the door pillar to be securely in position and able to react longitudinal and lateral loads. This in turn requires the large section of fuselage on the right side between stations 760 and 1000 (incorporating the right half of the floor) to be in position in order to locate the lower end of the door pillar. Thus both these sections must have been in position until the section from station 560 to 800 (right side) had completed its deflection to the right and peeled from the door pillar. Separation of the forward fuselage must thus have been complete by the time all three items mentioned above had fallen free.

2.7 Speed of initial disintegration

The distribution of wreckage in the bands between the datum line and the 250, 300, 600 and 900 metre lines was examined in detail. The positions of these items of structure on the aircraft are shown in Appendix B, Figures B-10 to B-13. It should be noted that the position on the ground of these items, although separated by small distances when measured in a direction along aircraft track, were distributed over large distances when measured along the wreckage trail. All were recovered from positions far enough to the east to be in that part of the southern trail which was sufficiently close, theoretically, to a straight line for any curvature effect to be neglected.

The wreckage found in each of the bands enabled an approximate sequence of break-up to be established. It was clear that as the distance travelled from the datum line increased, items of wreckage further from the station of the IED were encountered. The items shown on the diagram as falling on the 250 metre band also include those fragments of lower forward fuselage skin having evidence of explosive damage and presumed to have separated as a direct result of the blast. However, a few portions of the upper forward fuselage were also found within the 250 metre band, suggesting that these items had also separated as a result of the blast.

By the time the 300 metre line was reached much of the structure from the right side in the region of the explosive device had been shed. This included the area of window belt, referred to in paragraph 2.6 above, which gave clear indications that the forward structure had detached to the right and finally peeled away at station 800. It also included the areas of adjacent structure immediately to the rear of station 800 about which the forward structure would have had to pivot. By the time the 600 metre line was reached, there was clearly insufficient structure left to connect the forward fuselage with the remainder of the aircraft. Wreckage between the 600 and 900 metre lines consisted of structure still further from the site of the IED.

There is evidence that a manoeuvre occurred at the time of the explosion which would have produced a significant change of the aircraft's flight path, however, it is considered that the change in the horizontal velocity component in the first few seconds would not have been great. The original groundspeed of the aircraft was therefore used in conjunction with the distribution of wreckage in the successive bands to establish an approximate time sequence of break-up of the forward fuselage. Assuming the original ground speed of 434 Kts, the elapsed flight times from the datum to each of the parellel lines were calculated to be:

Distance (metres)	250	300	600	900
Time (seconds)	1.1	1.3	2.7	4.0

Thus, there is little doubt that separation of the forward fuselage was complete within 2 to 3 seconds of the explosion.

The separate assessment of the known grid references of tailplane and elevator wreckage in the southern trail revealed that those items were evenly distributed about the 600 metre line and therefore that most of the tailplane damage occured after separation of the forward fuselage was complete.

2.8 The manoeuvre following the explosion

The engine evidence, timing and mode of disintegration of the fuselage and tailplane suggests that the latter did not sustain significant damage until the forward fuselage disintegration was well advanced and the pitch/roll manoeuvre was also well under way.

Examination of the three dimensional reconstruction makes it clear that both main and upper deck floors were disrupted by the explosion. Since pitch control cables are routed through the upper deck floor beams and the roll control cables through the main deck beams, there is a strong possibility that movement of the beams under explosive forces would have applied inputs to the control cables, thus operating control surfaces in both axes.

2.9 Secondary disintegration

The distribution of fin debris between the trails suggests that disintegration of the fin began shortly before the vertical descent was established. No single mode of failure was identified and the debris which had struck the leading edge had not caused major disruption. The considerable fragmentation of the thick panels of the aft torque box was also very different from that noted on the corresponding structure of the tailplanes. It was therefore concluded that the mode of failure was probably flutter.

The finding, in the northern trail, of a slide raft wrapped around a flap track fairing suggests that at a later stage of the disintegration the rear of the aircraft must have experienced a large angle of sideslip. The loss of the fin would have made this possible and also subjected the structure to large side loads. It is possible that such side loading would have assisted the disintegration of the rear fuselage and also have caused bending failure of the pylon attachments of the remaining three engines.

2.10 Impact speed of components

The trajectory analysis carried out by Cranfield Institute of Technology calculated impact speeds of 120 kts for the nose section, and 260 kts for the engines and pylons. These values were considered to be reliable because the drag coefficients could be estimated with a reasonable degree of confidence. Based on the best available data at the time, the analysis also showed that the wing could have impacted at a speed, in theory, as high as 650 kts if it had flown in a streamlined attitude such that the drag coefficient was minimal. However, it was also recognized that relatively small changes in the angle of incidence of the wing would have produced a significant increase in drag with a consequent reduction in impact speed. Refinement of timing information and radar data subsequent to the Cranfield analysis has enabled a revised estimate to be made of the mean speed of the wing during the descent.

The engine evidence indicated that there had been a large nose down attitude change of the aircraft early in the event. The Cranfield analysis also showed that the rear fuselage had disintegrated while essentially in a vertical descent between

19,000 and 9,000 feet over Lockerbie. Assuming that, following the explosion, the wing followed a straight line descending flight profile from 31,000 feet to 19,000 feet directly overhead Lockerbie and then descended vertically until impact, the wing would have travelled the minimum distance practicable. The ground distance between the geographical position at which the disintegration started (Figure B-4, Point B) and the crater made by the wing impact was 2997 ±525 metres (9833 ±1722 feet). The time interval between the explosion and the wing impact was established in Appendix C as 46.5 ±2 seconds. Based on the above times and distances the mean linear speed achieved by the wing would have been about 440 kts.

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 separated at about 19,000 feet and the wing had then flown as much as one mile away from the overhead position before tracking back to impact, the total flight path length of the wing would not have required it to have achieved a mean linear speed in excess of 500 kts.

Any speculation that the flight path of the wing could have been longer would have required it to have undergone manoeuvres at high speed in order to arrive at the 19,000 feet point. The manoeuvres involved would almost certainly have resulted in failure of the primary wing structure which, from distribution of wing debris, clearly did not occur. Alternatively the wing could have travelled more than one mile from Lockerbie after reaching the 19,000 feet point, but this was considered unlikely. It is therefore concluded that the mean speed of the wing during the descent was in the region of 440 to 500 kts.

2.11 Sequence of disintegration

Analysis of wreckage in each of the bands, taken in conjunction with the engine evidence and the three-dimensional reconstruction, suggests the following sequence of disintegration:

(i) The initial explosion triggered a sequence of events which effectively destroyed the structural integrity of the forward fuselage. Little more then remained between stations 560 and 760 (approximately) than the window belts and the cabin sidewall structure imediately above and below the windows, although much of the cargo-hold floor structure appears to have remained briefly attached to the aircraft. [Appendix B, Figure B-24]

(ii) The main portion of the aircraft simultaneously entered a manoeuvre involving a marked nose down and left roll attitude change, probably as a result of inputs applied to the flying control cables by movement of structure.

(iii) Failure of the left window belt then occured, probably in the region of station 710, as a result of torsional and bending loads on the fuselage imparted by the manoeuvre (i.e. the movement of the forward fuselage relative to the remainder of the aircraft was an initial twisting motion to the right, accompanied by a nose up pitching deflection).

(iv) The forward fuselage deflected to the right, pivoting about the starboard window belt, and then peeled away from the structure at station 800. During this process the lower nose section struck the No 3 engine intake causing the engine to detach from its pylon. This fuselage separation was apparently complete within 3 seconds of the explosion.

(v) Structure and contents of the forward fuselage struck the tail surfaces contributing to the destruction of the outboard starboard tailplane and causing substantial damage to the port unit. This damage occurred approximately 600 metres track distance after the explosion and therefore appears to have happened after the fuselage separation was complete.

(vi) Fuselage structure continued to break away from the aircraft and the separated forward fuselage section as they descended.

(vii) The aircraft maintained a steepening descent path until it reached the vertical in the region of 19,000 feet approximately over the final impact point. Shortly before it did so the tail fin began to disintegrate.

(viii) The mode of failure of the fin is not clear, however, flutter of its structure is suspected.

(ix) Once established in the vertical dive, the fin torque box continued to disintegrate, possibly permitting the remainder of the aircraft to yaw sufficiently to cause side load separation of Nos 1, 2 and 4 engines, complete with their pylons.

(x) Break-up of the rear fuselage occurred during the vertical descent, possibly as a result of loads induced by the yaw, leaving a section of cabin floor and baggage hold from approximately stations 1241 to 1920, together with 3 landing gear units, to fall into housing at Rosebank Terrace.

(xi) The main wing structure struck the ground with a high yaw angle at Sherwood Crescent.

2.12 Explosive mechanisms and the structural disintegration

The fracture and damage pattern analysis was mainly of an interpretive nature involving interlocking pieces of subtle evidence such as paint smears, fracture and rivet failure characteristics, and other complex features. In the interests of brevity, this analysis will not discuss the detailed interpretation of individual fractures or damage features. Instead, the broader 'damage picture' which emerged from the detailed work will be discussed in the context of the explosive mechanisms which might have produced the damage, with a view to identifying those features of greatest significance.

It is important to keep in mind that whilst the processes involved are considered and discussed separately, the timescales associated with shock wave propagation and the high velocity gas flows are very short compared with the structural response timescales. Consequently, material which was shattered or broken by the explosive forces would have remained in place for a sufficiently long time that the structure can be considered to have been intact throughout much of the period that these explosive propagation phenomena were taking place.

2.12.1 Direct blast effect

2.12.1.1 Shock wave propagation

The direct effect of the explosive detonation within the container was to produce a high intensity spherically propagating shock wave which expanded from the centre of detonation close to the side of the container, shattering part of the side and base of the container as it passed through into the gap between the container and the fuselage skin. In breaking out of the container, some internal reflection and Mach stem interaction would have occurred, but this would have been limited by the absorptive effect of the baggage inboard, above, and forward of the charge. The force of the explosion breaking out of the container would therefore have been directed downwards and rearwards.

The heavy container base was distorted and torn downwards, causing buckling of the adjoining section of frame 700, and the container sides were blasted through and torn, particularly in the aft lower corner. Some of the material in the direct path of the explosive pressure front was reduced to shrapnel sized pieces which were rapidly accelerated outwards behind the primary shock front. Because of the overhang of the container's sloping side, fragments from both the device itself and the container wall impacted the projecting external flange of the container base edge member, producing micro cratering and sooting. Metallurgical examination of the internal surfaces of these craters identified areas of melting and other features which were consistent only with the impact of very high energy particles produced by an explosion at close quarters. Analysis of material on the crater surfaces confirmed the presence of several elements and compounds foreign to the composition of the edge member, including material consistent with the composition of the sheet aluminium forming the sloping face of the container.

On reaching the inner surface of the fuselage skin, the incident shock wave energy would partially have been absorbed in shattering, deforming and accelerating the skin and stringer material in its path. Much of its energy would have been transmitted, as a shock wave, through the skin and into the atmosphere [Appendix B, Figure B-25], but a significant amount of energy would have been returned as a reflected shock wave, back into the cavity between the container and the fuselage skin where Mach stem shock waves would have been formed. Evidence of rapid shattering was found in a region approximately bounded by frames 700 & 720 and stringers 38L & 40L, together with the lap joint at 39L.

The shattered fuselage skin would have taken a significant time to move, relative to the timescales associated with the primary shock wave propagation. Clear evidence of soot and small impact craters were apparent on the internal surfaces of all fragments of container and structure from the shatter zone, confirming that the this material had not had time to move before it was hit by the cloud of shrapnel, unburnt explosive residues and sooty combustion products generated at the seat of the explosion.

Following immediately behind the primary shock wave, a secondary high pressure wave - partly caused by reflections off the baggage behind the explosive material but mainly by the general pressure rise caused by the chemical conversion of solid explosive material to high temperature gas - emerged from the container. The effect of this second pressure front, which would have been more sustained and spread over a much larger area, was to cause the fuselage skin to stretch and blister outwards before bursting and petalling back in a star-burst pattern, with rapidly running tear fractures propagating away from a focus at the shatter zone. The release of stored energy as the skin ruptured, combined with the outflow of high pressure gas through the aperture, produced a characteristic curling of the skin 'petals' - even against the slipstream. For the most part, the skins which petalled back in this manner were torn from the frames and stringers, but the frames and stringers themselves were also fractured and became separated from the rest of the structure, producing a very large jagged hole some 5 feet longitudinally by 17 feet circumferentially (upwards to a region just below the window belt and downwards virtually to the centre line).

From this large jagged hole, three of the fractures continued to propagate away from the hole instead of terminating at the boundary. One fracture propagated longitudinally rearwards as far as the wing cut-out and another forwards to station 480, creating a continuous longitudinal fracture some 43 feet in length. A third fracture propagated circumferentially downwards along frame 740, under the belly, and up the right side of the fuselage almost as far as the window belt - a distance of approximately 23 feet.

These extended fractures all involved tearing or related failure modes, sometimes exploiting rivet lines and tearing from rivet hole to rivet hole, in other areas tearing along the full skin section adjacent to rivet lines, but separate from them. Although the fractures had, in part, followed lap joints, the actual failure modes indicated that the joints themselves were not inherently weak, either as design features or in respect of corrosion or the conditions of the joints on this particular aircraft.

Note: The cold bond process carried out at manufacture on the lap joints had areas of disbonding prior to the accident. This disbonding is a known feature of early Boeing 747 aircraft which, by itself, does not detract from the structural integrity of the hull. The cold bond adhesive was used to improve the distribution of shear load across the joint, thus reducing shear transfer via the fasteners and improving the resistance of the joint to fatigue damage; the fasteners were designed to carry the full static loading requirements of the joint without any contribution from the adhesive. Thus, the loss of the cold bond integrity would only have been significant if it had resulted in the growth of fatigue cracks, or corrosion induced weaknesses, which had then been exploited by the explosive forces. No evidence of fatigue cracking was found in the bonded joints. Inter-surface corrosion was present on most lap joints but only one very small region of corrosion had resulted in significant material thinning; this was remote from the critical region and had not played any part in the break-up.

The cracks propagating upwards as part of the petalling process did not extend beyond the window line. The wreckage evidence suggests that the vertical fractures merged, effectively closing off the fracture path to produce a relatively clean bounding edge to the upper section of the otherwise jagged hole produced by the petalling process. There are at least two probable reasons for this. Firstly the petalling fractures above the shattered zone did not diverge, as they had tended to do elsewhere. Instead, it appears that a large skin panel separated and peeled upwards very rapidly producing tears at each side which ran upwards following almost parallel paths. However, there are indications that by the time the fractures had run several feet, the velocity of fracture had slowed sufficiently to allow the free (forward) edge of the skin panel to overtake the fracture fronts, as it flexed upwards, and forcibly strike the fuselage skin above, producing clear witness marks on both items. Such a tearing process, in which an approximately rectangular flap of skin is pulled upwards away from the main skin panel, is likely to result in the fractures merging. Secondly, this merging tendency would have been reinforced in this particular instance by the stiff window belt ahead of the fractures, which would have tended to turn the fractures towards the horizontal.

It appears that the presence of this initial ('clean') hole, together with the stiff window belt above, encouraged other more slowly running tears to break into it, rather than propagating outwards away from the main hole.

2.12.1.2 Critical crack considerations

The three very large tears extending beyond the boundary of the petalled region resulted in a critical reduction of fuselage structural integrity.

Calculations were carried out at the Royal Aerospace Establishment to determine whether these fractures, growing outwards from the boundary of the petalled hole, could have occurred purely as a result of normal differential pressure loading of the fuselage, or whether explosive forces were required in addition to the pressurisation loads.

Preliminary calculations of critical crack dimensions for a fuselage skin punctured by a 20 by 20 inches jagged hole indicated that unstable crack growth would not have occurred unless the skin stress had been substantially greater than the stress level due to normal pressurisation loads alone. It was therefore clear that explosive overpressure must have produced the gross enlargement of the initially small shattered hole in the hull. Furthermore, it was apparent from the degree of curling and petalling of the skin panels within the star-burst region that this overpressure had been relatively long term, compared with the shock wave overpressure which had produced the shatter zone. A more refined analysis of critical crack growth parameters was therefore carried out in which it was assumed that the long term explosive overpressure was produced by the chemical conversion of solid explosive material into high temperature gas.

An outline of the fracture propagation analysis is given at Appendix D. This analysis, using theoretical fracture mechanics, showed that, after the incident shock wave had produced the shatter zone, significant explosive overpressure loads were needed to drive the star-burst fractures out to the boundary of the petalled skin zone. Thereafter, residual gas overpressure combined with fuselage pressurisation loads were sufficient to produce the two major longitudinal cracks and a single major circumferential crack, extending from the window belt down to beyond the keel centreline.

2.12.1.3 Damage to the cabin floor structure

The floor beams in the region immediately above the baggage container in which the explosive had detonated were extensively broken, displaying clear indications of overload failure due to buckling caused by localised upward loading of the floor structure.

No direct evidence of bruising was found on the top panel of the container. It therefore appears that the container did not itself impact the floor beams, but instead the floor immediately above the container was broken through as a result of explosive overpressure as gases emerged from the ruptured container and loaded the floor panels. Data on floor strengths, provided by Boeing, indicated that the cabin floor (with the CRAF modification) would fail at a uniform static differential pressure of between 3.5 and 3.9 psi (high pressure below the cabin floor), and that the floor panel to floor beam attachments would not fail before the floor beams. Whilst there is no direct evidence of the pressure loading on the floor structure immediately following detonation, there can be no doubt that in the region of station 700 it would have exceeded the ultimate failure load by a large margin.

2.12.2 Indirect explosive damage (damage at remote sites)

All of the damage considered in the foregoing analysis, and the mechanisms giving rise to that damage, resulted from the direct impact of explosive shock waves and/or the short-term explosive overpressure on structure close to the source of the explosion. However, there were several regions of skin separation at sites remote from the explosion (see para 1.12.3.2) which were much more difficult to understand. These remote sites formed islands of indirect explosive damage separated from the direct damage by a sea of more generalised structural failure characterised by the progressive aerodynamic break-up of the weakened forward fuselage. All of these remote damage sites were consistent with the impact of very localised pressure impulses on the internal surfaces of the hull - effectively high energy 'pressure blows' against the inner surfaces produced by explosive shock waves and/or high pressure gas flows travelling through the interior spaces of the hull.

The propagation of explosive shock waves and supersonic gas flows within multiple, interlinking, cavities having indeterminate energy absorption and reflection properties, and ill-defined structural response, is extremely complex.

Work has been initiated in an attempt to produce a three-dimensional computer analysis of the shock wave and supersonic flow propagation inside the fuselage, but full theoretical analysis is beyond present resources.

Because of the complexity of the problem, the following analysis will be restricted to a qualitative consideration of the processes which were likely to have taken place. Whilst such an approach is necessarily limited, it has identified a number of propagation mechanisms which appear to have been of fundamental importance to the break-up of Flight PA103, and which are likely to be critical in any future incident involving the detonation of high explosive inside an aircraft hull.

2.12.2.1 Shock wave propagation through internal cavities

When Mach stem shocks are produced not only are the shock pressures very high but they propagate at very high velocity parallel to the reflecting surface. In the context of the lower fuselage structure in the region of Mach stem formation, it can readily be seen that the Mach stem will be perfectly orientated to enter the narrow cavity formed between the outer skin and the cargo liner/containers, bounded by the fuselage frames [Appendix B, Figure B-25]. This cavity enables the Mach stem shock wave to propagate, without causing damage to the walls (due to the relatively low pressure where the Mach stem sweeps their surface), and reach regions of the fuselage remote from the source of the explosion. Furthermore, energy losses in the cavity are likely to be less than would occur in the 'free' propagation case, resulting in the efficient transmission of explosive energy. The cavity would tend to act like a 'shock tube', used for high speed aerodynamic research, confining the shock wave and keeping it running along the cavity axis, with losses being limited to kinetic heating due to friction at the walls.

Paragraph 1.6.3 contains a general description of the structural arrangements in the area of the cargo hold. Before proceeding further and considering how the shock waves might have propagated through this network of cavities, it should be pointed out that the timescale associated with the propagation of the shock waves is very short compared with the timescale associated with physical movement and separation of skin and structure fractured or damaged by the shock. Therefore, for the purpose of assessing the shock propagation through the cavities, the explosive damage to the hull can be ignored and the structure regarded as being intact. A further simplification can usefully be made by considering the structure to be rigid. This assumption would, if the analysis were quantitative, result in over-estimations of the shock strengths. However, for the purposes of a purely qualitative assessment, the assumption should be valid, in that the general trends of behaviour should not be materially altered.

It has already been argued that the shock wave emerging from the container was, in part, reflected back off the inner surface of the fuselage skin, forming a Mach stem shock wave which would then have tended to travel into the semi-circular lower lobe cavity. The Mach stem waves would have propagated away through this cavity in two directions:

(i) under the belly, between the frames [Appendix B, Figure B-3, detail A], and

(ii) up the left side, expanding into the cavity formed by the longitudinal manifold chamber where it joins the lower lobe cavity.

As the shock waves travelled along the cavity, little attenuation or other change of characteristic was likely to have occurred until the shocks passed the entrances to other cavities, or impinged upon projections and other local changes in the cavity. A review of the literature dealing with propagation of blast waves within such cavities provides useful insights into some of the physical mechanisms involved.

As part of a research program carried out into the design of ventilation systems for blast hardened installations intended to survive the long duration blast waves following the detonation of nuclear weapons, the propagation of blast waves along the primary passages and into the side branches of ventilation ducts was studied. The research showed that 90° bends in the ducts produced very little attenuation of shock wave pressure; a series of six right angle bends produced only a 30% pressure attenuation, together with an extension of the shock duration. It is therefore evident that the attenuation of shock waves propagating through the fuselage cavities, all of which were short with hardly any right angle turns, would have been minimal.

It was also demonstrated that secondary shock waves develop within the entrance to any side branch from the main duct, produced by the interaction of the primary shock wave with the geometric changes in the duct walls at the side-branch location. These secondary shock waves interact as they propagate into the side branch, combining together within a relatively short distance (typically 7 diameters) to produce a single, plane shock wave travelling along the duct axis. In a rigid, smooth walled structure, this mechanism produces secondary shock overpressures in the side branch of between 30% and 50% of the value of the primary shock, together with a corresponding attenuation of the primary shock wave pressure by approximately 20% to 25%.

This potential for the splitting up and re-transmission of shock wave energy within the lower hull cavities is of extreme importance in the context of this accident. Though the precise form of the interactions is too complex to predict quantitatively, it is evident that the lower hull cavities will serve to convey the overpressure efficiently to other parts of the aircraft. Furthermore, the cavities are not of serial form, i.e. they do not simply branch (and branch again) in a divergent manner, but instead form a parallel network of short cavities which reconnect with each other at many different points, principally along the crease beams. Thus, considerable scope exists for: the additive recombination of blast waves at cavity junctions; for the sustaining of the shock overpressure over a greater time period; and, for the generation of multiple shocks produced by the delay in shock propagation inherent in the different shock path (i.e. cavity) lengths.

Whilst it has not been possible to find a specific mechanism to explain the regions of localised skin separation and peel-back (i.e. the 'pressure blow' regions referred to in para 2.12.2), they were almost certainly the result of high intensity shock overpressures produced locally in those regions as a result of the additive recombination of shock waves transmitted through the lower hull cavities. It is considered that the relatively close proximity of the left side region of damage just below floor level at station 500, [Appendix B, Figure B-19, region D] to the forward end of the cargo hold may be significant insofar as the reflections back from the forward end of the hold would have produced a local enhancement of the shock overpressure. Similarly, 'end blockage effects' produced by the cargo door frame might have been responsible for local enhancements in the area of the belly skin separation and curl-back at station 560 [Appendix B, Figure B-19 and B-20, region E].

The separation of the large section of upper fuselage skin [Appendix B, Figure B-19 and B-20, detail B] was almost certainly associated with a local overpressure in the side cavities between the main deck window line and the upper deck floor, where the cavity is effectively closed off. It is considered that the most probable mechanism producing this region of impulse overpressure was a reflection from the closed end of the cavity, possibly combined with further secondary reflections from the window assembly, the whole being driven by reflective overpressures at the forward end of the longitudinal manifold cavity caused by the forward end of the cargo hold. The local overpressure inside the sidewall cavity would have been backed up by a general cabin overpressure resulting from the floor breakthrough, giving rise to an increased pressure acting on the inner face of the cabin side liner panels. This would have provided pseudo mass to the panels, effectively preventing them from moving inwards and allowing them to react the impulse pressure within the cavity, producing the region of local high pressure evidenced by the region of quilting on the skin panels [Appendix B, Figure B-19, region C].

2.12.2.2 Propagation of shock waves into the cabin

The design of the air-conditioning/depressurisation-venting systems on the Boeing 747 (and on most other commercial aircraft) is seen as a significant factor in the transmission of explosive energy, as it provides a direct connection between the main passenger cabin and the lower hull at the confluence of the lower hull cavities below the crease beam. The floor level air conditioning vents along the length of the cabin provided a series of apertures through which explosive shock waves, propagating through the sub floor cavities, would have radiated into the main cabin.

Once the shock waves entered the cabin space, the form of propagation would have been significantly different from that which occurred in the cavities in the lower hull. Again, the precise form of such radiation cannot be predicted, but it is clear that the energy would potentially have been high and there would also (potentially) have been a large number of shock waves radiating into the cabin, both from individual vents and in total, with further potential to recombine additively or to 'follow one another up' producing, in effect, sustained shock overpressures.

Within the cabin, the presence of hard, reflective, surfaces are likely to have been significant. Again, the precise way in which the shock waves interacted is vastly beyond the scope of current analytical methods and computing power, but there clearly was considerable potential for additive recombination of the many different shock waves entering at different points along the cabin and the reflected shock waves off hard surfaces in the cabin space, such as the toilet and galley compartments and overhead lockers. These recombination effects, though not understood, are known phenomena. Appendix B, Figure B-26 shows how shock waves radiating from floor level might have been reflected in such a way as produce shock loading on a localised area of the pressure hull.

2.12.2.3 Supersonic gas flows

The gas produced by the explosive would have resulted in a supersonic flow of very high pressure gas through the structural cavities, which would have followed up closely behind the shock waves. Whilst the physical mechanisms of propagation would have been different from those of the shock wave, the end result would have been similar, i.e. there would have been propagation via multiple, linked paths, with potential for additive recombination and successive pressure pulses resulting from differing path lengths. Essentially, the shock waves are likely to have delivered initial 'pressure blows' which would then have been followed up immediately by more sustained pressures resulting from the high pressure supersonic gas flows.

2.13 Potential limitation of explosive damage

Quite clearly the detonation of high explosive material anywhere on board an aircraft is potentially catastrophic and the most effective means of protecting lives is to stop such material entering the aircraft in the first place. However, it is recognised that such risks cannot be eliminated entirely and it is therefore essential that means are sought to reduce the vulnerability of commercial aircraft structures to explosive damage.

The processes which take place when an explosive detonates inside an aircraft fuselage are complex and, to a large extent, fickle in terms of the precise manner in which the processes occur. Furthermore, the potential variation in charge size, position within the hull, and the nature of the materials in the immediate vicinity of the charge (baggage etc) are such that it would be unrealistic to expect to neutralise successfully the effect of every potential explosive device likely to be placed on board an aircraft. However, whilst the problem is intractable so far as a total solution is concerned, it should be possible to limit the damage caused by an explosive device inside a baggage container on a Boeing 747 or similar aircraft to a degree which would allow the aircraft to land successfully, albeit with severe local damage and perhaps resulting in some loss of life or injuries.

In Appendix E the problem of reducing the vulnerability of commercial aircraft to explosive damage is discussed, both in general terms and in the context of aircraft of similar size and form to the Boeing 747. In that discussion, those damage mechanisms which appear to have contributed to the catastrophic structural failure of Flight PA103 are identified and possible ways of reducing their damaging effects are suggested. These suggestions are intended to stimulate thought and discussion by manufacturers, airworthiness authorities, and others having an interest in finding solutions to the problem; they are intended to serve as a catalyst rather than to lay claim to a definitive solution.

2.14 Summary

It was established that the detonation of an IED, loaded in a luggage container positioned on the left side of the forward cargo hold, directly caused the loss of the aircraft. The direct explosive forces produced a large hole in the fuselage structure and disrupted the main cabin floor. Major cracks continued to propagate from the large hole under the influence of the service pressure differential. The indirect explosive effects produced significant structural damage in areas remote from the site of the explosion. The combined effect of the direct and indirect explosive forces was to destroy the structural integrity of the forward fuselage allow the nose and flight deck area to detach within a period of 2 to 3 seconds, and subsequently allow most of the remaining aircraft to disintegrate while it was descending nearly vertically from 19,000 to 9,000 feet.

The investigation has enabled a better understanding to be gained of the explosive processes involved in such an event and to suggest ways in which the effects of such an explosion might be mitigated, both by changes to future design and also by retrospective modification of aircraft. It is therefore recommended that Regulatory Authorities and aircraft manufacturers undertake a systematic study with a view to identifying measures that might mitigate the effects of explosive devices and improve the tolerance of the aircraft structure and systems to explosive damage.

3. Conclusions

(a) Findings

(i) The crew were properly licenced and medically fit to conduct the flight.

(ii) The aircraft had a valid Certificate of Airworthiness and had been maintained in compliance with the regulations.

(iii) There was no evidence of any defect or malfunction in the aircraft that could have caused or contributed to the accident.

(iv) The structure was in good condition and the minimal areas of corrosion did not contribute to the in-flight disintegration.

(v) One minor fatigue crack approximately 3 inches long was found in the fuselage skin but this had not been exploited during the disintegration.

(vi) 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.

(vii) The analysis of the flight recorders, using currently accepted techniques, did not reveal positive evidence of an explosive event.

(viii) The direct explosive forces produced a large hole in the fuselage structure and disrupted the main cabin floor. Major cracks continued to propagate from the large hole under the influence of the service pressure differential.

(ix) The indirect explosive effects produced significant structural damage in areas remote from the site of the explosion.

(x) The combined effect of the direct and indirect explosive forces was to destroy the structural integrity of the forward fuselage.

(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.

(xv) The wing impacted in the town of Lockerbie producing a large crater and creating a fireball.

(b) Cause

The in-flight disintegration of the aircraft was caused by the detonation of an improvised explosive device located in a baggage container positioned on the left side of the forward cargo hold at aircraft station 700.

4. Safety Recommendations

The following Safety Recommendations were made during the course of the investigation :

4.1 That manufacturers of existing recorders which use buffering techniques give consideration to making the buffers non-volatile, and the data recoverable after power loss.

4.2 That Airworthiness Authorities re-consider the concept of allowing buffered data to be stored in a volatile memory.

4.3 That Airworthiness Authorities consider requiring the CVR system to contain a short duration, i.e. no greater than 1 minute, back-up power supply to enable the CVR to respond to events that result in the almost immediate loss of the aircraft's electrical power supply.

4.4 That the Department of Transport fund a study to devise methods of recording violent positive and negative pressure pulses, preferably utilising the aircraft's flight recorder systems.

4.5 That Airworthiness Authorities and aircraft manufacturers undertake a systematic study with a view to identifying measures that might mitigate the effects of explosive devices and improve the tolerance of aircraft structure and systems to explosive damage.

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