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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 6.14 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.

AVANT-PROPOS

Généralités

1. Le recueil d'accidents d'aviation a pour but de communiquer à tous les États contractants certains renseignements sur les rapports d'accidents. La publication du recueil a commencé en 1951. Au cours des années, les États ont manifesté à plusieurs reprises leur intérêt pour le recueil, parce qu'il constitue non seulement une source précieuse d'information pour la prévention des accidents, mais aussi une aide de formation pour les enquêteurs et un manuel éducatif pour les écoles techniques.

Sélection des accidents

2. Le recueil contient des rapports d'accidents choisis par le Secrétariat parmi ceux communiqués par les États. Ce choix repose sur les critères suivants:

a) intérêt du rapport pour la prévention des accidents;

b) utilisation fructueuse de techniques d'enquête utiles ou efficaces;

c) conformité aux spécifications de l'Annexe 13, y compris celles concernant la présentation du rapport final.

Le présent recueil ne saurait être considéré comme représentatif, du point de vue statistique, de la répartition des accidents dans le monde.

Normes de rédaction

3. Les rapports finals sont généralement publiés tels qu'ils sont reçus. Par conséquent, ils peuvent présenter certaines différences par rapport aux normes OACI de rédaction. Certains rapports particulièrement longs sont abrégés par l'omission de renseignements redondants, d'appendices, de pièces jointes ou de schémas. De légères modifications sont parfois apportées à la présentation, ainsi qu'à la terminologie, afin d'assurer la conformité avec les dispositions de l'Annexe 13.

Coopération des États

4. Les États sont invités à envoyer à l'OACI des rapports finals conformes aux critères de 6.14 de l'Annexe 13. Les rapports doivent être rédigés dans l'une des langues de travail de l'OACI et présentés comme il est indiqué dans l'Appendice à l'Annexe 13.

Publication des recueils d'accidents

5. Le recueil est publié une fois par an et comprend des comptes rendus d'accidents et d'incidents survenus au cours d'une année.

PREÁMBULO

Consideraciones de carácter general

1. El objeto de la Recopilación de accidentes de aviación es transmitir información sobre accidentes a los Estados contratantes. La publicación de esta serie se inició en 1951. Con el transcurso de los años, los Estados han reiterado su interés por la Recopilación, puesto que ésta constituye no sólo una valiosa fuente de datos para la prevención de accidentes, sino también una ayuda para la formación de investigadores, y sirve asimismo de material didáctico para las escuelas técnicas.

Selección de accidentes

2. La Recopilación contiene informes y accidentes elegidos por la Secretaría de entre los que envían los Estados. La selección se basa en los criterios siguientes:

a) su aportación a la prevención de accidentes; o

b) el empleo con éxito de técnicas de investigación consideradas útiles o eficaces; y

c) el cumplimiento del Anexo 13 y también la forma de presentación del Informe final.

Desde el punto de vista estadístico, la Recopilación no debe considerarse representativa de la distribución mundial de los accidentes.

Forma habitual de presentación

3. Usualmente los informes finales se publican tal como se reciben. Por eso es posible que existan algunas discrepancias en relación con la forma habitual de presentación de la OACI. A veces, los informes extensos se abrevian eliminando información oficiosa, apéndices, adjuntos o diagramas. Se pueden introducir pequeños cambios en la presentación y la terminología con miras a dar cumplimiento al Anexo 13.

Cooperación de los Estados

4. Se alienta a los Estados a que transmitan a la OACI únicamente los informes finales que satisfagan los criterios señalados en el párrafo 6.14 del Anexo 13. Los informes deben venir redactados en uno de los idiomas de trabajo de la OACI y del modo indicado en el Apéndice al Anexo 13.

Publicación de las recopilaciones

5. Las recopilaciones de accidentes se publican anualmente y contienen accidentes e incidentes ocurridos en el transcurso del año a que se refieren.

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No. 1

Ilyushin IL-62M, SP-LBG, accident near Warszawa-Okecie Airport on 9 May 1987. Report released by the General Directorate of Civil Aviation, Ministry of Transport, Poland.

SYNOPSIS

At 0912:13 UTC on May 9th, 1987, Polish Airlines LOT, type IL-62M crashed in the vicinity of Warszawa-Okęcie /Warsaw-Okęcie/ airport during its emergency approach.
About 24 minutes after take-off for New York, scheduled flight LO- 5055, the crew of the SP-LBG reported on the failure of 2 engines and elevator control system, then on the decision to come back to the Okęcie airport.
The accident resulted from the failure of the L.H. inner engine (N° 2). The low pressure turbine shaft broke loose, then, as a result of that fact the turbine reached its critical r.p.m. leading to the burst of the turbine disc whose fragments pierced the fuselage aft portion thus causing damage, among others, to engine N° 1, to the elevator control system and giving rise to fire in the baggage compartment. The return flight with 2 engines inoperative, while the elevator was out of control and the fire expanded, took about 31 minutes. The aircraft longitudinal control was effectuated by means of the horizontal stabilizer and elevator trim tab.
At a distance of 6 km from the runway 33 threshold of the Okęcie aerodrome the aircraft became fully uncontrollable

and struck the ground. The crash resulted in the remaining fuel explosion and fire. The aircraft was completely destroyed, all the crew members (11) and passengers (172 persons) died in the crash.

1. FACTUAL INFORMATION

1.1. History of the flight

At 0818 UTC on May 9, 1987 a PLL "LOT" IL-62M, SP-LBG, operated as flight LO-5055, took off in accordance with the flight schedule from Warszawa-Okęcie /Warsaw-Okęcie/ for New York.

The crew members were prepared for flight in accordance with the standard procedure that is obligatory in PLL "LOT" and consistent with Polish regulations.

The aircraft took off using runway 33 while the wind direction was 300°, wind velocity 22 km/h, ambient temperature +11°C, aircraft T.O. mass 166875 kgs. Being airborne the aircraft followed the planned air way R-23 towards the VOR GRU. At 0839 the aircraft passed over the VOR GRU, as reported by the crew, crossing level 265 and climbing to level 310.

At 0841, two minutes after having passed over the VOR GRU the aircraft was flying towards the VOR DAR along the R-23 air way axis, at an altitude of about 8200 m. At that moment an emergency situation began, engine N° 2 failed that fact resulting in damage to fuselage, depressurization of the aircraft, damage to engine N° 1, cutoff of the elevator control system and damage to the electric power network.

At 0842 the crew reported to be in danger, while an immediate descent was begun to an altitude of 4000 m with a simultaneous right turn and the air traffic control was notified about the decision of return to Warsaw. At the same time the crew stopped engine N° 1 and 2. The crew members were convinced that the fire was extinguished. However, the fuselage rear portion was still on fire of which fact the crew members were unaware because of lack of signalization /broken electric wires/. Upon the recovery from the turn the crew begun the emergency procedure of fuel jettisoning. At the same time the crew stated that the elevator was out of control.

During the return flight the crew stated troubles in the electric network as a result of which several systems lost their power supply and the emergency jettisoning of fuel was interrupted from time to time.

The aircraft longitudinal control was carried out only by means of stabilizer and trim tab. Since 0849 a further loss of height has been stated followed by worsening of the aircraft systems condition. At 0853 considering the situation on board the aircraft the crew determined to land on the Modlin aerodrome and informed the air traffic control about that decision.

However, at 0855 after having received the landing clearance and basic information concerning the Modlin aerodrome the crew resigned the landing at Modlin giving the reasons for landing in Warsaw i.e. mentioning better rescue equipment of the Warszawa-Okęcie /Warsaw-Okęcie/ aerodrome.

At 0900:52 the crew decided to land on the Okęcie aerodrome runway 33 while being still unaware of fire and convinced of possible effective sustaining the aircraft in the air by means of stabilizer and elevator trim tab as well as of the said better rescue equipment of the Okęcie aerodrome.

The flight continued to VOR PNO with a further loss of height. At the same time the fuselage rear portion was still on fire while the expanding fire caused damage to electric equipment thus precluding any possibility of further fuel jettisoning.

The crew carried out preparatory operations before emergency landing.

The still existing fire in the fuselage rear portion i.e. the fire of which the crew members were still unaware was signalled and correctly identified by the crew as a baggage compartment fire not before the moment at which the aircraft was abeam the threshold of runway 33.

The approach was begun with a left turn, vectored by the approach control radar, in the direction of runway 33 axis. The left turn was begun at 0909 at an altitude of 1450 m and an airspeed of 480 km/h.

When the second half of the turn was carried out, in spite of the transmitted message "zrobimy wszystko co możliwe" /we will do our possible/ the crew were not successful in controlling further flight of the aircraft, in particular to keep the desired altitude and to reach the runway central axis. At a distance of 6 km from the runway threshold the aircraft struck the forest trees while flying at an airspeed of 465 km/h, with a left bank of 11 deg., the flight path being 12 deg. below the horizontal line.

At 0912:13 the impact caused fire of the whole aircraft, the crew and passengers died in the crash.

The accident took place at latitude 52°06′20" N and longitude 021°03′00" E. The place of accident elevation is 102 m above sea level. The accident occurred in the daytime.

1.2. Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	11	172	-
Serious	-	-	-
Minor/None	-	-	-

1.3. Damage to aircraft

Due to the impact and post-impact fire the damage to the aircraft fuselage, wings, empennage and undercarriage was 100 per cent.

1.4. Other damage

Forest fire covering an area of 4 hectares.

1.5. <u>Personnel information</u>

a/ Crew

1. Captain , 59 years old, was in possession of licence L-887 valid until 25 August 1987. He held rating for pilot-in-command of the aircraft type IL-62. Flying proficiency check certificate valid until 2 September 1987. Theoretical knowledge check certificate valid until 22 February 1988. Certificate of proficiency check on flight simulator valid until 24 February 1988. Total flying time 19 745 hours 20 min. Flying time on IL-62M: 5546 hours 35 min. in that 3725 hours 14 min. as pilot-in-command. Last medical examination in GWKLL /Główna Wojskowa Komisja Lotniczo-Lekarska - Chief Military Committee for Medical Examination of Aviation Personnel/: 26 February 1987. Result: fit, group III-IV.

2. Co-pilot , 54 years old, licence L-5846 valid until 25 August 1988. He held rating for co-pilot of the aircraft type IL-62. Certificate of flying proficiency check valid until 20 October 1987. Certificate of theoretical knowledge check valid until 22 February 1988. Certificate of proficiency check on flight simulator valid until 24 February 1988. Total flying time 10.957 hours 47 min. in that 1965 hours 58 min on IL-62M. Last medical examination in GWKLL: 26 February 1987. Result: fit, group III-IV.

3. Flight navigator , 54 years old, licence N-5984 valid until 15 September 1987. He held navigator's rating for the IL-62. Certificate of practical check of navigator's proficiency valid until 26 June 1987. Total flying time 9562 hours 32 min. including 3187 hours 56 min. on IL-62M. Last medical examination in GWKLL: 15 April 1987, Result: fit, group IV-V.

4. Flight Engineer /Instructor/ , 54 years old. Licence L-2668 valid until 25 June 1987. He held rating for flight engineer of the aircraft type IL-62M. Certificate of practical check of flight engineer's proficiency valid until 24 February 1988. Total flying time 10 570 hours including 6696 hours on IL-62M. Last medical examination in GWKLL: 6 November 1986. Result: fit, group IV-V.

5. Flight Engineer , 43 years old, licence M-6217 valid until 25 June 1987. He held flight engineer's rating for IL-62M. Certificate of last practical check of flight engineer's proficiency valid until 8 May 1987. Total flying time 5148 hours 4 min. including 325 hours 10 min. on IL-62M. Last medical examination in GWKLL: 26 June 1986. Result: fit, group IV-V.

6. Radio Operator , 43 years old, licence R-6033 valid until 10 March 1988. He held radio operator's rating for IL-62M. Certificate of last practical

check of radio operator's proficiency valid until 14 February 1988. Total flying time 6374 hours 59 min. including 3186 hours 40 min. on IL-62M. Last medical examination in GWKLL: 11 March 1987. Result: fit, group IV-V § 53 clause 4 /physical conditions as after operation of left kidney/.

b/ Board personnel /stewardesses/

1. 39 years old. Ratings: - board personnel instructor since 1 December 1983, - senior stewardess since 6 October 1980. Last proficiency checks: evacuation 31 March - 2 April 1987, examination in swimming-pool 1 April 1987, tests /improving course/ - December 1986. Total flying time: 6300 hours. Last medical examination in GWLL: 20 June 1985.

2. 36 years old, senior stewardess since 1 January 1975. Last proficiency checks: evacuation 10-12 March 1987, examination in swimming-pool 11 March 1987, tests /improving course/ February 1987. Total flying time: 8300 hours. Last medical examination: 6 January 1987.

3. 41 years old, stewardess since 1 July 1978. Last proficiency checks: evacuation 11-12 February 1986, examination in swimming-poll 12 February 1986, tests /Committee for Qualification/ September 1986. Total flying time: 5800 hours. Last medical examination: 18 June 1985.

4. 29 years old, stewardess since 15 May 1986. Last proficiency checks: evacuation 21-23 April 1987, examination in swimming-pool 22 April 1987, tests /improving course/ May 1986. Total flying time: 2400 hours. Last medical examination: 20 May 1986.

5. 24 years old, junior stewardess since 15 August 1985. Last proficiency checks: evacuation 24-26 March 1987, examination in swimming-pool 25 March 1987, tests /course for junior stewardesses/ May 1985. Last medical examination: 16 December 1986. Total flying time: 1300 hours.

1.6. Aircraft information

1.6.1. Aircraft data:

a/ Kind of aircraft: cargo/passenger aeroplane

b/ Aircraft type: IL-62M

c/ Registration: SP-LBG

d/ Registered N^{o}: 2578

e/ Airframe and engines Manufacturer: USSR

f/ Airworthiness Certificate: valid until 20 October 1987

g/ Total airframe hours as of the day of accident: 6972 hours.

h/ Total number of landings: 1752

i/ Flying hours remaining until the major overhaul: 1028 hours and 948 landings.

1.6.2. Power plant data

a/ Number of engines: 4

b/ Kind of engines: two-rotor ducted-fan turbine engines

c/ Engine type: D-30KU

d/ Time between overhauls /TBO/: 3000 hours

e/ Engine running time and hours remaining to the next major overhaul.

Engine position	Reg. No	Date of expiry of Airworthiness Certificate	Working hours after last major overhaul related to those accumulated from the beginning of use	Hours before the next major overhaul
1	5974	20 October 1987	1179/4768	1821
2	5657	20 October 1987	2793/6692	207
3	5624	20 October 1987	1814/7415	1186
4	5302	20 October 1987	752/8632	2248

1.6.3. Routine maintenance, periodical inspections and all the operations imposed by Service Bulletins, foreseen in the aircraft maintenance documentation were carried out in accordance with valid Regulations.

During the Pre-flight Inspection before the last flight no troubles were found. In virtue of the maintenance documentation, technical reports concerning the aircraft preparation for flight, statements and testimonies of the personnel responsible for the aircraft preparation for the last flight it was found that the aircraft was fully airworthy.

1.6.4.

a/ The SP-LBG was equipped with a full set of avionic instruments.

b/ Before the last flight the aircraft fuel system was filled with 75 000 kg PSM-2A fuel.

c/ Each engine oil system was filled with oil grade MS-8p as required by the Standard.

d/ The aircraft T.O. mass was 166 875 kgs.

1.7. Meteorological information

The crew members of the PLL "LOT" aircraft were in possession of the weather forecast for the air route from Warsaw to New York.

The weather conditions on the Warsaw /Warszawa/ aerodrome and in its region as well as along the route Warsaw - Grudziądz-Warsaw had no influence on the accident. The weather between Warsaw and Grudziądz as well as on the nearby aerodrome was good.

During the take-off, en route and in the accident place no meteorological phenomena were observed which could influence the flight safety. The accident occurred in full daylight.

1.8. Aids to navigation

The aids to navigation along the air way 23 were:

- approach control radar /primary and secondary/
- area control radar /primary/ in Poznan
- radio navigation facilities on the Warszawa-Okęcie aerodrome.

All the mentioned aids to navigation were serviceable and ready to use according to their design except two of them viz.:

- ILS for runway 33, inoperative because of replacement of its assemblies
- non-directional radio beacon NDB-WAO that was inoperative because of failure of its power supply system.

The flight of the SP-LBG was surveyed /controlled/ and monitored /observed/ by radars operating in the Warszawa flight information region /Warszawa FIR/.

1.9. Communications

During all the flight the crew members of the SP-LBG maintained the established radio communication with the Air Traffic Control Center Warszawa /Warsaw/ and with the Area Control Center in Poznan.

The means of radio/telephone communications as used by the air traffic controlling personnel in order to control the flight of the SP-LBG were serviceable and their use was correct.

1.10. Aerodrome information

not applicable.

1.11. Flight recorders

1.11.1. Location of flight data recorders:

1/ Analog/digital flight data recorder type MSRP-64-2 /tape shifting mechanism MLP-14-5/ in protected container was located in the fuselage rear portion in the vicinity of the starting assembly.

2/ Analog/digital flight data recorder operational type MSRP-64-2 /with MLP-14-5/, non-protected, was installed in the rear technical compartment.

3/ Analog flight data recorder type MSRP-12-96, protected, was located in the rear technical compartment.

4/ Analog flight data recorder type K3-63, non-protected, was located in the central part under the bar.

5/ Cockpit Voice Recorder type MARS-BM, protected, was located in the fuselage rear section.

1.11.2. Conditions of flight data recorders after the accident

1/ The MSRP-64-2 /with the MLP-14-5/ of protected type showed external damage to its asbestos part, while the condition of internal elements was very good, the magnetic tape being also in excellent condition.

The flight data were recorded on that tape only until the moment of failure of engines 1 and 2.

2/ The unprotected flight data recorder operational type MSRP-64-2 /with MLP-14-6/ suffered severe damage as a result of which only one magnetic tape real was found with the damaged tape on which another flight was recorded.

3/ The MSRP-12-96 showed indents on one of its halves, in addition, the fixing grips located inside were broken. Besides, the magnetic tape jumped out of its rollers and was in some places broken, however, the record was correct until the end of the flight.

4/ The K3-63 was completely lost, even fragments of that flight recorder could not be found.

5/ The Cockpit Voice Recorder type MARS-BM was recovered intact.

1.11.3. Results

The recorded flight data taken from both the MSRP-64-2 /with MLP-14-5/ and MSRP-12-96 were subjected to analysis.

1/ The results obtained from the MSRS-64-2 flight recorder are as follows:
The said flight recorder was functioning from the moment of actuation till the moment of failure in the air i.e. from 0744 till 0841:45 UTC /time set by the crew on board the aircraft/.

In virtue of the recorded flight data some parts of the flight could be investigated as follows:

- crew operations after entering the cockpit
- take-off and climb along the air way
- moment of failure.

At 0817-34 the aircraft began the ground run, at 0818:20 she took off at an airspeed of 325 km/h IAS /V_R/.
During the climb and further flight the crew did not transgress any regulation.
The critical situation occurred at 0841:45 being caused by the failure of engine N° 2.

- Reactions and symptoms observed at the moment of engine failure -

About 12 to 15 seconds before the moment of engine failure the fuel consumption of engine N° 2 increased for a short time from 2850 to 3000 kg/h, then dropped to 2800 kg/h and remained at that level until the end of the record.
The record of the low-pressure rotor speed of engine N° 2 repeated the mentioned change in the fuel consumption i.e. the low-pressure rotor speed increased for 1 second from 87% to 88%, then dropped to 86%.
0.5 second before the engine failure the low-pressure rotor speed of engine N° 2 dropped by 2% i.e. to 84%.
At the moment of engine failure the gradient of decrease of speed of engine N° 2 was 18% within 0.5 second, while the speed of the low-pressure rotor of engine N° 1 dropped from 89% to 66.7% within 0.5 second.

Some effects of the failure as recorded by the LSRP-64-2 are as follows:

- failure of engine N^{o} 2 - primary incident
- decrease of pressure difference between the cabin and ambient atmosphere - secondary incident
- damage to the elevator control system - secondary incident that is concluded from the analysis of the last fragments of the record /at 0841:45/, where a significant discrepancy is observed between the recorded parameters of the elevator /channel N^{o} 10/ and the control column positions /channel N^{o} 45/. That fact proves that there was no interconnection between these assemblies
- damage to the recording system of the LSRP-64-2 flight data recorder - secondary incident.

The above mentioned troubles occurred simultaneously with the symptoms transmitted by the sensing elements as follows:

- the normal acceleration /normal load/ factor dropped from 0.930 to 0.640 within $\frac{1}{8}$ second, than increased up to 0.960 within a further $\frac{1}{8}$ s. lapse of time
- the airspeed /IAS/ drop was 21 km/h within $\frac{1}{2}$ second
- the pressure altitude drop was 117 m within $\frac{1}{2}$ second
- the position of spoilers changed.

The sensors are of brush/Potentiometer type sensitive to vibrations and shocks.

The above described symptoms prove the occurrence of rather great shocks. The aforementioned values of variable parameters were recorded on the last sections of the MSRP-64-2 /MLP-14-5/ magnetic tape.

2/ Results obtained from the MSRP-12-96

The flight data recorder type MSRP-12-96 was functioning from the moment of actuation on the ground till the moment occurring 1 min. before the crash.

The time history of flight/navigation parameters until the engine failure is consistent with the data recorded by the MSRP-64-2 /MLP-14-5/.

At the moment of engine failure a rapid drop of speed of engine N° 2 and N° 1 was observed down to zero.

After 20 seconds elapsed from the moment of engine 2 failure the pilot reduced the rotations of engines N° 3 and 4 to 79% for 4 minutes, then increased the rotations as follows:

- engine N° 3 up to 89%
- engine N° 4 up to 92%

The latter rotations were practically maintained at the said level in under to continue the flight.

The history of flight as counted from the moment of failure of engine N° 2 and based upon the recorded flight data can be represented as follows:

- the aircraft lost the altitude rather quickly,
- the aircraft gradually lost the airspeed,

- aboard the aircraft there were many electric troubles; the recorded flight data were perturbed to a great extent.

The aircraft stability margin enabled the pilot to sustain the aircraft in the air.

At 0909 UTC i.e. after 51 minutes of flight the aircraft made an unexpected rapid downward movement, shown on the record of the normal load factor which dropped by 0.3. A little sooner the elevator, that was till then in a relatively constant position, rapidly moved downwards.

From that moment the load factor began to "follow" the rapid deflections of the elevator.

After the initial downward oscillation of the aircraft followed by an upward oscillation the tape reveals binary signals of landing flaps and spoiler extension for 4 to 10 seconds. At that moment a momentary "appeasement" of the aircraft is visible, then the longitudinal oscillations are repeated.

At the same time there are visible sudden and intense but short-lasting perturbances of the recorded flight data, thereafter the said perturbance appears again but its effect does not influence all the flight data to the same extent.

Simultaneously the aircraft "waving" is still visible being somewhat appeased for a while and at that very moment the signals of flight data under record disappear.

At 0911 UTC the flight data recorder stopped recording but its mechanism was still working because the record data were systematically cancelled on the magnetic tape. 30 second before the impact some signals of flight data appeared but only for about 1 second /vestigial oscillograph record/, then the flight recorder went on functioning still cancelling the old record /from a precedent flight/. This situation lasted till the impact but no flight data were recorded on the MSRP-12-96 magnetic tape at the moment of impact and during the last minute of flight.

1.12. Wreckage and impact information

The aircraft was completely destroyed during the impact with the ground. The wreckage fragments were dispersed over an area of 3 hectares in a forest.

1.13. Medical and pathological information

The documents subjected to analysis were:

- relevant medical documentation delivered by the Committee for Medical Examination of Aviation Personnel
- patient's sheets
- certificates of pre-flight medical examination of the crew members.

The site of accident was inspected, in addition, the state of investigation was checked at the Forensic Medicine Centre of the Medical Academy in Warsaw. The crew members' files were examined, besides the investigation in the crew members circles. In virtue of the above data the investigators stated that the crew members were free of any health troubles which could influence their professional proficiency, being also free of any deviations of psychophysiological nature in the period of the critical flight.

1.14. Fire

The fire on board the aircraft started and expanded in the baggage compartment, the crew members being unaware of that fact because of lack of warning signals until 0906:36 UTC.

The aircraft's impact against the ground caused an explosion as a result of which the fire covered an area of about 4 hectares in the forest. The fire fighting teams arrived at the site of accident after 21 minutes as counted from the moment of the crash. Their action was reduced to extinguish several sources of fire, wreckage parts and trees.

1.15. Survival aspects

24 ambulances were present at the site of accident. After having recognized the situation and stated that all the crew members and passengers died in the crash two of the

ambulances remained still at the site of crash. The two ambulances were provided with the resuscitating equipment intended in case of need for the teams participating in rescue operations.

1.16. Tests and research

1/ Expertises:

a/ Examination of the engines technical condition

- rough estimation
- detailed evaluation

b/ Dismantling the engines

c/ Tests of materials used for the following elements:

- fragment of broken shaft of the low-pressure turbine of engine N° 2
- intershaft bearings from engines N° 2 and 4 and, for comparison, from engines N° 1 and 3
- sleeve of labyrinth seal of the intershaft bearing of engine N° 2
- centering pull rods from engine N° 2 and 1
- sleeve from the high-pressure rotor from engine N° 2
- roller bearing of the rear support of engine N° 2
- fragments of low pressure turbine disks of engine N° 2
- holding down nut of the intershafts bearing assembly of engine N° 2

d/ Calculation of the state of energy of the low pressure turbine rotor e/ Calculation of the state of stress in the turbine rotor and evaluation of turbine casings strength

f/ Mechanoscopic test of the case of guide ring V of the low pressure turbine

g/ Physical/chemical tests of deposits on the internal surface of the broken shaft and tests of fragments of the outer channel casing from engine N° 2

h/ Examination and investigation of the history of use of engine type D-30KU in PLL "LOT".

i/ Measurement of torque applied to the holding down nut of the intershaft bearing assembly.

j/ Checking the labyrinth sleeve for correct mounting on the turbine shaft.

k/ Records of radio messages and communications of the crew.

l/ Records taken from the flight data recorders.

m/ Data concerning metallic particles in oil in precedent flights.

n/ Materials obtained from special tests of engines.

o/ Flight tests aimed at the examination of possibility of controlling the aircraft and landing with the help of the elevator trim tab.

2/ Results:

The direct cause of damage to engine N° 2 was the destruction of the low-pressure turbine rotor as a result of breaking loose of the turbine shaft.

The source of that defect was the increased wear of the intershaft bearing, the said wear contributing to the increasing eccentric rotation of the shaft. That eccentric rotation resulted in decreasing the clearance between the low-pressure turbine shaft and some elements of the high-pressure turbine shaft.

The shaft broke loose because of the engine long-lasting run with the intershaft bearing being worn to an increased extent. In virtue of the Supplier's documents /results of experiments, experience gained in the aircraft operation/ it has been stated that such a wear of the intershaft bearing in all the cases was recorded by board type recorders. The data recorded in the MSRP /MARS-BM/ during the last flight revealed the changes in the speed and fuel consumption of engine N° 2 for 10 to 15 seconds before the engine failure, but the warning signals about an increased or dangerous vibration were not recorded.

In the critical flight the wear of the intermediate bearing reached the limits thus causing friction of the shaft elements and, consequently, significant heat emission. The L.P. turbine shaft strength, as influenced by high temperature, got reduced below the loads to be carried by that shaft. The shaft destruction broke any mechanical link between the L.P. turbine and the L.P. compressor assembly driven by that turbine. The turbine speed increased until the rotor destruction due to centrifugal forces. Some pieces of the destroyed L.P. turbine shaft caused damage to engine N° 1 /outer, left/ thus precluding its further operation, in addition, they pierced the pressurized tail section of the aircraft fuselage contributing to a partial depressurization. The elevator control system was destroyed, the electric bunched cables were broken, moreover the baggage compartment catched fire. The damage to electric wires caused incorrect functioning or breaks in operation of numerous indicators, sensing elements, systems and suchlike /including among others the MSRP-64-2 flight data recorder/. On the ground of investigations it has been stated that engines N^{os} 1 and 2 were not on fire while the fire warning systen could be actuated by the stream of hot gases flowing around the fire sensing elements.

1.17. <u>Additional information</u>

The exchange of information between the air traffic services concerning the emergency action and rescue operations was efficient and correct. It did not influence the accident.

1.18. <u>Useful or effective investigation techniques</u>

A system of computer programmes prepared at the Aircraft Propulsion Centres at technical universities was applied to evaluate the stresses in rotor elements as well as to evaluate the limit strength of the rotor stages and the engines' casings resistance to collision with rotating loose elements.

2. ANALYSIS

The crew members held proper and valid certificates and ratings according to the actual Regulations. The psychophysical state and reactions of the crew members were at the normal level during all the flight.
The aircraft had a valid Certificate of Registration and a valid Airworthiness Certificate. The aircraft was equipped and maintained in accordance with actual Regulations and acceptable procedures. The accident was caused by the engine failure /see 1.16.2/.

Before the engine failure the crew carried out the normal procedures prescribed by the Flight Manual.

At 0841 i.e. two minutes after having passed over the VOR GRU the crew received acoustic signals informing about

- autopilot switching off
- depressurization of the cabin
- fire.

At the same time a pressure drop occurred in the cockpit. At 0842 UTC the crew stated the failure of engines N^{os} 2 and 1 and the impossibility of controlling the elevator with the help of the control column.

Considering the circumstances the crew determined to come back to Warsaw. Following the Flight Manual of the IL-62M, Chapter 3 "Emergency Procedures" the crew, after having received the signal of fire extinction, began the emergency descent then the fuel jettisoning for some 20 min. in order to get the permissible landing mass.

In spite of an extremely difficult situation the crew went on continuing the return flight, while the aircraft longitudinal control was carried out only by means of the horizontal stabilizer and elevator trim tab.

As it has been proved in a test flight after the accident the aircraft is controllable by means of the elevator trim tab so as to bring the aircraft to a low height and to perform an emergency landing.

Since 0852 till 0900 UTC a further loss of height and worsening condition of the aircraft systems have caused the consideration of an earlier emergency landing on the Modlin aerodrome. The crew members, after exchange of their opinions and remarks asked the clearance to land in Modlin. The landing clearance was granted after 2 minutes. However, after a further discussion, the crew took into consideration better possibility of conducting the rescue action on the Okęcie aerodrome and determined to fly to Warsaw and to land there with the 330° heading. That decision could be substantiated by the fact that there was no fire warning and that the crew managed to control the aircraft by means of the elevator trim tab.

The flight continued towards the VOR PMO with a further descent while the fire in the fuselage tail section was still expanding /without being signalled to the crew/.

After reaching the aerodrome the crew began the prescribed preparatory operations before an emergency landing, choosing runway 33 because of the wind favourable direction and velocity.

The two first landing alternatives in Modlin or Warsaw /with a straight-in approach, 150°/ are unobjectionable, whereas the third decision to land on runway 33 on the Okęcie aerodrome has its advantages and disadvantages.

The advantages were as follows:

- the head wind
- the obstacle free zone under the approach path.

Note: It should be noted that the fire warning system was inoperative until the aircraft was abeam the threshold of runway 33 i.e. in the point from which a quick landing was possible only on runway 33.

The disadvantages were as follows:

- prolongation of flight duration by 8 minutes or so
- necessity of carrying out some additional manoeuvres /turns/ during the approach to land. In the meanwhile the fire destroyed further elements of airframe, control system and accessories.

3. CONCLUSIONS

The cause of accident was the destruction of engine N° 2 resulting in disconnection of the longitudinal control system from the control column, cabin depressurization, damage to the electric system and fire. At the end stage of flight the fire caused the loss of the aircraft longitudinal control and the impact with the ground after 31 minutes as counted from the beginning of the emergency situation.

The destruction of engine No 2 occurred without any signal from the warning/testing system. Under the circumstances the crew members were not able to stop the engine in good time, consequently an emergency situation was created on board the aircraft.

4. SAFETY RECOMMENDATIONS

Proceed as follows:

1. Immediately inspect the internal surfaces of the L.P. turbine rotor shaft in order to detect eventual overheatings and oil deposits.
2. In the course of each inspection "B" measure the time from the moment of switching off the turbines till the moment of stopping the H.P. and L.P. rotors.
3. Check without any delay, irrespective of scheduled routine inspections the condition of oil system filters in all the engine type D-30KU viz.:
   - main oil filter MFS-30
   - CWS-30 signalling filter
   - filters of the MNO-30K sucking off pump.
4. Check the content of metal particles in oil /in particular Fe and Cu/ in PLL "LOT", in all the engines D-30KU after each arrival at Warsaw.
5. Check the engine vibration level in flight every flying hour at least /irrespective of mandatory filling in the Vibration Sheet in each flight/.

6. Introduce the vibration check by the ratio of amplitude increments in particular supports /bearings/ into the set of analytical/statistic data concerning the D-30KU engines.

7. Limit the TBO of the engines type D-30KU by reducing it from 3000 to 2500 running hours.

8. Forward the detailed statements of the accident investigating Committee to the Manufacturer for further research and proper action aimed at obtaining higher reliability of the D-30KU engine, at improving the methods of checking its condition and working parameters and, finally, at reducing the adverse effects of possible engine failure of the airframe.

ICAO Note.— Names of personnel were deleted.

ICAO Ref.: 117/87

No. 2

McDonnell Douglas DC-9-82, N312RC, accident at Detroit Metropolitan Wayne County Airport, Romulus, Michigan, USA, on 16 August 1987. Report NTSB/AAR-88/05 released by the National Transportation Safety Board, USA.

SYNOPSIS

About 2046 eastern daylight time on August 16, 1987, Northwest Airlines, Inc., flight 255 crashed shortly after taking off from runway 3 center at the Detroit Metropolitan Wayne County Airport, Romulus, Michigan. Flight 255, a McDonnell Douglas DC-9-82, U.S. Registry N312RC, was a regularly scheduled passenger flight and was en route to Phoenix, Arizona, with 149 passengers and 6 crewmembers.

According to witnesses, flight 255 began its takeoff rotation about 1,200 to 1,500 feet from the end of the runway and lifted off near the end of the runway. After liftoff, the wings of the airplane rolled to the left and the right about 35° in each direction. The airplane collided with obstacles northeast of the runway when the left wing struck a light pole located 2,760 feet beyond the end of the runway. Thereafter the airplane struck other light poles, the roof of a rental car facility, and then the ground. It continued to slide along a path aligned generally with the extended centerline of the takeoff runway. The airplane broke up as it slid across the ground and postimpact fires erupted along the wreckage path. Three occupied vehicles on a road adjacent to the airport and numerous vacant vehicles in a rental car parking lot along the airplane's path were destroyed by impact forces and/or fire.

Of the persons on board flight 255, 148 passengers and 6 crewmembers were killed; 1 passenger, a 4-year-old child, was injured seriously. On the ground, two persons were killed, one person was injured seriously, and four persons suffered minor injuries.

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's failure to use the taxi checklist to ensure that the flaps and slats were extended for takeoff. Contributing to the accident was the absence of electrical power to the airplane takeoff warning system which thus did not warn the flightcrew that the airplane was not configured properly for takeoff. The reason for the absence of electrical power could not be determined.

1. FACTUAL INFORMATION

1.1 History of the Flight

On August 16, 1987, a Northwest Airlines (Northwest) flightcrew picked up a McDonnell Douglas DC-9-82 airplane, N312RC, at Minneapolis, Minnesota, and operating as flight 750, flew the airplane to Saginaw, Michigan, with an en route stop at Detroit Metropolitan Wayne County Airport (Detroit-Metro), Romulus, Michigan, arriving at Saginaw about 1840 eastern daylight time. At Saginaw N312RC became flight 255 and was flown by the same flightcrew which had brought the airplane in. Flight 255, was a regularly scheduled passenger flight between Saginaw and Santa Ana, California, with en route stops at Detroit and Phoenix, Arizona. The flight was to be conducted in accordance with the provisions of 14 Code of Federal Regulations (CFR) Parts 91 and 121. About 1853, flight 255 departed Saginaw and about 1942 arrived at its gate at Detroit- Metro. Except for taxiing past and having to make a 180° turn to return to its assigned arrival gate, the flight to Detroit was uneventful.

After the disembarking passengers had left the airplane, a Northwest mechanic entered the cockpit and reviewed the airplane and cabin maintenance logbooks. He stated that no discrepancies were entered in either logbook. There was no record of any maintenance having been performed on the airplane while it was at Detroit-Metro.

About 10 to 15 minutes before the flight was due to depart the gate, a company transportation agent brought the flight release package to the airplane. He was met by the first officer who told him that the captain was not on board. The first officer inspected the package which contained the dispatch documents, signed the release, and returned the signed copy to the agent. As the agent left the airplane, he met the captain who had been conducting a walkaround inspection of the airplane and showed him the signed copy of the flight release. The captain studied the release, told the agent that it was all right, and thanked him.

About 2029, the final weight tabulation (weight tab) was delivered to the flightcrew. About 2032, flight 255 departed the gate with 149 passengers and 6 crewmembers on board. Flight 255 was pushed back to spot four. 1/ (See figure 1.) During the pushback, the flightcrew accomplished the BEFORE (engine) START portion of the airplane checklist, and, at 2033:04, they began starting the engines.

At 2034:40, after the engines had been started, the ground crew disconnected the tow bar from the airplane, and, at 2034:50, the west ground controller cleared the flight to "taxi via the ramp, hold short of (taxiway) delta and expect runway three center [3C] (for takeoff). . . ." The controller also informed the flightcrew that Automatic Terminal Information Service (ATIS) Hotel ("H") was now current and asked them if they had the information. The flightcrew repeated the taxi instructions and stated that they had the ATIS information. At 2035:43, the ground controller cleared flight 255 to continue taxiing, to exit the ramp at taxiway charlie (C), to taxi to runway 3C, and to change radio frequencies and then contact the ground controller on 119.45 Mhz. At 2035:48, the first officer repeated the taxi clearance, but he did not repeat the new radio frequency nor did he tune the radio to the new frequency. Thereafter, the first officer told the captain, "Charlie for three center, right."

ATIS "H" had been transcribed at 2028:35 and was being broadcast at the time of the accident. Examination of the cockpit voice recorder (CVR) recording showed that the flightcrew had not received information "H" before they began to taxi. However, at 2035:18, information "H" began on the first officer's radio channel, and, at 2035:55, he told the captain that he was leaving the airplane's No.1 radio "to get the new ATIS."

1/ A designated spot located on the outer ramp near taxiway Mike.

About 2025, the tower supervisor began coordination to change Detroit-Metro from a runway 21 configuration to a runway 3 configuration. The change was completed at 2028. ATIS "H" was the first ATIS transcription to contain and broadcast this information. It also described the ceiling and visibility and stated in part that the temperature was 88° F, that the wind was 300° at 17 knots, and that "... ILS approaches are in use to runways three left (3L) and three right (3R) departing runways three ... low level windshear advisories are in effect ..."

The takeoff performance data in the flightcrew's dispatch package was based on using either runways 21L or 21R; however, the flight had been instructed by the ground controller to taxi to runway 3C, the shortest of the three available runways. The final takeoff weight for the airplane was 144,047 pounds. At 2037:08, the captain asked the first officer if they could use runway 3C for takeoff. Because of the runway change, the first officer had to refer to the company's Runway Takeoff Weight Chart Manual to verify that their takeoff weight was below the allowable limits for runway 3C. The takeoff weight chart showed that with the flaps set at 11°, the maximum allowable takeoff weights for runway 3C at 85° F and 90° F were 147,500 pounds and 145,100 pounds, respectively. After consulting the manual, the first officer told the captain runway 3C could be used for takeoff and the captain concurred with the first officer's evaluation.

During the taxi out, the captain missed the turnoff at taxiway C. When the first officer contacted ground control, the ground controller redirected them to taxi to runway 3C and again requested that they change radio frequencies to 119.45 Mhz. The first officer repeated the new frequency, changed over, and contacted the east ground controller. The east ground controller gave the flight a new taxi route to runway 3C, told them that ATIS "H" was still current, that windshear alerts were in effect, and that the altimeter setting was 29.85 inHg. The flightcrew acknowledged receipt of the information.

At 2042:11, the local controller cleared flight 255 to taxi into position on runway 3C and to hold. He told the flight there would be a 3-minute delay in order to get the required "in-trail separation behind traffic just departing." At 2044:04, flight 255 was cleared for takeoff.

The CVR recording showed that engine power began increasing at 2044:21 that the flightcrew could not engage the autothrottle system at first, but, at 2044:38, they did engage the system, and that the first officer called 100 knots at 2044:45.6. At 2044:57.7, the first officer called "Rotate," and, at 2045:05.1, the stall warning stick shaker activated and continued operating until the CVR recording ended. At 2045:09.1, 2045:11.4, 2045:14.3, and, 2045.17.1, the aural tone and voice warnings of the supplemental stall recognition system (SSRS) also activated. Between 2044:01 and 2045:05.6, the CVR recording did not contain any sound of the takeoff warning system indicating that the airplane was not configured properly for takeoff.

Witnesses generally agreed that flight 255's takeoff roll was longer than that normally made by similar airplanes. They stated that the flight began its rotation about 1,200 to 1,500 feet from the departure end of the runway, agreed that it rotated to a higher pitch angle than other DC-9s, and agreed that the tail of the airplane came close to striking the runway.

Only a few witnesses recalled any details about the position of the airplane's leading edge wing slats, trailing edge wing flaps, or landing gear. Most of these witnesses said that the landing gear was retracted after liftoff. Two Northwest first officers recalled that the flaps and slats were extended. One first officer was in the airplane directly behind flight 255 in the takeoff sequence. According to her, "the flaps were extended, which is normal, but I could not ... state the actual degree of flap extension." She did not describe the position of the slats. The second first officer's airplane was parked on taxiway "A" between the ramp and taxiway "J." The airplane was facing runway 3C and about 150 feet from it. (See figure 1.) He testified that he observed the flaps and slats as flight 255 rolled past his airplane and, "The slats and flaps were extended." However, he was unable to estimate their degree of extension.

After flight 255 became airborne it began rolling to the left and right. Witnesses estimated that the bank angles during the rolls varied from 15° to 90°. Some witnesses stated that the airplane wings leveled briefly and then banked to the left just before the left wing hit a light pole in a rental car lot. Most witnesses did not see fire on the airplane until it was over the rental car lot. The first officer of the Northwest airplane parked on taxiway "A" testified that flight 255 was intact until the left wing struck the light pole in the auto rental car lot. After the wing struck the pole, he saw what appeared to be "a four- to five-foot chunk of the wing section . . ." fall from the airplane. He did not see any fire on the airplane until after it struck the light pole and then he saw "an orange flame. . . ." emanating from the left wing tip section.

After impacting the light pole, flight 255 continued to roll to the left, continued across the car lot, struck a light pole in a second rental car lot, and struck the side wall of the roof of the auto rental facility in the second rental car lot. Witnesses stated that the airplane was in a 90° left-wing-down attitude when it struck the roof and that it continued rolling and was still rolling to the left when it impacted the ground on a road outside the airport boundary. The airplane continued to slide along the road, struck a railroad embankment, and disintegrated as it slid along the ground. Fires erupted in airplane components scattered along the wreckage path. Three occupied vehicles on the road and numerous vacant vehicles in the auto rental parking lot along the airplane's path were destroyed by impact forces and or fire.

On board flight 255, 148 passengers and 6 crewmembers were killed; 1 passenger, a 4-year-old child was injured seriously. On the ground, two persons were killed, 1 person was injured seriously, and 4 persons suffered minor injuries.

The coordinates of the accident were 42°14' N latitude and 83° 20' W longitude.

1.2 Injuries to Persons

See table 1.

1.3 Damage to the Airplane

Table 1.--Injuries to Persons

	Crew	Passengers	Other	Total
Fatal	6	148	2	156
Serious	0	1	1	2
Minor	0	0	4	4
None	0	0	0	0
Total	6	149	7	162

The DC-9-82 was destroyed by ground impact and postimpact fires. According to the October 1987 Worldwide Aviation and Marketing Service (AVMARK) Newsletter, the price of a DC-9-82 varied between about $20.5 million and $21.5 million depending on how it was equipped.

1.4 Other Damage

The front and rear walls above the roof of the auto rental facility were damaged by impact forces and fire; the roof was damaged by fire. Three light standards in the rental car lots were damaged by impact forces. Numerous unoccupied automobiles in the rental car parking lot were damaged or destroyed by either impact forces, fire, or both. Two automobiles and a GMC truck located on the road outside the airport boundary were destroyed by either impact forces, fire, or both.

1.5 Personnel Information

The flightcrew and cabin crew of flight 255 were qualified in accordance with applicable Federal and Northwest regulations and procedures. (See appendix B.) Examination of the flightcrew's training records did not reveal anything unusual. In addition, the investigation of the flightcrew's personal background and actions during the 2 to 3 days before the accident flight did not reveal anything remarkable.

The Captain.-- The 57-year-old captain was hired originally by West Coast Airlines on October 3, 1955. In 1980, as a result of two mergers, West Coast evolved into Republic Airlines. On January 23, 1986, Northwest Airlines bought Republic Airlines and the combined companies were renamed Northwest Airlines Inc. The captain remained employed continuously by the companies throughout the transactions. During his 31 years with these companies, the captain was type rated on seven different airplanes ranging from the McDonnell Douglas DC-3 to the Boeing 757 (B-757). He also served as a Federal Aviation Administration (FAA) designated check airman in the B-727 (September 1978-July 1979) and the DC-9 and DC-9-82 (September 1979-April 1984) airplanes.

The captain upgraded initially to captain in December 1972. Except for one 17-month period during 1978-79 and one of about 4 months during 1985 while serving as captain on Boeing 727s (B-727), the captain had flown airplanes with a two-pilot crew. (See appendix B.)

The captain had upgraded to captain on the B-757 in February 1986. However, after the merger, Northwest disposed of the six B-757s which had been operated by Republic. The disposal of these airplanes required the captain to return to the DC-9-82. 2/ The captain requalified as captain in the DC- 9-82 in May 1987. Northwest pilots are not cross utilized in the DC-9-82 and other DC-9 series airplanes. Since May 1987, the captain had been assigned to and had flown only the DC-9-82.

Virtually all of the interviewed first officers and other captains who had flown with the captain described him as a competent and capable pilot. They stated that the captain always used the airplane checklist. One first officer stated that the captain had a reputation "as a strict, by-the-book pilot who would not tolerate any deviation from standard procedures."

Three of the captain's present or former supervisors stated that they had never had any professional or personal problems with him.

The First Officer. --The 35-year-old first officer was hired by North Central Airlines in May 1979. Republic Airlines resulted from a merger of North Central and Southern Airlines. The first officer has been employed continuously by North Central, Republic, and Northwest Airlines since his date of hire.

With the exception of one training report during his early probationary period with the airline, all of the captains with whom the first officer had flown graded his performance as average or above average. Comments contained in some of his grade sheets described him as follows: "competent pilot," "easy to work with," "good in all respects," and "very personable, thorough job . . ."

2/ The DC-9-82 is a derivative of the McDonnell Douglas DC-9-80 series airplane. The airplane is also referred to as MD-80 or MD-82. The description DC-9-82 will be used herein unless a referenced publication, document, or quote specifies another name, in which case the referenced name will be used.

One captain with whom the first officer recently had flown stated that he appeared to be a good pilot. Although he did not remember if the first officer had initiated checklists, he stated that the first officer did not appear to be a "yes man" and that he remembered the first officer handling a very busy period "very well and calling a potential problem [to his] attention." Other captains who recently had flown with the first officer described his ability and performance in favorable terms.

The first officer's supervisors stated that they had not had any personal or professional problems with him.

The Northwest records showed that the captain and first officer had flown together on August 7-10 and 14-15, 1987. During this 6-day period they had flown 18 trip legs.

1.6 Airplane Information

The DC-9-82, U.S. Registration N312RC, was manufactured on October 15, 1981; it was delivered to Republic Airlines on December 8, 1982. Since delivery, N312RC has been operated by Republic Airlines and, after its purchase of Republic, by Northwest Airlines, Inc.

The airplane was powered by two Pratt and Whitney Model JT8D-217 turbofan engines. The JT8D-217 engine has a normal and maximum sea level static thrust ratings of 20,000 pounds and 20,850 pounds at 84° F and 77° F, respectively; these ratings are limited to 5 minutes.

Examination of the airplane flight and maintenance logbooks did not reveal any discrepancies or malfunctions that would have contributed to the accident. In addition, the examination disclosed that, at the time of the accident, there were no discrepancies or malfunctions in the logbooks involving minimum equipment list (MEL) items. 3/

1.6.1 Weight and Balance

According to the Northwest DC-9-82 Airplane Pilots Handbook (APH), the maximum certificated takeoff weight of the airplane is 149,500 pounds. The airplane is limited to a maximum tailwind of 10 knots for takeoff and landing and a maximum demonstrated crosswind of 30 knots for takeoff and landing. The actual airplane weight for the takeoff at Detroit Metro was 144,047 pounds, its computed center of gravity (c.g.) for the ensuing takeoff was 9.8 percent of the mean aerodynamic chord (MAC) of the wings and was within the forward and aft c.g. limits of 3.1 percent and 24.4 percent MAC, respectively.

The CVR showed that the latest runway temperature information known to the flightcrew was the 88°F reading contained in ATIS "H." The CVR also showed that the flightcrew planned to use 11° flaps for the takeoff. Based on the 88°F ambient temperature, flaps at 11°, and the slats at the takeoff or mid-sealed position, the company's takeoff weight chart showed that the maximum allowable takeoff weight for runway 3C was 146,060 pounds and that reduced engine thrust could not be used for takeoff. The required engine pressure ratio (EPR) for the ensuing takeoff would have been 1.95. The takeoff weight charts provided weight corrections based on headwind or tailwind components. On runway 3C, the maximum allowable weights either could be increased by 230 pounds for each knot of headwind or had to be decreased by 960 pounds for each knot of tailwind.

3/ A list containing the equipment and procedures required for continuing flight beyond a terminal point.

1.6.2 Flap and Slat Systems

The trailing edge flaps and leading edge slats are extended and retracted by the flap/slat handle (flap handle) located on the right side of the control pedestal.

The wing trailing edge flap system consists of an inboard and outboard flap segment on each wing. Each flap segment is powered by an inboard and outboard hydraulic cylinder on each wing. The outboard cylinders are operated by the left hydraulic system; the inboard cylinders are operated by the right hydraulic system. Although the flaps normally operate on pressure from both hydraulic systems, they will operate on a single system at a reduced rate. All flap segments are linked together mechanically to provide synchronization during extension and retraction.

Six fixed position detents are located along the left side of the flap handle, track, or race: UP/RET, 0°, 11°, 15°, 28°, and 40°. When the flap handle is positioned in any of the detents, a pin on the left side of the handle drops into the detent and keeps the handle at the selected position while the flaps move to the commanded position. To move the flap handle from, for example, the 11° detent to the UP/RET detent, a spring-loaded lever, or trigger, on the left side of the handle must be raised to release the pin from the detent. As the lever is moved forward, the trigger must be held in the raised position until the flap handle has cleared the 0° detent. After passing the detent, the trigger must be depressed to transit the slat retract gate and reach the UP/RET detent.

The numbers on the fixed position detents describe the flap position in degrees. When the flap handle is in the UP/RET detent, the flaps and leading edge slats are retracted. When the flap handle is in the 0° detent, the flaps are still retracted, but the slats are extended to the mid-sealed position. When the flap handle is moved to the 15° or higher degree detents, i.e. the 28° or 40° detents, the slats extend fully.

A movable, or dial-a-flap detent allows the flightcrew to select takeoff flap settings anywhere in the 0° to 13° range or 15° to 24° range. The movable detent is positioned by a thumbwheel on the flap handle module. It moves along the right side of the flap handle track and provides a detent which is engaged by a pin on the right side of the flap handle. A takeoff flap setting in the 0° to 13° range will extend the slats to the mid-sealed position; flap settings in the 15° to 24° range will place the slats in the extended position. The movable detent was not used for the accident takeoff.

The flap positions are portrayed on an indicator located on the lower right side of the center instrument panel and almost directly in line with the flap handle. A transmitter mounted on the inboard hinge of each outboard flap segment provides flap position information to the cockpit indicator, the stall warning computer, and the digital flight guidance computers (DFGC). The flap position indicator contains superimposed pointers and a dial which is graduated in degrees of flap travel. The pointers respond to actual flap movement and will normally move in unison.

The slats are wing lift augmentation devices located on the leading edge of the wings. Each wing slat is divided into six segments that are fastened together and operate as a single unit. Each slat is actuated by two hydraulic cylinders. One cylinder is operated by the left hydraulic system and the other cylinder is operated by the right hydraulic system. The actuating cylinders extend and retract the slats through a pulley, a closed cable, and a track system. The slats normally are operated by pressure from both hydraulic systems, but they will continue to operate, at a reduced rate, by pressure from a single hydraulic system. Movement of the flap handle from the UP/RET position drives a pushrod to rotate a cable drum in the lower portion of the control pedestal. Two closed loop cable systems transmit the handle motion to a cable drum within the flap and slat sequence mechanism which in turn positions hydraulic control valves to extend the slats.

Positioning the flap handle to the 15° or higher degree detents will move the slats to the extended position. The movement of the flap handle through this selection range rotates a cable drum in the control pedestal. The rotation of the cable drum drives a nonadjustable pushrod which positions a synchro and a rotary switch containing five microswitches. The synchro provides a flap position signal to the speed command system. Two microswitches are used in the slat position indication system; one microswitch provides information to the auto brake system, and the two remaining microswitches provide 28 volt d.c. (28V d.c.) signals to the two stall warning computers. The output of the stall warning computers drive two electric jackscrew actuators (the autoslat actuators) to position the hydraulic control valves to drive the slat to the extended position in response to the pilot commands from the flap handle.

Slat position status is provided by four slat advisory lights located to the right of the flap position indicator. When the flap/slat handle and slats are in takeoff range the takeoff light (blue) will illuminate. The other three positions that can be displayed by the advisory lights are disagree, auto, and land. These advisory lights are not lit when the slats are retracted.

1.6.3 Takeoff Condition Computer

The Takeoff Condition Computer (TCC) is used by the flightcrew to determine the airplane's stabilizer trim setting for takeoff. The stabilizer trim settings are determined by entering calculated takeoff values for c.g. and flap setting into the computer mounted on the left side of the control pedestal. When the appropriate c.g. and flap setting appear in their respective readout windows, the stabilizer setting numeric value will appear in the takeoff condition longitudinal trim window and the computer will position the longitudinal trim takeoff position indicator to the same value contained in the trim window. This value may then be set by moving the stabilizer until its longitudinal trim indicator is aligned with the longitudinal trim takeoff position indicator. In addition, the flap setting inserted into the takeoff condition computer is used as the reference value by the takeoff warning system to determine that the flaps are set for takeoff.

1.6.4 The Digital Flight Guidance System

Thrust Computer Indicator.--The thrust computer indicator (TCI) provides EPR limit values for six flight modes based on temperature. The modes of flight, which can be selected by depressing the appropriate pushbuttons on the TCI, include takeoff (T.O.), reduced thrust takeoff or takeoff flexible (T.O. FLX), go-around (GA), maximum continuous thrust (MCT), climb (CL), and cruise (CR).

Flight Director System.--The DC-9-82 is equipped with a flight guidance system for flight guidance throughout the entire flight envelope (takeoff to landing). The flight director (F/D) function of this system provides visual guidance commands to fly the airplane manually or to visually monitor autopilot and autothrottle response to the guidance commands. Flight guidance system operating modes can be selected for the F/D function with autopilot and autothrottle functions disengaged. The F/D modes selected by the pilots are annunciated on the pilot's flight mode annunicators (FMA) located on the top of each pilot's instrument panels. The digital flight data recorder (DFDR) records the F/D and autothrottle system modes that are annunicated on the FMA.

Pitch and roll data from the flight guidance computers are displayed on the attitude director indicator (ADI). A V-shaped command bar (command bar) directs the pilot to turn, climb, or descend. Although the F/D provides visual guidance commands throughout the entire flight envelope, the events leading to the accident occurred during the takeoff roll and initial liftoff phases of flight. Therefore, the discussion herein will be limited to the takeoff mode of operation which was relevant to those phases of the flight.

The F/D's "Takeoff"mode uses two different methods to position the command bars from takeoff roll up to the altitude at which the F/D is either turned off or the pilot selects another mode of operation. The method of operation is based on either the airplane's height above the ground or the elapsed time since liftoff. After the airplane has either climbed to 80 feet agl or 11 seconds have elapsed since main gear liftoff, whichever occurs first, the F/D's commands compensate for changes in the airplane's flap/slat configuration. The control laws in the digital flight guidance computers (DFGC) continuously calculate the desired reference speed for the existing airplane configuration, compare the actual airspeed to the reference speed, and position the command bar to provide the appropriate nose-higher or nose-lower cues to the pilot to correct the variation between the actual and reference airspeeds.

The F/D operates differently when the airplane is either below 80 feet agl or before the requisite 11 seconds since main gear liftoff has expired. The DFGC laws use longitudinal acceleration (in the form of airspeed change) airplane configuration, and angle of attack. The F/D's system logic is designed to provide a target pitch attitude after rotation as the airplane is accelerating to the first segment climb speed. It assumes that the airplane is in an acceptable takeoff configuration and is rotated at the proper speed for that configuration. While the airplane is still on the runway and below the normal climb speed, the F/D predicts what the pitch attitude should be and positions the command bar to display this attitude during rotation and liftoff. However, the command bar position only displays 37 percent of the unsatisfied pitch command. For example, if the predicted pitch attitude during the takeoff roll was 20° nose-up, the command bar position would present a 7° nose-up pitch command to the pilot. The major contribution to the display is acceleration.

After rotation, the airplane's horizontal acceleration declines because the energy used to accelerate it is traded for climb angle. The F/D cue, still a predictor of proper pitch attitude continues to use the airplane's configuration and angle of attack, and it compares the predicted flightpath angle to the actual flightpath angle which is calculated from the existing vertical speed and airspeed. The sum of the predicted flightpath angle and the required angle of attack (based on airplane configuration) yield the commanded pitch attitude. As a result, the F/D command bar generally will require a nose-up attitude which will allow the airplane--with both engines operating at takeoff power--to reach V2 4/ + 10 KIAS at 35 feet agl and to maintain that airspeed. After the airplane either climbs through 80 feet or 11 seconds have elapsed after main gear liftoff, whichever occurs first, the DFGC adds a reference airspeed term to determine the applicable pitch attitude correction.

After the F/D has been turned on, pressing either of the two takeoff-go-around (TOGA) palm switches while the airplane is operating in ground mode will place the F/D in the takeoff mode; pressing either switch after the airplane lifts off places the F/D in the go-around mode. (A TOGA palm switch is located on each throttle lever just below the knob on top of the lever.) The FMA annunciations recorded by the DFDR showed that the F/D entered the go-around mode about 4 seconds after the weight of the airplane had moved off its main landing gears. After go around has been selected the F/D commands a minimum +6° flightpath angle by inserting a nose-up pitch command above the existing command bar position for about 7 seconds. In this case, the command bar would rise about 2° above the existing position. Thereafter it will phase in speed command data to reposition the command bar. Assuming the flaps were at 11° and the slats were in the mid-sealed position, with both engines operating, the command bars would have commanded a pitch attitude which would capture and maintain V2 + 10 KIAS. However , assuming that the flaps and slats were retracted, with both engines operating, the command bars would be positioned to command a pitch attitude which would capture and maintain 1.5 Vs, 5/ or about 252 KIAS. At the

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4/ V2--Takeoff safety speed.

5/ The stalling speed or the minimum steady flight speed at which the airplane is controllable.

Safety Board's public hearing in Romulus, the director of the McDonnell Douglas Flight Guidance and Controls Design Engineering Department testified, however, that the accident flight had terminated before the F/D presented any commands designed to achieve the 1.5 Vs target speed.

With regard to takeoff procedures, the normal procedures section of the Northwest APH states that, at the call of rotate, the pilot flying "will initiate a smooth steady up elevator movement normally requiring a positive pull force and approximately a 6-8 second interval to rotate to a maximum of 20° pitch attitude. Following the V COMMAND bar will give proper V2 pitch attitude."

Autothrottle System.--The autothrottle system (ATS) function of the autothrottle speed command system automatically positions the throttles to maintain airspeed or engine thrust as required for the operational mode selected and the airplane control configuration. The ATS will control the throttles for the following maneuvers: takeoff, climb, cruise, holding, approach, flare, and go-around. The ATS is engaged by moving the autothrottle switch on the flight guidance control panel on the glare shield from the OFF position to the autothrottle (AUTO THROT) position. The solenoid-held switch will not remain in the AUTO THROT (engage) position until all interlocks and engage requirements have been satisfied.

The ATS takeoff mode will provide automatic engine thrust control during the takeoff roll, liftoff, and climbout. However, with the F/D in takeoff mode, the autothrottle switch will not engage unless the TCI has been placed in either the T.O. or T.O. FLX modes. Thus, the ATS takeoff mode is initiated by selecting T.O. or T.O. FLX on the TCI, pushing the takeoff palm switch on the throttle, and engaging the autothrottle switch on the flight guidance control panel. When the autothrottle switch has been engaged, the ATS will advance the throttles until the EPRs have reached the limit set in the TCI. When the airplane has accelerated to 60 KIAS, the ATS will enter the clamp mode. Power is removed from ATS's servo motor, movement of the autothrottles is prevented during rotation and liftoff, and the acronym "CLMP" is annunciated in the thrust window of the FMA.

Automatic Reserve Thrust System.--During takeoff, the automatic reserve thrust system (ART) provides automatic engine failure detection and a subsequent thrust increase on the operating engine. The system is completely self-testing and requires no action by the flightcrew except for extending the slats and enabling the system by placing the guarded ART switch in the automatic (AUTO) position. Two annunciator lights are provided on the center instrument panel. With both engines running and the self-test function satisfied, a green READY light illuminates when the slats have been extended, indicating that the system is available for use. An amber ART light indicates that the system has detected a 30 percent differential in N_1 rpm and the ART solenoid in the fuel control has actuated to provide the increased thrust on the remaining engine. The system is disabled automatically when the slats are retracted after takeoff, extinguishing the green READY light.

1.6.5 Stall Protection System

The DC-9-82 uses a two-computer stall warning recognition and protection system; either computer can detect an approach to stall and operate the system. The system monitors angle of attack (AOA), the rate of change of the AOA, and airplane configuration to provide several warnings to the pilots. When the airplane is in a takeoff configuration, i.e., the flaps and slats are extended to their commanded positions, the system will predict an impending stall, activate the autoslat extend portion of the warning, and extend the slats from the mid-sealed to the full-extend position. If the near stall condition persists or develops again, the stick shaker will activate providing the pilot with the standard Federal Aviation Administration (FAA) prescribed warning of impending stall. This warning has at least a 4 percent speed margin above the 1 G stall speed. 6/ As the AOA increases to near the stall AOA, a supplemental stall recognition system (SSRS) will illuminate "STALL" signs on the left and right sides of the cockpit glare shields, activate a series of aural tones, and state the word, "stall." This is an announcement that the stall AOA has been reached and that there is no more safety margin. If the condition lasts for 6 seconds or the AOA increases an additional 3°, a post stall recovery system (PSRS) activates a stick pusher that forces the control column forward, pitching the airplane in a nose-down direction. If the slats are retracted, autoslat extension and the PSRS are disabled.

1.6.6 Central Aural Warning System

The DC-9-82's central aural warning system (CAWS) provides distinctive aural (horn, "C" chord, chime, and bell sounds) and vocal (electronically-generated system identification words) indications when potentially unsafe operating conditions, unsafe airplane configurations, or system malfunctions exist. Each voice message is preceded by an associated warning tone. The voice message is cycled with a 1-second aural tone, followed by a 1- (second voice message identifying the unsafe configuration, condition, or malfunction for the duration of the warning period. The CAWS contains 12 defined warning systems; however, given the circumstances of the accident, the discussion herein will center on the SSRS and the takeoff warning system.

The components of the CAWS include the CAWS unit located on the forward right radio rack in the electrical and electronics compartment and two speakers located, one each, in the captain's and first officer's side consoles. The CAWS unit contains three internal power supplies which are powered individually by 28V d.c. electrical power from the airplane's electrical distribution system. In accordance with Federal certification requirements, circuit breakers have been installed on the 28V d.c. input lines to protect the airplane's electrical system from overloads caused by high electrical current draws. The three circuit breakers are located on the circuit breaker panel mounted on the aft cockpit bulkhead directly behind the captain's seat. Thus, the 28V d.c. input to power supply-1 within the CAWS unit is routed from the d.c. transfer bus through circuit breaker U-31; 7/ the 28V d.c. input to power supply-2 is routed from the left d.c. bus through circuit breaker P-40; and the 28V d.c. input to power supply-3 is routed from the right d.c. bus through circuit breaker R-41. The failure or loss of power to any of the three d.c. distribution buses will be annunciated by a failure light on the overhead cockpit annunciator panel. The failure of either the left or right d.c. bus also illuminates the airplane's master caution light.

The 12 warning systems are divided among the three power supplies of the CAWS units. Except for the SSRS, there is no redundancy, and the failure of a power supply will result in the loss of its associated warning systems. SSRS-1 operates off power supply-2 and SSRS-2 operates off power supply-3. When SSRS-1 and -2 are activated by the stall protection system, SSRS-1 will provide a tone and the word "stall" to the captain's speaker; it also will illuminate the stall warning light on the captain's side of the glare shield. SSRS-2 will provide the same data to the first officer's speaker and will illuminate the stall warning light on his side of the glare shield. Although SSRS-1 and -2 are activated simultaneously, the word warnings are not, and one word trails the other by a small fraction of time and produces an "echo" type sound within the cockpit. According to the Northwest APH, flightcrews must check the stall warning system during the RECEIVING AIRPLANE checklist. The

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6/ Title 14 CFR 25.201(d)(1) states, in part, that the "airplane may be considered stalled when, at an angle of attack measurably greater than that for maximum lift, the inherent flight characteristics give a clear and distinctive indication to the pilot that the airplane is stalled." The flight characteristics used to determine the stall speed of the DC-9-80 series airplanes are contained in 14 CFR 25.201(d)(1)(ii) which states, in part, "A roll that cannot be readily arrested . . . "

7/ Grid positions are used to locate each circuit breaker on this panel. Circuit breaker U-31 is on horizontal row "U" and vertical row No. 36.

APH states, in part, that the RECEIVING AIRPLANE checklist will be completed when originating a flight following an overnight layover; when a new flightcrew accepts an airplane; when an interrupted flight is resumed when the airplane has been left unattended for an extended period of time or the TERMINATING checklist has been completed; when maintenance has been performed that requires the repositioning of cockpit switches with no crewmember present; and whenever the captain deems it necessary. The APH contains the following note:

> During the aural portion of the test, an echo effect will be heard if both channels are producing the STALL voice of the central aural warning system at the same time.

The takeoff warning system is powered by power supply-2 and is programmed to provide a modulating horn for 1 second, followed by a voice warning identifying the system or systems, control or controls not properly configured for takeoff. Thus, if the slats are not set for takeoff and the slat takeoff light is not illuminated, the warning system will state the word "slats"; if the flap handle is not in agreement with the value set in the flap window of the takeoff condition computer, the warning system will state the word "flaps;" and, if the horizontal stabilizer is not set within the green band of the longitudinal trim indicator, the warning system would state the word "stabilizer." If more than one out-of-configuration condition exist, the voice warning will identify, in turn, each out-of-configuration control.

The takeoff warning system is disabled in flight by the R2-5 ground sense relay. This relay is controlled electrically by the operation of the nose gear strut and removes power from the warning system when the strut extends on takeoff.

At the time of the accident, the APH required the flightcrew to check the takeoff warning system during the RECEIVING AIRPLANE checklist. The check is made during the spoiler check when the throttles are advanced to about 4 inches of throttle travel to check the performance of the spoiler lever. The APH states, in part:

> The takeoff warning horn will sound after the throttles have been advanced to the takeoff position. Allow the CAWS to cycle through at least one cycle: " STABILIZER, AUTO BRAKES, BRAKES, FLAPS AND SLATS."

The warning is activated by throttle lever position and not by engine power settings.

The company MEL required the takeoff warning system to be operational for flight. Given the checklist requirement that the system be checked during the RECEIVING AIRPLANE checklist, the system should have been checked before the airplane departed Santa Ana for Minneapolis and by the accident flightcrew when they took over the airplane at Minneapolis. The captain who flew the airplane to Minneapolis testified that he had checked the system before leaving Santa Ana and found it functional. In addition, a Northwest first officer who rode in the cockpit jump seat with the accident flightcrew from Detroit to Saginaw on the day of the accident testified that the captain had to add power to make a sharp turn off the runway to a taxiway. He stated that during the turn he heard the words "flaps, flaps" annunciated by the SSRS. He testified that he did not recall hearing the warning horn, just the vocal warning.

On September 1, 1987, McDonnell Douglas issued a telex to all DC-9-80 operators. The telex recommended that the airplane checklist be changed and that the takeoff warning system be checked before departing the gate on each flight. All DC-9-80 operators have incorporated this change in their checklist procedures.

On September 23, 1987, the FAA issued a memorandum creating a special team to review the performance of takeoff configuration warning systems on all type air carriers so equipped and the procedures used by the carriers' flightcrews to verify that the warning system is operational. The review team investigated the types of takeoff warning systems that are in use and the procedures used by maintenance and flightcrew personnel to check the performance of these systems. As of the date this report was adopted the review team has not released the results of its investigation.

1.6.7 CAWS Unit Self-Monitor System

Normal operation of the CAWS occurs when the airplane's 28V d.c. buses are energized and the circuit breakers protecting the input lines to the CAWS unit are closed. The CAWS unit has a self-monitoring capability that encompasses about 80 percent of its internal components. When an internal failure is detected, CAWS fail lights on the overhead cockpit annunciator panel and on the front of the unit are illuminated. If the failure mode within the unit is corrected, the annunciator light in the cockpit will go out. However, the fail light on the unit is operated by a latching-type relay and once lit, the relay latches and the light remains lit until the unit is removed by maintenance personnel, opened, and the relay is reset.

Although the self-monitoring programs compare the input power to and the output power from the three power supplies within the CAWS unit, the program logic will not classify the loss of 28V d.c. input to a power supply as a fault and illuminate the two fail lights. In this case, the logic would note that there is no power output from the power supply because input power is missing, and therefore, the internal power supply has not malfunctioned. During the postaccident investigation in a like-type airplane and CAWS unit, the P-40 circuit breaker latch was opened manually removing 28V d.c. power from power supply-2 of the CAWS unit. The two CAWS fail lights did not illuminate.

During the development of the CAWS for certification by the FAA, McDonnell Douglas and the FAA conducted a failure mode and effects analysis (FMEA) of the system. The FMEA analyzed the types of possible system failures, how the failures could be detected, and the results of the failures. Severity of the hazards to flight resulting from these failures were categorized into four classes: Class I - Safe; Class II - Marginal; Class III - Critical; and, Class IV - Catastrophic. Also, the FMEA evaluated whether the airplane could be dispatched with a particular component or system inoperative. The failure of the entire CAWS and the failure of just the takeoff warning channel of the CAWS were classified as a Class I risk. The FMEA stated that the airplane should not be dispatched with an inoperative CAWS, but it could be dispatched with the takeoff warning channel inoperative.

With regard to the takeoff warning channel, the FMEA stated that the loss of the input 28V d.c. to power supply-2 will cause the CAWS fail lights to illuminate. The director of the McDonnell Douglas Flight Guidance and Controls Design Engineering Department and a supervisory aerospace engineer in the Systems and Equipment Branch at the FAA Aircraft Certification Branch, Long Beach, California, testified this statement was erroneous. The FAA supervisory aerospace engineer testified that FAA approval of FMEAs of noncritical systems were normally granted by an FAA-designated engineering representative (DER). 8/ However, in this case, because the incumbent DER did not have the requisite experience to approve the FMEA, it was submitted to the Systems and Equipment Branch at the Aircraft Certification Branch where it was approved.

8/ An employee of the manufacturer deputized by the FAA in accordance with the provisions of 14 CFR Part 183.11(c)(1) to review and verify certain elements of the design.

The FAA supervisory aerospace engineer also testified that the FMEA would have been approved even if it had portrayed correctly that the loss of the 28V d.c. input power would not illuminate the CAWS fail lights, "because it's a non-essential system. There's other means by which the pilot can verify the event that's causing that warning or would cause the warning had it not failed. There's other means by which he would normally check his airplane."

Finally, with regard to the cockpit CAWS fail light, the McDonnell Douglas director of Flight Guidance and Controls Design Engineering testified that the light was installed as a maintenance aid and that "if the crew had any squawks about the central aural warning system, if there weren't a light, [maintenance personnel] would have to climb around the avionics compartment and first off run through the tests on the front of the [CAWS unit] and see if there was a fault light . . . . We thought it would be an aid to the maintenance of the airplane to put a light in the overhead which would indicate the computer had failed . . . the flightcrew could write it up . . . if the light were on . . . and the maintenance crew would know where to go." He testified that this was the reason that the CAWS unit monitors only its internal components.

1.7 Meteorological Information

The August 16, 1987, 2000 surface map, prepared by the National Weather Service (NWS), showed a low-pressure system just north of central Lake Superior with a cold front extending south then south-southwest through central Wisconsin, southwestern Iowa, northwestern Missouri, and into the Texas Panhandle. There was an instability line about 60 miles to the east and parallel to the front from northwestern Wisconsin into north central Texas. Conditions in the vicinity of Detroit were characterized by light, southerly winds; broken clouds; and haze.

The following aviation surface weather observations were recorded by the NWS at Detroit-Metro before and at the approximate time of the accident:

> Time--1950; clouds--2,500 feet scattered, 4,500 feet scattered, ceiling estimated 15,000 feet broken; 25,000 feet broken; visibility--6 miles, haze; temperature--88° F; dew point--68° F; wind--180°/ 7 knots; altimeter--29.83 inHg.; remarks--cumulonimbus west through northwest through north moving east.
>
> Time--2048; clouds--2,500 feet scattered, ceiling estimated 4,500 feet broken, 10,000 feet overcast; visibility--6 miles, haze; temperature--79° F; dew point--66° F; wind--280°/12 knots; altimeter--29.85 inHg.; remarks--cumulonimbus northwest through north moving east.

At 1930, the NWS radar observation at Detroit-Metro placed the airport within an area that was 3/10 covered by thunderstorms with very heavy rain showers and thunderstorms that were increasing in intensity. The cells were moving from 260° at 20 knots, and the maximum top was 40,000 feet 21 miles west of the airport.

At 2054, the NWS radar observation placed Detroit-Metro within an area that was 5/10 covered by thunderstorms with very heavy rain showers. The cells were moving from 260° at 25 knots, and the maximum top was 40,000 feet 39 miles northeast of the airport.

The NWS radar observer at Selfridge Air Force Base, Michigan, stated that there were no thunderstorms in the immediate vicinity of Detroit-Metro at the time of the accident. Between 2000 and 2010, the Detroit Edison Company's lightning detection system recorded a lightning strike about 12 miles north-northwest of Detroit-Metro , and between 2000 and 2100, no other lightning activity was recorded in Wayne County.

Only one pilot report (PIREP) pertinent to Detroit-Metro was found on the teletype summaries at the Detroit Flight Service Station (FSS). The PIREP stated, in part, that at 2006, a Boeing 727 had encountered moderate turbulence 5 miles west of Detroit-Metro.

The following winds were recorded by the centerfield anemometer of Detroit-Metro's low level windshear alert system (LLWAS). (See section 1.10.)

From 2015:52 to 2016:49 -- 220° magnetic (M) to 230° M at 8 to 9 knots.

From 2016:16 to 2018:54 -- 230° M to 280° M at 8 to 14 knots gusting to 30 knots.

From 2019:10 to 2020:16 --280° M to 300° M at 16 to 21 knots gusting to 30 knots.

From 2021:39 to 2022:37 -- 290° M at 19 to 21 knots.

From 2029:31 to 2030:29 -- 290° M at 20 to 21 knots.

At 2045, about the time of the accident, the centerfield anemometer recorded 300° M at 13 to 15 knots.

On August 16, 1987, sunset at Detroit-Metro was at 2034; civil twilight ended at 2058. At the time of the accident, the moon was below the horizon.

1.8 Navigational Aids

There were no known navigational aids difficulties.

1.9 Communications

There were no known difficulties with communication equipment or facilities.

1.10 Aerodrome Information

Detroit-Metro, elevation 639 feet msl, is located in Romulus, Michigan, about 15 miles south of downtown Detroit. The airport was certificated in accordance with the applicable provisions of 14 CFR Part 139.

Detroit-Metro was served by four runways: 3L/21R, 3C/21C, 3R/21L, and 9/27. At the time of the accident, runway 9/27 was closed because of construction and a Notice to Airmen (NOTAM) denoting its status was issued on August 10, 1987.

Runway 3C/21C was 8,500 feet long and 200 feet wide. The first 4,387 feet of runway 3C was grooved concrete; the remaining 4,113 feet was grooved asphalt, and its magnetic heading was 33.5°. Runway 3L/21R, the principal instrument runway, was 10,500 feet long, 200 feet wide, and was constructed of grooved concrete. Runway 3R/21L was 10,000 feet long, 150 feet wide, and constructed of grooved concrete. Since none of the instrument approach procedures were used by flight 255 during the accident sequence, descriptions of the procedures have been omitted.

At the time of the accident, runway 3C was being used as the primary departure runway. Runways 3L and 3R were being used for landing aircraft. Runway 3L was not available for takeoffs because taxiway Golf was closed from taxiway Hotel south to the runup area of runway 3L; however, if requested by a pilot, runway 3R was available for takeoff. In addition, taxiway Hotel was closed between taxiways Golf and Foxtrot (see figure 1) in conjunction with the runway 9/27 construction project. Notice of the closures were included in the Foxtrot, Golf, and Hotel ATIS messages.

During the accident sequence, flight 255 struck a light pole located in a rental car lot on the airport property. The light pole was 42.2 feet high and was 2,760 feet beyond the departure end of runway 3C. Based on the applicable provisions of 14 CFR 77.23 and 77.25, the pole did not penetrate any civil airport imaginary surfaces and, therefore, did not constitute an obstruction to air navigation.

The light pole had been constructed in accordance with an approved airport layout plan as required by the provisions of Advisory Circulars (AC) 150-5300-4, 4B, Utility Airports, Air Access to National Transportation. On May 5, 1986, before the light pole was built, the airport authority requested the FAA Airspace Branch to conduct an aeronautical study of the construction proposal which included the construction of 40-foot-high light poles in the rental car lot. On June 12, 1986, the Airspace Branch completed the study and informed the airport authority that, "Based on that study we interpose no objection from an airspace utilization standpoint." However, due to the bases used to support the light poles, the poles extended 42.2 feet above the ground.

Low Level Windshear Alert System.-- At the time of the accident, a low level windshear alert system (LLWAS) was operating at Detroit-Metro . The LLWAS detects and displays the presence of possible hazardous, low-level windshears by continuously comparing the winds measured by six anemometers (sensors) located at the center and around the periphery of the airport. The Detroit-Metro LLWAS also records data generated by the system's sensors. (See section 1.18.)

The centerfield sensor is located near the geographic center of the airport. Boundary sensors are located near the approach and/or departure areas of the various runways at the north, northeast, east, south, and west sections of the airport periphery.

The LLWAS computer compares the vector components (wind direction and speed) collected by the boundary sensors with the vector components collected by the centerfield sensor. The centerfield sensor uses a tachometer to generate a wind gust input signal. The computer determines windshear magnitude by calculating the vector differences between the vector component values collected at the boundary sensors and the values collected at the centerfield sensor. When the vector difference exceeds 15 knots, the LLWAS computer initiates a windshear alarm and identifies the boundary sensor(s) where the shear is occurring.

LLWAS data are portrayed on a display in the control tower cab. The display portrays the wind data and gusts collected by the centerfield sensor continuously. The display also shows the wind direction and speed collected at each boundary sensor; however, a boundary sensor(s) wind data display is normally blanked out (unlit) unless it is involved in a windshear alarm. When the LLWAS computer generates one or more windshear alarms, an aural tone occurs at the display unit, and the wind data indicators on the affected boundary sensor(s) begin flashing. The aural warning beeps twice after the alarm occurs. The affected boundary sensor(s) continue to flash for the duration of the shear and for about 1 minute after the computed windshear alarm ceases.

The ATC recording of the local controller east (LC-E) position showed that LLWAS alarms had been received in the tower cab between 2015 and 2030 and had been broadcast by the LC-E controller over his frequency. The recording also showed that, at 2019, Northwest flight 1146 had reported a variation of plus or minus 20 KIAS between 500 and 300 feet agl while on final approach to runway 21R. ATIS Golf and Hotel were transcribed at 2020:32 and 2028:35, respectively. Both messages stated "windshear advisories are in effect."

Selection of Active Runways.--The tower supervisor has the primary responsibility to determine which runways are to be designated as active runways. Under normal circumstances, the supervisor selects the runways that are aligned closest with the wind. However, in addition to the wind direction and speed on the airport surface, the supervisor must consider the weather and wind conditions in the vicinity of the airport, weather forecasts, LLWAS indications, availability of lighting and electronic navigational aids, runway and taxiway closures, and the operational impact of the proposed change.

The tower supervisor stated that during the last 15 to 20 minutes that Detroit-Metro had been operating in the runway 21 configuration there were four or five LLWAS alarms and that he observed the wind shift toward the northwest. He stated that, about 2015 or 2020, a United Airlines B-727 reported a microburst moving from west to east with no rain associated with it. In addition, at 2019, the tower received a windshear report from an airplane on final approach to runway 21. He stated that runway 27 was closed; that a NOTAM had been issued; and that it was more advantageous to operate, winds permitting, in the runway 3 configuration. Therefore, at 2025, the tower supervisor began coordination to change from a runway 21 to a runway 3 configuration. The change was completed at 2028, and, at 2029, the instrument landing systems (ILS) were changed to the runway 3 configuration.

The guidelines for runway configuration changes by ATC personnel at Detroit-Metro are contained in tower order DTW ATCT 7110.3, dated April 29, 1981. The configuration change was completed in accordance with the subject order.

1.11 Flight Recorders

The DC-9-82 was equipped with a Fairchild model A-100-A cockpit voice recorder, serial No. 25334, and a Fairchild model F800 digital flight data recorder, serial No. 102. The recorders were taken to the Safety Board's flight and voice recorder laboratories in Washington, D.C., for examination and readout.

1.11.1 The Cockpit Voice Recorder

Except for some minor impact damage and sooting on its exterior dust cover, the CVR was in excellent condition. The recording medium was not damaged, and it had not been subjected to any excessive heating during the postcrash fire. The audio quality of the 32-minute, four-track tape was excellent. Track-1 of the tape was connected to the captain's radio/intercom panel; track-2 contained no recorded information (this track is usually connected to the flight engineer's radio control panel in a three-crewmember airplane); track-3 contained the cockpit area microphone (CAM) information; and track-4 was connected to the first officer's radio/intercom control panel.

The recording, which started at 2013:27 while the airplane was parked at the gate loading passengers and continued until 2045:24, was transcribed. (See appendix C.) The captain and first officer were in the cockpit and remained there throughout the entire recording. At 2035:35, a 0.35-second interval on the tape was devoid of any information on all four tracks; the void area was caused by a factory splice which connects the two ends of the tape to make the endless loop required for a Fairchild CVR.

While the airplane was at the gate and while it was taxiing, only the radio transmissions to and from flight 255 and between ATC and other airplanes which influenced the conversation between the captain and the first officer were transcribed. After the flight switched to the tower local control frequency, all ensuing recorded radio transmissions were included in the transcript. Flightcrew members' voices were identified by persons who were familiar with the captain and the first officer.

At 2028:53, the Northwest ramp controller cleared flight 255 for pushback from the gate. Examination of the first 15 minutes of the transcript showed that during the initial 8 to 9 minutes, the captain and first officer were occupied for the most part with mapping weather data on the company's turbulence plot. Thereafter, they became engaged in a conversation with members of the cabin crew concerning whether they would be able to arrive at Santa Ana before the local noise abatement curfew and the logistics involved in the event they were unable to leave Phoenix in sufficient time to arrive at Santa Ana before the curfew. Other portions of this transcript will be referred to herein as they become relevant to the subject under examination.

Four SSRS alarms were recorded by the CVR after the airplane lifted off. The portion of the recording containing these alarms were used to perform a sound spectrum analysis. (See section 1.16.2.)

1.11.2 The Digital Flight Data Recorder

The digital flight data recorder (DFDR) was damaged by impact forces and postaccident fire. The dust cover was dented and scraped and the frame of the recorder was deformed slightly. The fire damage was confined to sooting and there was no appreciable heat damage. The DFDR was opened and examined. The interior was clean and undamaged and the recording medium was in place on all capstans, pulleys, and guides.

Most DFDRs record up to sixty-four 12-bit words of digital information every second. Each 64-word group which is provided by the flight data acquisition unit (FDAU) to the DFDR is called a subframe, and four subframes comprise a frame. Each subframe in the frame has a unique (Barker Code) 12-bit synchronization word identifying it as subframe 1, 2, 3, or 4, and the synchronization words are the first word in each subframe. Each data parameter (i.e., altitude, airspeed, heading) is recorded in a fixed sequence within the subframe. If the data stream is interrupted, the synchronization words will not appear at the proper interval or sequence and synchronization will be lost, thus affecting the ability to decipher data in that subframe or until another synchronization word is detected.

However, the Fairchild model F800 incorporates a different recording technique. The FDAU data stream is reformatted from the standard 12-bit word to a 15-bit word. This technique, known as group code recording (GCR), replaces 4-bit nibbles with 5-bit input groups.

At the time of the accident, the DFDR was using the sixth of it six recording tracks to record data and the strength of the signal recorded on the edge tracks, tracks 1 and 6, was significantly lower than the others. Because of the lower signal strength and the fact that at the time of the initial readout the Safety Board's playback station had to reformat the recorded data from GCR to the standard 12-bit word format, the synchronization on track 6 could not be maintained at an acceptable level. As a consequence of the synchronization loss, a significant amount of data could not be deciphered and the DFDR tape was taken to the manufacturer for readout.

The manufacturer's playback equipment was able to recover the data in the GCR format, and the recovered data was of sufficient quality to perform an evaluation of the airplane's configuration and performance. However, the readouts also had a number of random synchronization losses wherein the periods of losses varied from one readout to the next. Consequently, a number of data transcriptions were accomplished in an attempt to recover all the data. As a result of these attempts, all pertinent data relating to the accident flight have been recovered.

After the initial readout at the manufacturer's facility, the Safety Board wrote a custom software package tailored to the specific requirements of this readout. The software package allowed the Safety Board to transcribe the GCR words directly. It enhanced the method of establishing synchronization by increasing the number of synchronization references. The package not only reduced the out-of-synchronization shifts in the recording, but, when these shifts did occur, the new software identified and marked the subframe in which the out-of-synchronization shift began. Using this software, the Safety Board produced a more complete readout of the DFDR's recorded data which was used to reproduce the values cited throughout this report.

The DC-9-82's FDAU receives information from the airplane's sensors, converts the sensors' inputs to digital form, and transmits the resultant signals to the DFDR where it is recorded. Flight 255's FDAU, a Teledyne Control, part No. 2222601-6, serial No.1795, was recovered from the wreckage. It was shipped to the manufacturer's facilities in Los Angeles, California, where two separate tests were performed under the supervision of Safety Board investigators.

On September 4, 1987, a visual inspection of the FDAU found that it had been damaged slightly. Power was applied and the unit functioned normally. Thereafter, the synchronization values which affect parameters, such as flap position and pitch and roll attitudes were tested and found to have been out of tolerance. However, functional tests of the discrete signals which indicate the slat position, the flap handle disagree position, and the FMA mode parameters showed that all these discrete parameters were correct.

The first test did not develop sufficient information to quantify the extent of the FDAU's synchronization error throughout its full 0° to 360° range of values. Therefore, on December 17, 1987, a second test was conducted at the manufacturer's facility. During this test the FDAU's synchro values were evaluated at 5° increments throughout their entire range. The test showed that the 0°/360° and 180° values were within tolerance but that the error increased as the values moved away from those positions. The maximum error occurred about 45° on either side of the 0° and 180° positions. As a result of the test, correction algorithms were developed. The correction algorithms were applied to the results of the previous DFDR readouts and the values contained therein were corrected.

The corrected values were then compared to known conditions that existed during the accident flight, the landing and takeoff at Saginaw, and the landing and subsequent taxi to the gate at Detroit-Metro. To verify the corrected data, the heading, flap, and spoiler position parameters were chosen for comparison because of their predictability. The original DFDR readout showed that flight 255's heading during the takeoff run was between 27° and 28°. The corrected data show these values to be between 32° and 33° and the actual runway heading was 33.8°.

The recorded flap angles during the Saginaw takeoff indicated a setting of 9.3 transitioning to -0.336 shortly after liftoff. The corrected values show settings of 10.8° transitioning to -0.304°. Normal takeoff flap settings are 7° and 11°. The DFDR showed the following uncorrected flap positions for the landing at Detroit-Metro: 13.2°, 24.7°, 34.5°, and -0.336°. The corrected values were 15.1°, 27.3°, 39.3°, and -0.304°; detents are provided for the 0°, 11°, 15°, 28°, and 40° flap settings.

During landings, the spoilers are automatically extended to the 60° or full deployed position after main wheel spinup on ground contact or after nosegear oleo strut compression actuates the ground shift relays. The recorded left and right spoiler positions during the previous landings at Saginaw and Detroit-Metro were 51.2° and 51.8° uncorrected and 59.6° and 59.5° corrected, respectively. Examination of the above data showed that the corrected data is in closer agreement with known or expected conditions.

All recorded DFDR data cited throughout this accident report are the corrected readout values.

The airplane's pitch attitudes are recorded on two separate DFDR readout channels. Although the pitch attitude data for these channels are retrieved from the same sensory sources, the sensors are sampled separately by each channel during a 1-second interval and the data contained in the pitch attitude-2 channel is processed to a higher resolution by the FDAU than the data contained in the pitch attitude-1 channel. Examination of the readouts showed that their recorded pitch attitude values varied about 0.15° until the airplane was rotated for takeoff. During the rotation, the recorded values began separating and, thereafter, the pitch attitude-1 values exceeded the pitch attitude -2 values by 1.5° to 2.9°.

Correlation of the CVR recording with the recorded pitch attitudes showed that SSRS alarms on the CVR were more compatible with the pitch attitudes contained in the pitch attitude-2 channel.

During takeoff, the tail of the DC-9-82's will strike the runway when the airplane is rotated to about an 11.7° pitch attitude. During the 3 seconds before flight 255 lifted off the runway, pitch attitudes of about 12.4°, 13.2°, and 12.9° were recorded by the pitch attitude-1 channel, whereas, the pitch attitudes recorded in channel-2 were about 10.8°, 11.3°, and 11.3°. During this 3-second interval, the airplane would have rolled about 835 feet; however, there was no evidence on the runway of a tail strike and the tail bumper of the airplane was not scratched.

An engineering evaluation of these data indicated that the pitch attitudes contained in the pitch attitude-2 channel reflected more accurately the airplane's pitch attitudes during rotation and the subsequent flight. These values were used by the Safety Board during the subsequent airplane performance study.

The DFDR and the CVR were time correlated by comparing the radio microphone keying recorded by the DFDR with the radio transmissions from flight 255 recorded on the CVR. The correlation began at 2035:48 on the CVR and ended at 2045:19, when the sound of impact was recorded; the elapsed CVR time was 9 minutes 31 seconds. Based on the times contained on the DFDR recording, the correlation begins at 0117:14 and ends when all reliable data is lost at 0125:52; the elapsed DFDR time was 8 minutes 34 seconds. Examination of the DFDR recording showed that a synchronization loss encompassing all recorded data begins at 0124:44 (2043:18 on the CVR transcript) and synchronization was not regained until 0124:49 (2044:14.8 on the CVR transcript). At 2042:11, flight 255 was cleared into position on runway 3C and to hold. The DFDR recording indicated that the flight completed its turn to the runway heading about 2043:14, and at 2043:18, a sound of a click was recorded on the CVR transcript and the DFDR lost synchronization. At 2044:04, the local controller cleared flight 255 to takeoff and, at 2044:08, the first officer repeated the clearance. At 2044:14.8, a "sound similar to parking brake released" was recorded on the CVR's CAM followed, at 2044:21, by the "sound of increasing engine power." Examination of the DFDR readout showed that, at 0124:49 on the DFDR recording, the engine power was increasing. In correlating the DFDR and CVR, it was also necessary to take into account that on this airplane when the parking brakes are set power is removed from the DFDR and that it will not record useable data immediately upon the reapplication of power.

Examination of the recorded data from the two flights previous to the accident flight showed that, except for short time intervals when the slats were in transit to a commanded position, the flap handle position was always in agreement with the slat position.

DFDR data recorded during the taxi out and takeoff at Detroit-Metro showed that throughout the entire period the flap setting was -0.304°, the slats were retracted, and there was no disagreement between the flap handle and the slat position. During the period surrounding the loss of synchronization just before the start of the takeoff roll, the positions and values noted above were the same immediately before synchronization was lost and immediately after synchronization was regained.

The DFDR data, CVR cockpit communications, ATC communications, airplane geometry, and airport environs were integrated by the Safety Board to construct a visual depiction of flight 255's departure. The visual displays starts when flight 255 is still at the departure gate and includes the flight's pushback from the gate, taxi to runway 3C, takeoff, and initial impact. (See appendix D.)

1.12 Wreckage and Impact Information

The first object flight 255 struck after liftoff was a 42.2-foot-high light pole located in a rental car lot. The pole was about 2,760 feet beyond the departure end of runway 3C. There were no ground impact marks and no pieces of airplane structure between the light pole and the end of runway 3C. The wreckage path ran along a road outside the airport boundary and along a heading oriented essentially with the departure runway. The last major piece of airplane fuselage structure, a section of the forward fuselage containing the cockpit, came to rest about 2,980 feet beyond the light pole. Virtually all of the wreckage was found between the light pole and the forward fuselage section.

The left wing struck the light pole about 37 feet agl and, thereafter, the airplane began to disintegrate. The majority of the witnesses stated that the airplane caught fire after the left wing struck the light pole.

The nose and left main landing gears were found in the extended and partially extended positions, respectively. The right main landing gear had broken apart, and it was not possible to determine if it was extended or retracted.

Both engines had separated from their mounts during the accident sequence. The left and right engines came to rest about 3,090 feet and 2,393 feet, respectively, beyond the initial impact point. The left engine had not been exposed to ground fire, and all engine appurtenances external to the core engine had separated during the impact sequence. Most of the fan blades were bent opposite to the engine's direction of rotation.

The right engine was exposed to extensive ground fire which was fueled, in part, by ignition of the magnesium castings of the engine gearbox. All of the recovered fan blades had been bent opposite to the direction of rotation of the engine.

On August 30, 1987, a teardown inspection was conducted at the Pratt & Whitney Aircraft Group Facility, East Hartford, Connecticut. The blades on the left engine's low pressure compressor's 1.5 stage and second stage rotors and on its high pressure compressor were bent opposite to the direction of rotation of the compressors. Also, carbon deposits were found inside the engine's front accessory drive case. The blades on the second and third stages of the right engine's low pressure compressor were bent opposite to the compressor's direction of rotation.

Fuselage and Empennage. --The fuselage structure had disintegrated and was scattered throughout the wreckage path. Only two relatively large pieces of structure remained: the forward area from fuselage station (FS) 7 to FS 541 and the aft area from FS 1007 to FS 1338.

The forward fuselage section and cockpit were battered heavily and the top and upper sections broke open and tore away during the accident sequence. The cockpit area also broke open and the roof and side walls tore away. This section also had some localized burn damage.

The aft section contained the main rear wall of the landing gear well aft to the rear pressure bulkhead and the auxiliary power unit (APU). The front portion of the section was lying upright with the upper cabin section broken and burned away. The exposed cargo area was empty and gutted by fire. The APU section was not damaged heavily by either fire or explosion and the APU was relatively intact.

The empennage had broken into two major pieces. The major pieces consisted of the top 3 feet of the vertical stabilizer and right horizontal stabilizer and the base of the vertical stabilizer. These two pieces were found about 2,120 feet beyond the initial impact point.

The left horizontal stabilizer and elevator had disintegrated and pieces of these two structures were scattered throughout the wreckage site. The first pieces from the two structures were found about 650 feet beyond the initial impact point along with pieces of the left wing leading edge slat and slat support structure.

The horizontal stabilizer trim jackscrew was found mounted in position in the vertical stabilizer with the jackscrew extended. The jackscrew extension measured 9.87 inches which corresponds to a 6.65° airplane nose-up stabilizer trim setting.

Left Wing.--After striking the light pole, the left wing broke apart and pieces were scattered throughout the wreckage area. The largest intact piece, a relatively unbattered 17-foot-long section of outboard wing with most of the left aileron and outboard (No. 5) slat still attached, was found about 1,000 feet beyond the initial impact point. The slats on each wing are numbered zero through 5 beginning with the inboard slat and then moving outboard along the wing. About 19 inches of the outboard end of the No. 5 slat was broken away and the slat could be moved manually to the extended or retracted positions.

The leading edge of the separated outboard wing section was crushed aft at the point where it had separated from the inboard section of the wing. The separation line was relatively straight between the leading and trailing edges of the wing section. The fractured area included the integral fuel tank structure and was sooted and discolored by heat. Except for a 4-foot section of the outboard trailing edge which was warped, sooted, and discolored by heat, the remaining portion of the wing outboard the fuel tank had little fire damage.

The No. 4 slat had broken away from the separated wing section and an outboard section of the slat was found near the separated wing panel. The inboard broken area of the slat was crushed aft, and the location of the break and crushing aligned with the inboard separation line on the wing panel.

The remaining leading edge slats on the left wing were broken apart and their pieces were recovered throughout the wreckage area. Fourteen of the 15 left wing slat tracks were identified; the common idler track between the Nos. 2 and 3 slats was missing. The slat tracks are either drive or idler tracks. The drive tracks are connected to the slat positioning mechanism by cables and are moved by the cables to drive the slats to the commanded positions. The idler tracks are attached to and move with the slats and provide structural support to the slats. The slat tracks were examined for damage marks which may have been caused by the track rollers as the airplane broke apart.

The No. 5 slat's outboard idler track had a brinell mark that matched the diameter of the track support and guide rollers on the upper face of the lower outboard flange located about 3 1/8 inch aft of the flange's forward end. A similar brinell mark was located on the upper face of the lower inboard flange about 3 1/4 inch aft of the flange's forward end. When the rollers were aligned with the brinell marks, the position of the drive track corresponded to a fully retracted slat.

The No. 5 slat's outboard driver track was intact in the slat support assembly with the drive cables connected to the transition drum. Roller damage on the track flanges corresponded to a near full extended slat, and portions of the forward support rollers were found in the rental car lot just beyond the initial impact point. Damage on the No. 5 slat's inboard driver track was similar to that found on the outboard driver track. The No. 5 slat's common idler track which supports the Nos. 4 and 5 slats was undamaged.

The cables of the transition drum of the No. 5 slats were attached to the drum, and there was no slippage around the drum groove. The cables were continuous from the drum to the separation point on the outboard wing section. When the drum was positioned to extend the slats to their full extend position, the breaks in the forward and rear cables were misaligned 15 1/2 inches. This misalignment placed the forward cable fracture point outboard the wing separation point (inside the wing structure) and the rear cable fracture point inboard the wing separation line. When the cables' fracture points were aligned, the fractures also were aligned with the wing separation point and the slat tracks would have positioned the slats in the full retracted position. Also, application of tension on the rear cable moved the slat tracks toward the slats extended position.

The brinell marks on the Nos. 3 and 4 slat driver tracks corresponded to the slats being extended fully. The remaining slat tracks did not have notable damage.

The slat drive mechanism located in the center wing section separated from the airplane; however, the slat drive drum and its two actuators were recovered in one piece. The actuator rod on the left side was broken, but the actuator rod on the right side was intact. The actuator rod for the right actuator was almost fully retracted and measured about 4 inches between the centerline of the rod attachment bolt and the raised center area on the actuator's face. According to McDonnell Douglas, the measured distances between these two points for the slat retracted and the mid-sealed position were 3.6 and 9.6 inches, respectively.

The inboard and outboard trailing edges flap sections were torn from the left wing and destroyed. The two actuators of the inboard flap section remained attached to a 16-foot-long inboard section of the left wing which was found about 2,800 feet beyond the initial impact point. When first examined, both actuators were extended 16.3 inches when measured between their attachment point to the airplane structure. However, the inboard flap sections of the two actuators exhibited a dirt pattern on both the actuator housing and the rod end with clean piston rod exposed between the housing and rod end. When the actuator rod was positioned so that the dirt areas were continuous, the actuator measured 13 inches between its attachment points. This measurement corresponds to the flap retracted position.

The inboard actuator from the left outboard flap section exhibited a dirt pattern similar to that described above. The actuator measured 13 inches between attachment points when the dirt areas were continuous which corresponded to a full retracted flap position. The outboard actuator of this flap section was not found.

The left flap track assembly, which was relatively intact and undamaged, was still attached to the inboard end of a section of left inboard flap. A 1 3/4-inch-long dent was found on the inside surface of the track flange about 1 1/4 inches forward of the track's aft end. The size and shape of the dent matched the size and shape of the carriage rollers which ride along the inside of the flange and the location of the dent corresponded to the flap retracted position.

Examination of the flaps, the flap hydraulic system, and the actuators disclosed that the integrity of the flap hydraulic system was destroyed and that the actuators' plumbing was open to the atmosphere.

Right Wing.--The right wing was destroyed by impact forces and postimpact fire. Pieces of the wing structure were scattered throughout the wreckage path. The largest piece of wing structure, an 18-foot-long inboard wing section, came to rest about 2,700 feet beyond the initial impact point. A section of the inboard and outboard trailing edge wing flaps was still attached to the wing section by three of the four flap actuators and their respective hinge attachment points. The fourth flap actuator, the right inboard flap section's inboard actuator, was attached to fuselage structure. A section of the leading edge slats also was attached to this wing section by five track attachment points. The slat section was in one piece. It was burned heavily, discolored by heat, and could be moved manually from the extended to the retracted position.

Fourteen of the 15 slat tracks were found; the No. 1 slats inboard idler track was not found. Only two of the 14 tracks had notable marks. The No. 4 slat drive track had brinell marks at a position which corresponded to a fully extended slat. A small section of the No. 3 slat drive track was broken away at a position which corresponded to a fully extended slat.

The right inboard flap section's inboard actuator (No. 1) measured 17 7/8 inches between attachment points, and the rod was sooted evenly. The inboard flap section's outboard actuator (No. 2) was attached to the wing and flap structure as were the outboard flap section's inboard (No. 3) and outboard (No. 4) actuators. The Nos. 2 and 3 actuators measured 13 1/2 inches between attachment points. The No. 4 actuator measured 14 3/4 inches between attachment points; however, sooted and clean areas were found on the piston rod. There was a 1 5/16-inch clean area between the actuator housing and the start of the sooted area on the rod end of the piston rod. A measurement of 13 inches between the actuator attachment points corresponded to the flaps retracted position.

The right flap track assembly had separated from the flap structure but was recovered intact. The track assembly damage was similar to the left flap track assembly. The track flange was damaged about 3/4 inches from the aft end of the flange and about 2 3/8 inches of the flange was torn away. The size of the damage matched the size of the track carriage rollers, and the location of the damage corresponded to the flap retracted position.

The Cockpit.--The position of the cockpit controls and indicators were fully documented. The following pertinent observations are listed herein.

The ART switch was in the automatic position, and two zeros were showing in the TCI's assumed temperature window indicating that normal takeoff power was to be used.

The throttles were found in the full forward positions.

The TCC had 10.1 percent inserted in the c.g. window; 9.7° appeared in the longitudinal trim setting window; the stabilizer green band was at 8.5° airplane nose-up;and the stabilizer was set at 8.5° airplane nose-up. The position of the TCC flap setting thumbwheel could not be established during the on-site investigation because the wheel had broken away in the area of the pedestal window. When the unit was examined more closely at the Douglas facility in Long Beach, portions of the wheel were found intact within the unit. Interpolating between the two nearest numbers on the remaining portions of the thumbwheel established that it was set at 11°.

The annunciator pull-to-dim switch on the overhead switch panel was in the dim position and the switch stem was bent aft.

The flap handle was in the UP/RET detent and the dial-a-flap movable detent assembly was stowed. The cockpit control pedestal containing the flap handle and the flap and slat selection mechanisms was removed for teardown and detailed inspection. The following systems and parts of airplane structure were removed for further detailed examination (see section 1.16): numerous circuit breakers, the CAWS unit, portions of the cockpit instrument and annunciator panel and warning light systems, the DFGC, the stall warning computers, the central air data computers (CADC), and the proximity switch electronics unit (PSEU).

1.13 Medical and Pathological Information

The postmortem examinations of the captain and first officer determined that their deaths were caused by severe blunt force trauma. No evidence of preexisting disease processes were noted.

Toxicological tests conducted after the postmortem examinations were negative for drugs and alcohol. There was no evidence that indicated either pilot was using prescription or nonprescription medication either at or before the time of the accident.

The captain sometimes wore an "in the canal" hearing aid in his left ear which was adjusted for high frequency emphasis. The captain's wife stated that she and some friends had encouraged him to purchase the hearing aid not because of conversational difficulties but because he required the television to be tuned to higher volumes than others would require.

The captain was examined for the hearing aid by a private firm on September 8, 1986, and the evidence indicated that he received the aid on September 24, 1986. On April 22, 1987, the captain passed his first class FAA physical examination. The medical certificate did not contain any remarks concerning his using a hearing aid nor did it contain any remarks requiring him to use the aid while exercising his airman's privileges. During the examination, his hearing was evaluated by "whispered voice, standing sideways, distant ear closed." The medical examiner concluded that the captain could hear the whispered voice satisfactorily at a distance of 20 feet with both his left and right ears. Friends and crewmen with whom he had flown stated that they had no difficulties communicating with him.

With regard to the first class medical examination, question No. 21 on the medical form (FAA Form 8500.8, dated 10- 75) requires the applicant to supply his medical history to the examiner. None of the 24 conditions requiring an answer in question No. 21 addresses either a hearing loss or treatment for hearing problems, and the captain did not mention his hearing evaluation under question No. 23 which asks the applicant to describe any "Medical Treatment Within Past 5 Years."

External examination of the other airplane occupants showed that all had sustained multiple injuries. According to the Wayne County Medical Examiner, autopsies of the victims were not performed in view of obvious injuries which caused instantaneous death. The medical examiner stated that 10 percent of the victims "sustained burns and all fire injuries were post mortem." The survivor, a 4-year-old female child, sustained third degree burns, a skull fracture, fractures of the left femur and clavicle, and multiple lacerations, abrasions, and contusions.

1.14 Fire

The DC-9-82 caught fire after its left wing struck the light pole. The postimpact fire contributed to the destruction of the airplane.

1.15 Survival Aspects

The DC-9-82 was configured for a two-person flightcrew and 143 passengers. The passenger cabin was configured with 12 first class passenger seats: three rows of double seats on the left and right sides of the cabin. The 131 tourist class seats, including a designated flight attendant seat (29D) consisted of 28 rows of triple seats on the right side and 24 rows of double seats on the left side of the cabin. A double occupancy aft facing flight attendant seat was on the aft left side of the cockpit rear bulkhead; a double-occupancy forward facing flight attendant seat was located on the ventral airstairs aft exit door.

The wreckage was distributed over a 3,000-foot crash path which traversed a railroad embankment and overpass and two interstate highway overpasses. Except for two fairly large fuselage sections, the cabin area disintegrated during the crash sequence. The cabin components were deformed severely and fragmented by the impact forces. Most of the interior components were damaged to varying degrees by fire. The main entry door, the rear galley and ventral doors, and the overwing emergency exits were separated from their frames. All of the passenger seats were separated from the fuselage and were scattered along the wreckage path. Most seatbacks were separated from the seat bottoms.

The left side of the cockpit was destroyed. The left and right side sliding windows were deformed and separated from the cockpit structure. The windshield and side windows were found along the wreckage path. The captain's and first officer's seats separated during the impact sequence.

The survivor was found in the wreckage beneath one of the highway overpasses. According to the company's passenger manifest, she had been assigned seat 8F.

1.15.1 Crash, Fire, Rescue

Detroit-Metro airport fire department operates in accordance with Crash, Fire, Rescue (CFR) Index E contained in 14 CFR 139.49(b)(5). 9/

At 2046, the airport fire department was notified of the accident by the local controller in the tower, and all available CFR equipment was dispatched and proceeded to the accident scene. At the same time, a unit of the Wayne County's Sheriff's Department notified its communications dispatcher that an airplane was down at Middlebelt and Goddard Roads. Another sheriff's department unit responded, took command of the scene, and called for all available units to assist at the site.

At 2049, airport fire department personnel arrived at the scene about 2 1/2 miles from Fire Station 1 and began to fight the fires. At the same time, two units from the Romulus Fire Department arrived at the highway overpass where the cockpit wreckage was located and began rescue and firefighting operations. About 36,000 pounds of Jet- A fuel were on board the airplane when it crashed.

A major command post was established at the sheriff's department about 2 miles from the crash site and a mobile command post was established at the site. Other fire departments, affiliated through the Western Wayne County Mutual Aid Agreement, reported to the scene as required by the agreement. At 2102, after extinguishing localized fuselage and spot fires, firefighting efforts were ended. A total of 19,908 gallons of water and 775 gallons of aqueous film forming foam (AFFF) were expended by the airport fire department; 3,075 gallons of water were expended by the Romulus Fire Department.

At 2050, Detroit-Metro issued a NOTAM stating that the airport was closed. At 2115, the previous NOTAM was canceled, and, in accordance with 14 CFR 139.89(c), a second NOTAM was issued stating that the airport was below (the Part 139) index without specifying which index. At 2400, a third NOTAM was issued canceling the 2115 NOTAM and advising that the CFR equipment was back in service. There were 75 air carrier operations at Detroit-Metro during the period that it was below the CFR index.

Police Response.--The Wayne County Sheriff's Department responded with all available personnel. After evaluating the crash scene, the Sheriff's Department notified the Michigan State Police and surrounding police departments. About 40 police departments

9/ The applicable CFR index in 14 CFR 139.49 is determined by the longest large aircraft operated by an air carrier user with an average of five or more departures per day, served or expected to be served by the airport. Index E applies to aircraft more than 200 feet long.

Michigan State Police and surrounding police departments. About 40 police departments volunteered personnel and equipment. Surrounding police departments were assigned to maintain site security and to control traffic.

Medical Response.--At 2054, the Health Emergency Medical Services, Inc. (HEMS), an independent corporation contracted by area hospitals to dispatch emergency medical services, was notified. After verifying the alert, HEMS notified personnel to staff the emergency operations center at the sheriff's department. At 2102, the HEMS dispatcher began alerting hospitals of the accident; 11 were alerted. At 2110, the dispatcher polled all hospitals for a bed count, however, at 2140, the command post at the accident site notified HEMS that there were no additional survivors. At 2204, HEMS secured its disaster plan and notified its member hospitals.

1.15.2 Disaster Plans

Detroit-Metro Emergency Plan met the requirements of 14 CFR 139.55. The airport's last FAA annual inspection was completed satisfactorily on April 7, 1987, and its last airport disaster drill, a simulated major airplane crash, was conducted on September 11, 1985.

On March 4, 1987, Detroit-Metro's fire department responded to an actual disaster when a commuter air carrier's CASA 212 airplane crashed and burned at concourse F on the airport.

During May 1987, HEMS, in conjunction with fire departments and private ambulance services, conducted a disaster drill in which a simulated tornado struck an elementary school.

1.16 Tests and Research

1.16.1 The CAWS Unit

N312RC's electrical and electronics (E&E) compartment was found virtually intact in the wreckage path. The CAWS unit, serial No. 131, was removed from the E&E compartment and taken to Northwest's maintenance facilities at Minneapolis. On August 27 and 28, 1987, it was examined by the Safety Board's system group.

Except for a dent in the top left corner of the dust cover, N312RC's CAWS unit was undamaged. The dust cover was removed, the interior inspected, and all of the circuit boards appeared to be intact. Another CAWS unit, serial No. 61, was drawn from Northwest's stores, placed on Northwest test equipment, and subjected to a complete test procedure. The test results showed that the CAWS was operational. Thereafter, the five circuit boards from the accident CAWS were substituted in the test CAWS and a functional test was performed with each circuit board; the results were satisfactory. Each of the three power supplies in the accident CAWS' empty chassis were then tested and proper operation of the power supplies were verified. The original circuit boards were then reinstalled in the accident CAWS unit and a full acceptance check was performed; no discrepancies were noted.

The accident CAWS unit was then installed on another Northwest DC-9-82, N309RC, after proper operation of the existing CAWS unit had been verified. All takeoff warning functions were tested repeatedly and no discrepancies were found. The stall warning, fire warning, and stabilizer-in-motion horn also were tested repeatedly; no defects were noted.

Since activation of the takeoff warning is a function of the throttle lever angle and not power setting, the amount of movement required to trigger the warning was measured between the idle stop and the aft face of the throttle lever, at the level of the pedestal. Measurements of 1 13/16 and 1 15/16 inches were obtained for the left and right throttles, respectively, and produced a throttle split of about 2/3 of a throttle knob diameter. The measurements obtained were slightly reference stabilized power setting for activation of the takeoff warning system. With a field elevation of 840 feet msl, a temperature of 62°F, and an altimeter setting of 30.18 inHg, the engine EPR was 1.44 with the No. 2 throttle set at the position at which the takeoff warning activated.

While the accident CAWS unit was installed in N309RC, the system's two SSRSs were tested. The results of the test were recorded on N309RC's CVR for future sound spectrum analysis at the Safety Board's audio laboratory. The recordings were made with all three CAWS unit power supply circuit breakers closed and then with each circuit breaker open in turn. The circuit breaker panel locations of the circuit breakers and their affected CAWS power supply and warnings were:

- Circuit breaker U-31, power supply-1 with overspeed, engine fire, and horizontal stabilizer warnings, and the evacuation signal.
- Circuit breaker P-40, power supply-2 with the SSRS-1, landing gear, takeoff, autopilot disconnect, cabin altitude, and speed brake warnings.
- Circuit breaker R-41, power supply-3, with the SSRS-2 and altitude alert warnings.

The results of the tests indicate that when the stall warning test switch was activated with all three power supply circuit breakers closed, both CAWS speakers operated, both stall warnings were heard with the processor controlled (primary) audio stall warning on the left speaker and the redundant audio stall warning on the right speaker (see section 1.16.2, sound spectrum analysis), and both the captain's and first officer's stall warning lights illuminated. With the U-31 circuit breaker open, the results were identical.

When the stall warning test switch was activated with circuit breaker P-40 open, both speakers operated, only the audio alarms generated by the SSRS-2 was heard on both speakers, and only the first officer's stall warning light illuminated. When the test switch was activated with circuit breaker R-41 open, the audio alarm generated by the SSRS-1 was heard on the right speaker, the left speaker did not operate, and only the captain's stall warning light illuminated. In addition, there was no combination of open CAWS power supply circuit breakers that would cause the "CAWS Fail" light to illuminate.

The captain's and first officer's stall warning light bulbs from the cockpit glare shield were taken to the Safety Board's material laboratory for filament analysis. The cover plate had been knocked from the captain's stall warning bulbs, but the bulbs were not broken. There was no significant stretching damage noted on the filaments from either bulb.

The glass from the first officer's right stall warning bulb was broken but the left bulb was intact. The base of the broken bulb was removed from its housing, thereby freeing the broken pieces of bulb glass. The major portion of the bulb filament was broken off and found lying in the glass debris. Examination of the filament piece showed stretching, typical of an impact while the filament was hot, on various portions of the filament length. Examination of the filament of the undamaged bulb showed that it also contained some localized stretching.

1.16.2 CAWS Sound Spectrum Analysis

Three recorded tapes of the audio warnings generated by the CAWS unit's two SSRSs were used by the Safety Board's audio laboratory to perform the sound spectrum analysis. The first tape was recorded by the accident airplane's CVR during the accident flight. The second was recorded on August 28, 1987, as described in section 1.16.1. The third tape was made on October 1, 1987, by connecting the recorder to the CAWS unit's audio outputs.

The CAWS stall warning system's vocabulary was obtained by electronically digitizing a female subject's voice saying the words of the warning. These words were then stored in the CAWS' memory chips. The normal stall warning consists of four aural alert tones followed by the word "stall."

The two stall words spoken by the CAWS for the primary and the redundant stall warnings are different. Although they were both produced by the same subject and digitized using similar methods, two different samples were chosen for each warning system. The *primary* system word, which is generated by SSRS-2 and power supply-3, has a very limited fundamental frequency range and, therefore, a flat, almost monotonous pitch. Its frequency range is only 42 hz wide, ranging from a high frequency of 471.15 hz at the start of the word to a low frequency of 427.88 hz at the end of the word. The duration of the word is about 0.37 second. When seen on the sound spectrum analysis chart, the word produces a level spectrum signature.

The redundant warning, which is produced by SSRS-1 from power supply-2, is much more dynamic in frequency. Its frequency range is about 168 hz wide, ranging from a high frequency of 586.54 hz at the start of the word to a low frequency of 418.22 hz at the end of the word. The duration of the word is about 0.32 second. When seen on the sound spectrum analysis chart, the word produces a descending diagonal stroke signature. Each of the two "stall" words has a unique sound spectrum signature. Examination of the sound spectrum analysis chart made from the CVR recording of the accident flight showed that the the word "stall" produced a flat, level spectrum signature. A comparison between the spectrum analyses made from the test runs and those made from the accident flight CVR recording shows that the stall warning given on the accident flight was the primary system only, i.e., it was produced by SSRS-2 which was operated by power supply-3. There were no frequency components of the redundant "stall" word present in any of the warnings issued by the CAWS on the accident CVR.

1.16.3 Electronic Equipment

Numerous components were recovered intact from their racks in the E&E compartment and later subjected to standard bench test procedures. These components included both DFGCs, both CADCs, both stall warning computers, the FDAU, and the PSEU. Except for the FDAU and the DFGCs, none of these units exhibited any evidence of discrepancies that would have affected its normal operation during the standard bench test procedures.

The examination of the FDAU indicated that the synchronized signals were out of calibration. Additional data was obtained from the manufacturer and the signals were recalibrated. (See section 1.11.2.)

The memory readout of both DFGCs revealed the presence of a "flap handle failure" message on nearly every flight segment stored in the memories. The DFGCs will log this message if the flap handle position differs from the flap position by more than 3°, or if a synchronization leg has failed. However, it was established that a discrepancy resulting in this failure message would not affect the mechanical operation of the flaps nor the proper functioning of the takeoff warning system. The DFGC memories would also log faults detected in the angle of attack signal, various CADC parameters, flap position signals, the ground sensing system, and slat position. None of these faults appeared in either of the accident airplane's DFGCs' memories.

1.16.4 *Cockpit Wiring and Circuit Breakers*

Except for the wiring of the microswitches on the throttles which were damaged by impact forces, the takeoff warning system's wiring between the control pedestal's mating connectors and the CAWS was intact and undamaged. The wiring and switches in the pedestal, including the stabilizer and flap takeoff setting switches, were tested at the McDonnell Douglas facility at Long Beach; no discrepancies were noted. The wiring between the PSEU and the CAWS also was intact and undamaged, as was the wiring from ground through the R2-5 relay contacts to the CAWS rack. The R2-5 ground sensing relay was tested and found to be functional. The left ground shift circuit, which controls the R2-5 relay, was electrically intact; however, the left ground shift switch, which is located on the nosegear oleo and supplies liftoff information, was missing.

The CAWS speakers were wired correctly to the connectors in the cockpit console and the wiring was intact. Damage to the speaker wires precluded determining their condition between the console connectors and the FS 110 junction box; however, the wires were intact and undamaged between the junction box and the CAWS rack. The P-40 circuit breaker was broken free of the circuit breaker panel and the bus, but both of its circuit wires remained attached to the remnant of circuit breaker by the terminal hardware. The bus terminal had broken free from the breaker housing and remained attached to the left 28V d.c. bus. The wiring between the breaker and the CAWS rack was intact and undamaged. The other wire of the P-40 circuit breaker which connects to the landing gear lever relay was shorted to ground on the initial test, but after the position of the wire was changed, the electrical short indication ceased. Visual inspection of the wire disclosed a small chafed area in the wire's insulation about 9 inches from the circuit breaker's terminal. A microscopic inspection of the chafed area revealed no evidence of electrical arcing or shorting on the exposed wire.

The P-40, type 7274-55, circuit breaker was manufactured by the Klixon Division of the Texas Instruments Corporation ("7274" identifies the type circuit breaker; "-55" identifies the airplane manufacturer). The investigation disclosed that McDonnell Douglas had issued three All Operator Letters (AOL) concerning operator-reported problems with the 7274 series circuit breaker: AOL 9-1281, April 4, 1981; AOL 9-1281A, November 22, 1982; and AOL 9-1281B, January 14, 1983. The AOLs state that the most common of the reported failure modes was an "open circuit, however, externally, the circuit breakers would appear to be closed." The reported problems appeared to be related to circuit breakers manufactured between January 1979 and November 1980. The AOLs stated that the causes of these failures included:

- Broken lower contactor spring members. Because of design differences, this is confined to circuit breakers rated at less than 7.5 amperes. The problem is apparently related to circuit breakers that are functioned manually, making and breaking circuits. The repeated cycling causes the spring member to break.

- Internal insulator hanging up. The manufacturer indicated this is related to circuit breakers containing a warped case half which was not detected at inspection.

- Bimetallic element hang up. This problem is due to undetected assembly operation weld splatter within the case.

Douglas reviewed the circuit breaker failure data of two DC-9-80 operators and also analyzed its rejection history on in-house problems. The results of these actions indicated that the Klixon circuit breakers rejection rate was about 1/2 of 1 percent, which according to Douglas "constitutes an acceptable quality level of rejections . . ." The rejection rate also paralleled that of two other manufacturers.

Douglas also drew from existing stock a random sample of 315 circuit breakers of the 1- through 10-ampere rating of the affected 1979 and 1980 date codes and subjected them to a "Douglas monitored intensive test program at Klixon. Not one of these circuit breakers failed the tests." AOL 9-1281B states, "Douglas feels that there is no definable problem with these particular circuit breakers other than the possibility of experiencing an unannunciated open of the circuit breaker due to the contacts hanging up."

Numerous circuit breakers, in addition to the damaged P-40 circuit breaker, were removed from the wreckage. Seventy date codes were positively identified, and all but three (dated June 1981, December 1981, and June 1982) were found to be within the manufacturing time interval designated in the AOLs. The 67 circuit breakers that fell within the date code, as well as other circuit breakers that were relatively intact but had illegible date codes, were removed from the airplane and taken to the Klixon facilities in Attleboro, Massachusetts, for further examination. None of the 69 circuit breakers exhibited mechanical or electrical continuity problems, but some particulate matter was found randomly in some of the devices. The observed condition of their internal components was commensurate with expected service conditions.

The impact-damaged P-40 circuit breaker was taken to the Safety Board's materials laboratory for further examination. The circuit breaker housing was broken when received, and the portion containing the reset mechanism was missing. The breaker's bimetallic strip and one of the terminals were contained within the remaining housing structure. In addition, the terminal attached to the circuit breaker panel bus bar also was recovered. Examination of the circuit breaker's contacts under high magnification indicated that three of the four contacts were clean. The fourth contact that was connected to the bus bar that had separated from the breaker had dark tarnish film on the outer perimeter. Electric resistance testing of the surfaces on the three clean contacts showed good electrical continuity. However, there was some intermittency on the outer area of the film on the bus bar terminal contact when tested with a 1.5 volt probe. In addition, the examination did not disclose any evidence of the anomalies cited in the Douglas AOLs.

According to Klixon personnel, the tarnish on the P-40 circuit breakers bus contact appeared to be typical of a silver sulfide buildup that can occur on the contacts of the breakers during normal service. A chemical analysis of the contact at the Safety Board's materials laboratory using x-ray energy dispersive spectroscopy (EDS) indicated that the surface of the contact was rich in silver. EDS of various areas of the contact revealed the presence of small amounts of (in decreasing order) silicon, sulphur, copper, zinc, iron, calcium, and aluminum, in addition to a large amount of silver. Further probing of the surface of the contact with a higher voltage probe than used earlier (22V versus 1.5 V) revealed that the sulfide was conductive. Some of the contacts on the other 69 circuit breakers also had a silver sulfide tarnish buildup. However, the tarnish buildup on the bus bar contact of the P-40 circuit breaker was among the heaviest of all the contacts examined.

An examination was conducted at the Klixon facilities, on another 19 CAWS circuit breakers that were removed from the Northwest DC-9-82 fleet and subjected to test. After removal from the airplane, each circuit breaker was subjected to no more than 10 cycles in a mocked up circuit representative of the CAWS input circuit. Three circuit breakers did not conduct current when the latching mechanism was closed after several cycles, and another exhibited intermittent conductivity which could not be duplicated. An X-ray examination of the three nonconducting circuit breakers disclosed that the contacts appeared to be closed.

The initial test on the three nonconducting breakers was a continuity check in a circuit representative of the CAWS input circuit. Two of the breakers remained in the nonconductive state, while the third conducted current in the circuit and exhibited continuity with a 1.5 volt continuity tester. Windows were then milled in the cases of the breakers so that the contact areas could be observed, and the continuity of the breakers was tested again. It was found that another of the breakers conducted current with both 28 and 1.5 volts applied. At this point, one breaker remained electrically open even though the latch was closed and the contacts appeared mated, and two others, that had originally been nonconducting with the latch closed, now conducted current.

Further examination disclosed that the contacts of the open breaker were held apart by particulate matter that was comprised chiefly of silicon. Examination of the stationary contacts of the now-closed breakers revealed the presence of silver sulfide tarnish. Continuity tests with 28 volts revealed that the surface of the contact was conductive, but probing with a 1.5-volt tester disclosed areas of intermittent conductivity on the stationary contact surfaces of the now-closed breakers. These results are similar to the behavior of the tarnished bus bar contact of the P-40 circuit breaker from flight 255.

Examination of the contacts of the circuit breaker that was removed from service and exhibited intemittency that could not be duplicated revealed the presence of black particulate matter on one stationary contact. Additionally, one circuit breaker that was removed from service had a stationary contact that had areas of intermittency around the periphery of the contact surface. The breaker behaved normally during the 10-cycle bench test described earlier.

1.16.5 Flap Handle Module

Following the accident, the flap handle module was examined at Douglas' Long Beach facilities and at the Safety Board's materials laboratory. The right side of the flap handle module had been displaced to the left, causing permanent deformation. The flap handle's pivot shaft supports were broken and the handle and dial-a-flap movable detent had been displaced downward. As a result of this displacement, the dial-a-flap pin on the right side of the flap handle rested between the cam finger and the movable detent. The left side of the flap handle was contacting the fixed detent track, and the fixed detent pin was found in the UP/RET position. The left side detent track was neither deformed nor moved from its normal mounted position.

The module was disassembled and examined for damage associated with the detent pins on each side of the handle. On the right side of the module, the stowed dial-a-flap mechanism had gouge marks on the side of the cam finger which were consistent with abnormal contact with the end of the dial-a-flap detent pin. This pin contact damage continued onto the forward lobe of the stowed movable detent. The damage areas on the cam finger and on the movable detent were located in line with and just below a position on the cam finger that would correspond to the UP/RET position of the flap handle. Examination of the end of the dial-a-flap pin revealed damage on one side of the pin end that was consistent with sliding contact damage of the type described above.

On the left side of the module, an examination of the fixed detent track revealed a heavy contact area in the bottom of the UP/RET position. This area contained a circular imprint and associated sliding damage caused by contact with the end of the fixed detent pin. A raised lip of metal found around most of the pin end corresponded to the distinct circular impression found in the detent track. No unusual damage was found in any of the other detent positions on this track.

1.16.6 Airplane Performance

The Safety Board's performance study was based on data derived from the airplane's DFDR, CVR ,and time-correlated DFDR and CVR information.

Based on the airplane's final weight tabulation and the information contained in the company's dispatch papers, the airplane's takeoff weight was 144,047 pounds and the flap and slat settings to be used for takeoff were 11° and mid-sealed position, respectively. The position of the TCC flap setting thumbwheel further corroborated the intended 11° takeoff flap setting. The takeoff speeds on the Northwest takeoff card for that weight and configuration were as follows: critical engine failure speed (V1) was 142 KIAS, rotation speed (Vr) was 144 KIAS, and V2 was 153 KIAS. The minimum speeds for flap and slat retraction were 158 KIAS and 198 KIAS, respectively.

The performance study's computations were based on the following data: takeoff weight--144,000 pounds; c.g.--10 percent MAC.; runway elevation--631 feet msl; runway gradient to liftoff--0.05 percent down; altimeter setting--29.85 inHg; surface winds--300° at 14 knots; and the temperature at the time of takeoff--79° F. (The temperature in the last ATIS message was 88° F.)

The DFDR data indicated that the takeoff was made with the airplane's trailing edge flaps and leading edge slats retracted. The DFDR data also indicated that both engines were operating at or above takeoff thrust until all recorded data were lost.

The reconstruction of the actual takeoff showed that the airplane's acceleration up to and through Vr was in accordance with predicted rates. The first officer called both V1 and Vr, and these callouts were consistent with the computed values cited above. The airplane began to rotate at Vr. Assuming proper takeoff configuration, the DC-9-82 normally will liftoff between 6° and 8° noseup pitch; however, in this case the airplane did not. The airplane continued rotating until it reached a 11° to 12° pitch angle and stabilized at that angle. (The DC-9-82's tail will strike the ground at a 11.7° pitch angle. There was no evidence that a tail strike occurred.)

The airplane lifted off the runway at the 11° to 12° pitch angle as it was accelerating through 168 KIAS. The computed flaps and slats retracted stall speed for the airplane was 170 KIAS. The stall warning system's stick shaker activated 0.5 second after liftoff and continued to operate until the end of the CVR tape. The airplane continued to accelerate after liftoff and began to climb. At 4.5 seconds after liftoff, when the airplane was over the departure end of the runway at 10 feet agl, the SSRS aural alarm activated. There were three more SSRS activations before the initial impact; these occurred about 6, 9, and 12 seconds after liftoff. During the 14 seconds between liftoff and initial impact, the DFDR data indicated that the airplane climbed about 45 feet and accelerated to about 186 KIAS.

According to Douglas' manager of aerodynamics and acoustics for the DC-9 and DC-9-80 programs, the roll stability is decreased significantly when the airplane is flying near its stall angle of attack. "It can be flown there, but it's a very difficult thing to do." The recorded data showed that, about the time of the first SSRS alarm, the airplane began a slight roll to the left which was reversed when a bank angle of about 8° was achieved. The airplane then rolled right about 16°, left about 33°, right about 35°, and then left; and initial impact occurred about 22° left roll as the airplane was rolling to the left. The data showed that the spoilers were used to counteract these rolls and that on two occasions almost full deflection (60°) was employed. The recorded elevator control data also indicated that the pilot had applied down elevator at the onset of each SSRS alarm followed by an up elevator input as the alarm ceased.

Except for momentary nose-down corrections, the pitch angle continued increasing throughout the flight until it reached between 14° and 15°. Stick shaker activation was continuous and there were intermittent SSRS activations. The programmed angles of attacks for stick shaker and SSRS activation were about 11° and 13°, respectively, and, in this case, the angles of attack and the fuselage pitch angles were about the same. Although the airplane was being flown at angles of attack between those that activated the stick shaker and the SSRS, it was still accelerating and climbing. However, the airplane's aerodynamic performance in this area was reduced by two factors: the rolls and the spoiler deflections used to counteract the rolling moments. During the last 6 seconds of the flight, the roll oscillations and subsequent spoiler deflections adversely affected the airplane's climb performance by degrading the lift component by as much as 20 percent.

The deployment of flaps and slats on a wing increases its lift capability and reduces its stalling speed. In this case, the I-G stall speed for the clean wing was 170 KIAS. Extending the slats to the mid-sealed position would reduce the stall speed 40 KIAS; extending the flaps to 11° would have reduced the stall speed an additional 6 to 8 KIAS. The reduced stall speeds would have reduced the airplane's liftoff speed, reduced its takeoff ground roll distance, improved its climb capability, increased its climb angle, and improved the roll stability. Given these data, the Safety Board explored six climb profiles.

The first profile reflected the airplane's performance with the flaps at 11°, the slats at the mid-sealed position, and the takeoff performed at programmed speeds contained on the company's 144,000-pound takeoff chart. Under these conditions, the airplane would have lifted off 6,520 feet down the runway and cleared the initial impact point by 600 feet. (See figure 2.)

The second profile reflected the airplane's performance with the flaps retracted, the slats at the mid-sealed position, the takeoff performed at the programmed speeds above, and the pitch angle during the climb as required to maintain a V2 + 10 KIAS climb. The resulting performance was virtually identical with the first profile. (See figure 2.)

The third profile was the same as the second except that the pitch angle after liftoff was maintained at 15° nose-up and the airplane was allowed to accelerate beyond V2 + 10 KIAS. In this case, the liftoff distance was the same and the airplane would have cleared the impact point by 400 feet. (See figure 2.)

The fourth profile depicts the performance of the airplane with flaps and slats retracted. The airspeeds, pitch, and roll attitudes of the airplane were based on values derived from the DFDR readout of the takeoff roll. The profile placed the airplane at 41 feet agl at the impact point. (See figure 2.)

The fifth profile was based on a performance study which assumes that the captain used the stall recovery procedures contained in the APH. (See section 1.17.2.) The study was based on the values derived from the DFDR readout of the takeoff roll, liftoff, and the flightpath of the airplane until 3 seconds after the initiation of the stick shaker. The study assumes that the captain recognized that his airplane was approaching a stall 3 seconds after the stick shaker activated, and, in accordance with the procedures contained in the APH, called for maximum power, called for the flaps to be extended to 15°, and relaxed the back pressure on the control column to stop the stick shaker. Based on the delays required for the engines and the flaps and slats to respond to the power and control inputs, the study indicated that the airplane would clear the light pole by about 350 feet. However, any delay in recognition and reaction time would reduce the margin of clearance.

The sixth profile reflected the airplane's performance with the wing flaps and slats retracted and maintaining an 11° angle of attack, i.e., at or just below the stick shaker activation. In this case, the airplane would have cleared the light pole by 80 feet.

The Safety Board's systems group used the DFDR data to simulate the performance of the airplane's F/D during the accident takeoff and to reproduce the visual cues provided to the captain by the system's command bar. The visual cues presented by the command bar are superimposed on the presentation provided by the airplane's attitude director indicator (ADI). Thus, the pilot can relate the command bar clues to the actual attitude of the airplane depicted on the ADI by the position of the fixed airplane symbol relative to the ADI's horizon reference bar and pitch ladder. The pitch ladder consists of four lines below and four line above the horizon reference lines. The lines are parallel to the horizon reference line, they are spaced to portray 5° intervals, and, the resultant ladder depicts 20° of either nose-up or nose-down airplane pitch attitude.

Two simulations were performed: the first reproduced the performance of the command bars during the actual takeoff wherein the go-around mode was selected about 8 seconds before impact. The second reproduced the command bar performance without the selection of the go-around mode.

The first simulation showed that the command bar moved upward during the takeoff roll. Forty seconds after the takeoff roll began (T.O. +40 sec.) and about 8 seconds before the airplane reached V_r, the fixed airplane symbol and the command bars were positioned about 2° nose-down and 5° nose-up, respectively, on the ADI's pitch ladder. At T.O + 54 sec., during rotation, at main landing gear liftoff, the fixed airplane symbol and the command bar were positioned about 9° and 11° nose-up, respectively, on the pitch ladder. About 4 seconds after main gear liftoff when the first SRSS alarm activated, the simulation showed that the captain had essentially satisfied the command bar cues and no further pitch attitude change was being requested.

At T.O. +60 sec., the F/D entered the go-around mode and the command bar immediately began to move upward between the third and fourth SSRS alarm. About 1 second after the go-around mode was annunciated, the CVR recorded the remark, "(right up to the vee bar.)" At that time, (T.O. +61 sec.) the command bar was passing through about a 1° nose-up pitch command en route to its final command presentation, the stick shaker was activated, and a SSRS alarm was either in progress or had just ceased. At T.O. +65 sec., the fixed airplane symbol and the command bar were about 13° and 15°, respectively, on the pitch ladder (see figure 3), and they maintained that presentation until impact.

The second simulation showed that, had the go-around mode not been selected, the command bar would have moved downward. About 5 seconds after go-around was annunciated (T.O. +65 sec.), the fixed airplane symbol and the command bar were positioned about 13° and 12° nose-up, respectively, on the pitch ladder (see figure 4). At T.O. +68 sec., about 1 second before impact, the fixed airplane symbol and command bar were positioned about 14.5° and 12° nose-up, respectively, on the pitch ladder.

Also the Safety Board investigated the possibility that the airplane might have encountered a windshear during the takeoff. The computed ground speed of the airplane during the takeoff roll was integrated with an indicated airspeed plot derived from the DFDR-indicated airspeed data. The two plots were virtually identical throughout their entire length. Had a windshear occurred, the ground speed and airspeed plots would have diverged from each other.

1.17 Other Information

1.17.1 Northwest Airlines and Republic Airlines Merger

On July 31, 1986, Northwest's acquisition of Republic Airlines was approved by the Department of Transportation. On August 12, 1986, Northwest Orient Airlines completed its purchase of Republic Airlines. The new corporate name became Northwest Airlines, Inc., and new operations specifications were issued on that date. Although the former Republic and Northwest personnel and equipment operate under the name of Northwest Airlines, each operates as a separate entity, or company, and a separate set of operations specifications was issued to each company under certificate No. 301-F. The former and current certificate holding office for the carrier is Air Carrier District Office (ACDO) No. 34, Minneapolis, Minnesota.

The FAA has allowed each company to use its respective operations specifications, maintenance programs, and operations programs that were in effect on August 12, 1986, for a period of 18 months. Neither carrier is permitted to use a combined program without an approved provision to its operations specifications.

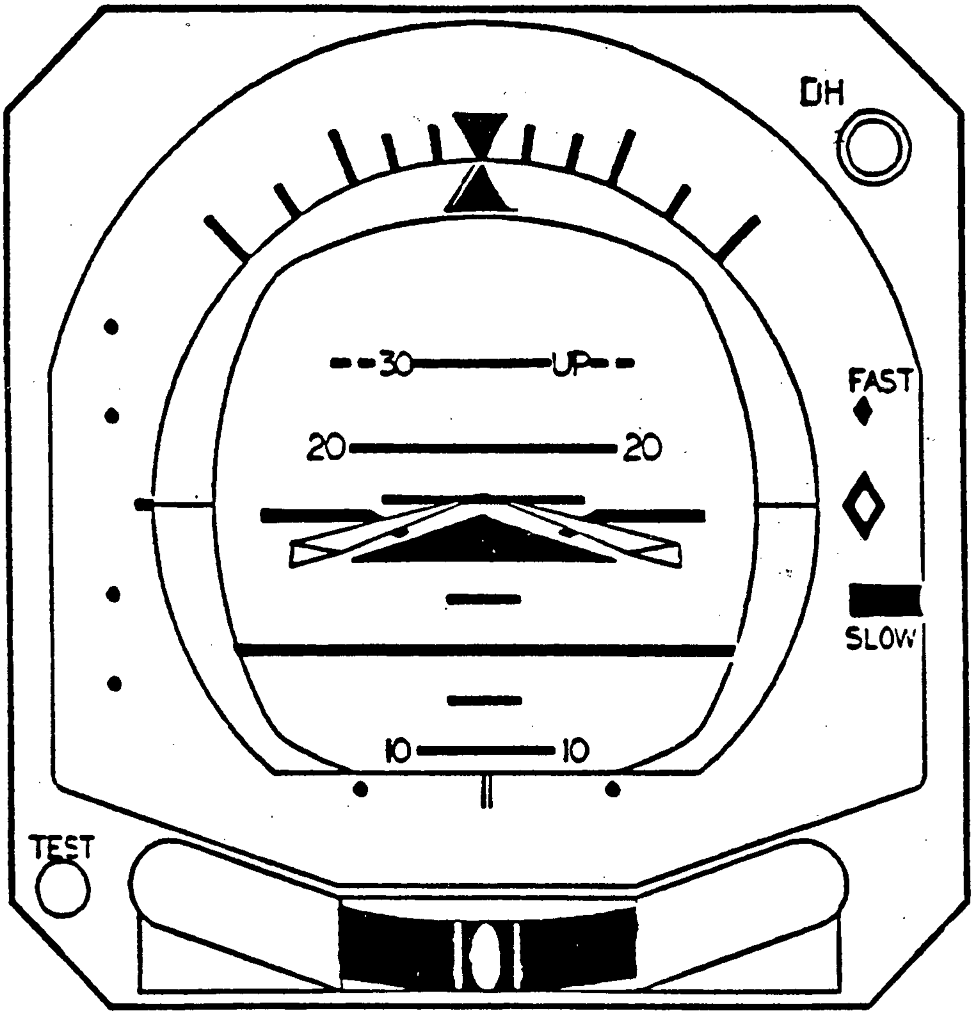

Figure 3.--Displays theoretical pitch attitude information presented by the ADI and the F/D command bar for the conditions existing 65 seconds after the start of the takeoff roll and after the F/D has entered the go-around mode. Roll attitude information and command bar roll guidance information is not displayed.

On October 1, 1986, plans to merge the two company's operations were issued with the integration of a consolidated flight schedule. The companies consolidated their route structure but continued to segregate their respective airplanes and flightcrews. However, the maintenance and flight attendant programs were integrated and the combined procedures were approved by the FAA. Flight attendants are now qualified to serve on all Northwest airplanes; this is the only change arising out of the merger thus far to the flightcrew checklists . Communications procedures between the flight and cabin crews on all airplanes were changed to coincide with those in use on former Northwest airplanes. However, the pilot groups continue to operate their respective airplanes in accordance with their respective operations specifications and their respective labor contracts.

Before the merger, the Northwest fleet consisted of Boeing airplanes and McDonnell Douglas DC-10s. During the merger, Northwest acquired a fleet of 134 DC-9s, 3 B-727s, and 6 B-757s

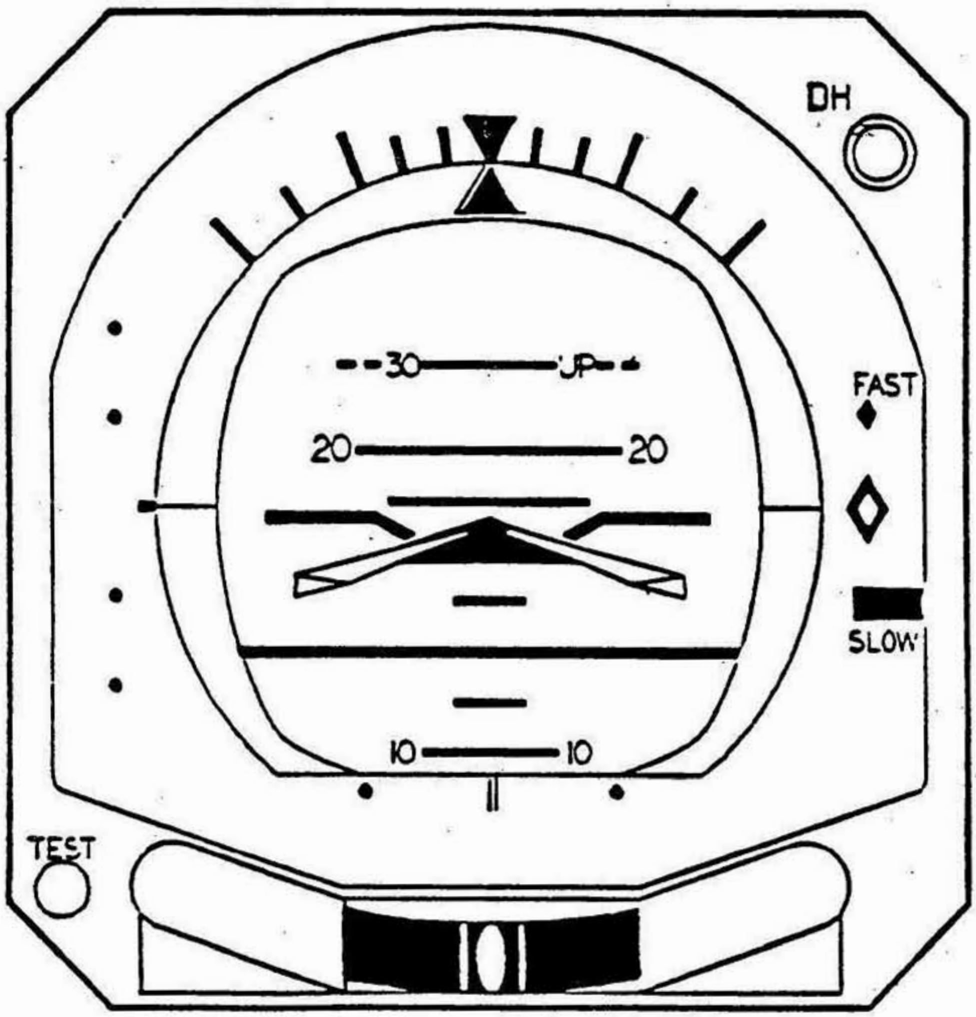

Figure 4.--Displays theoretical pitch attitude information presented by the ADI and the F/D command 65 seconds after the start of the takeoff roll with the F/D in Takeoff mode. Roll attitude information and command bar roll guidance is not displayed.

with 3 more on order. After the merger, the new corporation sold the B-727s and the B-757s and canceled the orders for the new B-757s.

1.17.2 Proficiency Training

Since the premerger Northwest Orient Airlines did not operate DC-9 type airplanes, the former Republic DC-9 training staff, except for some procedural changes in chain-of-command structure and reporting, remained virtually intact throughout the changeover. Thus, the DC-9-82 proficiency training program remained unchanged, and the evidence showed that the curricula complied with the regulatory requirements.

The DC-9-82 simulator proficiency training curriculum required students to demonstrate their proficiency in stall recovery procedures and coping with various windshear models. The recommended procedures for accomplishing recoveries from these situations are contained in the Flight Maneuvers section of the company's APH. With regard to stall recovery, the APH states, in part, that the approach to stall "is reached at the first indication of the stall warning, stick shaker, or buffet, whichever occurs first." The recommended recovery procedures state:

a. Apply and call "MAX POWER FLAPS 15" while simultaneously relaxing the back pressure enough to stop stick shaker or buffeting . . . The pilot not flying will select 15° flaps and trim the throttles to MAX POWER. Do not allow a pitch up to occur with the power and configuration changes, to avoid including a secondary stall.

With regard to windshear recovery, the APH states, in part:

a. Advance the throttles to the mechanical stops.

b. Smoothly rotate to a pitch attitude that will prevent ground contact. Although a stick shaker can be anticipated during this maneuver, do not rotate beyond the point that the stick shaker is activated.

NOTE

The airspeed may indicate considerably below V2 or VREF bug (a computed landing approach speed based on the airplane's landing weight.)

c. When descent has been arrested, position the flaps to go-around (if required) and be prepared to increase the body angle to prevent descent.

d. When a climb is noted on the altimeter call "GEAR UP" (if required). . .

e. After the recovery is completed, use standard climb procedures.

With regard to item c above, the rejected landing procedures contained in the APH state that the flap setting is 15°; however, it should be noted that this procedure is normally begun with landing flaps (28° or 40°) set on the airplane.

On May 31, 1987, the captain completed his DC-9-82 requalification simulator rides. Since there was no line first officer available, the Northwest DC-9-82 training manager, who was administering the requalification check, served as first officer. Examination of the applicable training documents showed that the captain demonstrated proficiency on stall recoveries in both the landing and takeoff configurations on two simulator flights and "stall recoveries using windshear recovery procedures" on the second flight; however, he did not receive stall recovery training with the airplane in the flaps up, slats retracted configuration. The training manager commented on the training form "Very nice requalification."

The first officer training records showed that he demonstrated his proficiency in recovering from stalls with airplane in the takeoff and landing configuration; however, he did receive stall recovery training with the airplane's slats and flaps retracted. The records showed that during his recurrent training, he had received windshear training. The training records also indicated that his last proficiency check was a one pilot-session, i.e., the instructor occupied the captain's seat in the simulator.

The training manager also testified, "I would comfortably say that every pilot that flies the MD-80 has at some point in his training been alerted to the fact that we have got a central aural warning system fail light on the annunciator panel . . . and if there is a failure in that system we would expect to somehow be annunciated. Although I cannot say that we train to that because there is not a requirement to train to that."

1.17.3 The DC-9-82 Checklist

Copies of the DC-9-82 checklist are kept on board each airplane. (See appendix E.) To view the checklist, pilots fold it along the dashed line and expose the applicable portions of the list as they perform the required tasks. The checklist normally is mounted to a clip on top of the pilot's control column and, thus, is displayed to the pilot between the horns of the control wheel.

Before May 21, 1985, the flaps were extended to 15° after the airplane began taxiing. Douglas had recommended that the flaps be extended to 15° to minimize engine exposure to foreign object damage (FOD), and the company had adopted that procedure for taxi out. However, the DC-9-82 generally uses takeoff flap settings of either 7° or 11° which required the flightcrew to reposition the flaps to the takeoff setting before taking the runway. Consequently, the BEFORE TAKEOFF checklist contained the item "FLAPS" at which time the flightcrew would reposition them from 15° to the required takeoff position. Subsequently, Douglas informed operators that the concern over FOD, as well as the effectiveness of the flaps to protect the engines, was not as great as originally believed. Therefore, Republic's Flight Standards Department decided to have its flightcrews set the flaps to the takeoff setting instead of 15° when the airplane began taxiing. Republic believed that would be more efficient since it would require only one movement of the flap handle and would lessen the crew's duties during the before takeoff environment. On May 21, 1985, "FLAPS" was added to the TAXI CHECKLIST, and crewmembers were directed to check and verify that the flaps and slats were positioned to the required takeoff setting in response to the challenge "FLAPS." The item "FLAPS," requiring the same challenge and response verification, was not deleted from the BEFORE TAKEOFF CHECKLIST. Having "FLAPS" on both checklists was intended to be temporary for the purpose of providing an orderly transition of the item from one checklist to the other.

On December 15, 1986, after receiving FAA approval to implement the change, a checklist change removed "FLAPS" from the BEFORE TAKEOFF checklist.

1.17.4 Checklist Procedures

The Standard Operating Procedures section of the Northwest APH contains the company's procedures and policies concerning how the airplane's checklist is to be used. The APH states, in part:

> Good cockpit management requires consistent checklist usage. Proper use of checklist is reliable, and fosters predictable and standardized crewmember interaction.
>
> Checklists are developed to provide convenient and natural flow patterns in the cockpit and are sequenced to meet operational requirements. Checklist items may be performed without direct reference to the checklist, however, all checklist items will subsequently be read aloud in sequence while visually checking the items to assure completion. Upon completion of an individual checklist, the pilot completing the checklist will state "(CHECKLIST NAME) CHECKLIST COMPLETE."

> During all ground operations it is the Captain's responsibility to call for all appropriate checklists. . . Giving consideration to other required crewmember duties and allowing for adequate time for completion. The First Officer will query the Captain if there is abnormal delay in the call for any checklist.
>
> The checklist items will be read in a loud clear voice and the proper response will be equally clear and understandable. Where a challenge and response item is performed, a response is required from another crewmember, the crewmember reading the checklist will repeat the challenge if necessary until the proper response is provided. Undue haste in the execution of any checklist is neither necessary nor desirable.

The normal checklist uses asterisks to delineate the division of duties between the captain and first officer. (See appendix E.) The duties are defined as follows:

> No asterisks - The captain will perform the checklist item and provide the proper response.
>
> * - The first officer will perform the checklist item and state both the challenge and proper response.
>
> ** - Both pilots will perform the checklist item and both will state the proper response.
>
> (AS REQ) - The crewmember responsible for completing the checklist item will check, or reposition, the referenced switch or control and then STATE THE POSITION OF THE SWITCH OR CONTROL.

Section 2-23 of the APH amplifies the procedures contained on the TAXI checklist. The APH states that the first officer may, once clear of the ramp area, perform some of the checklist items, (i.e., extend the flaps, set the trim or EPR bugs, etc.) in preparation for the captain calling for the TAXI checklist. Thereafter, with regard to the first item on the checklist, the APH states, in part:

FLAPS.......................(SETTING)**

The checklist challenge "FLAPS" requires a standard response from both pilots. The APH states, in part, that the first officer will issue the challenge after leaving the ramp and then check the position of the flap handle. If the flap handle is not set to the takeoff flap setting, he will extend the flaps to the takeoff setting and accomplish the following: check that the flap handle is in the desired position; check that the flap indicator reading corresponds with the handle's position; and check that the slat takeoff light is on. After the above checks have been accomplished and the flap and slat settings verified, he will call out the flap setting, i.e., "FLAPS 11." The captain will then check that the flap indicator agrees with the first officer's call out and respond with the observed setting, i.e., "FLAPS 11."

The CVR recording showed that the required flap setting call outs were not made. The recording also showed that the captain did not call for the TAXI checklist and that the first officer did not ask him if he wanted to perform the checklist. During this period, the CVR recording contained references to only two items on the TAXI checklist. At 2036:37, an unidentified voice in the cockpit said, "Vee (V) speeds -- okay"; there was no response to the remark. At 2036:40, the captain said, "Trim setting;" there was no response to the remark.

The APH's TAXI Checklist Amplification section described flightcrew duties required by the item EPR & AIRSPEED BUGS. The section contained guidance relating to the airplane's TCI. Since reduced thrust could not be used for takeoff, only the guidance relating to normal takeoff thrust procedures are discussed herein. Based on this section of the APH, this checklist item required the flightcrew to either program or verify that the TCI was programmed properly for a normal thrust takeoff: "00" should have been inserted in the TCI's assumed temperature window and the "T.O." button pressed to obtain the takeoff EPR limit setting.

The next item on the TAXI checklist required the ART switch to be positioned "(As Required)." The amplified checklist procedures stated, in part, that the ART switch should be "ON" in the "Auto" position with the guard closed when "T.O" mode has been selected on the TCI. When the "T.O./Flex" mode is selected, the "ARTs switch must be off." On this takeoff, since the "TO" mode should have been selected, the flightcrew should have verified that the ART switch was either in "Auto" or placed in "Auto." If the slats were extended, the green ART ready light would have illuminated when the ART switch was placed in "Auto,"and the autothrottle system would have been available when the autothrottle switch was activated.

With regard to the other applicable sections of the checklist, the CVR recording showed that the only checklist that was called for and pronounced complete almost in accordance with the APH procedures was the BEFORE (engine) START checklist. At 2029:10, the first officer called the first challenge item on the checklist, "Brakes." The captain did not respond to the challenge, but, at 2029:18, he said, "Lets do the checklist." At 2032:54, the first officer announced, "The before start checklist is complete." However, the recording also showed that, at 2032:46, the first officer read the last three challenges on the checklist, "Ignition, seat belt sign, beacon." The captain was required to accomplish these items and reply that all three of these switches were "On." However, at 2032:52, the first officer stated, "They're all on," and thereafter, that the checklist was complete. At 2032:57, the captain stated "On, on, on."

At 2034:08, the first officer stated "annunciator," to which the captain responded "checked," followed at 2034:09 by the first officer's verbal accomplishment of the remaining items on the AFTER START CHECKLIST. The CVR recording showed that the captain did not call for the AFTER START CHECKLIST, nor did the first officer ask the captain if he was ready to perform the checklist. The CVR recording also showed that the first officer did not state "after start checklist complete."

The BEFORE TAKEOFF checklist contains four items and this checklist was not accomplished in accordance with the standards contained in the APH. The captain did not call for the checklist nor did the first officer ask the captain if he was ready to perform it. The first item required the first officer to challenge "Flight Attendants" and then respond "Notified." Although, at 2042:36, the first officer had notified the flight attendants to be seated, he did not accomplish this checklist item properly. The remaining three items were accomplished properly, but the first officer did not tell the captain that the checklist was completed.

1.17.5 Human Performance Research Projects

During the Safety Board's public hearing, the Board sought and received testimony from psychologists concerning projects which either have evaluated or are evaluating the effects of automation on flightcrew performance and how interpersonal relations between flightcrew personnel affect their performance of cockpit duties.

A professor of management sciences and computer information (management sciences) at the University of Miami, Coral Gables, Florida, testified about the effects that the automated systems in the advanced modern airplanes cockpits appear to have had on flightcrew performance. With regard to the term "complacency," the professor testified that it was an "ill defined" term; however, if forced to describe it he would state that it was a "relaxing of one's guard." He testified, "that the notion in automation is that if the equipment is reliable, and most of it is extremely reliable, this will generate complacency, a relaxing of one's guard."

The management sciences professor testified that the research projects had identified a phenomenon which the researchers called the "primary backup inversion where the primary system, which is the human and human vigilance, becomes the backup system, and the backup system, the machine, becomes the primary." He cited as an example the altitude alerting system which, during climb or descent, is programmed to provide an alert to the flightcrew 700 feet above or below the inserted level off altitude. Virtually all air carrier procedures require the nonflying pilot to provide a 1,000 (foot)-to-go alert call to the pilot flying the airplane when climbing or descending. He testified that "it doesn't work that way. So what do you see on climbing or descending? The pilot will sit there . . . until the altitude reminder sounds (and then) say 'a thousand to go.' That's the primary backup inversion. He has used a backup system to human vigilance and made it the primary system and then he reacts."

The management sciences professor described what he thought of as six lines of defense against an untoward consequence resulting from human error. The first line of defense was human vigilance; the second, another crewmember detecting error; the third, secondary indications, such as cockpit displays and instrumentation; the fourth, warning and alerting devices; the fifth, persons other than crewmembers detecting the error, i.e., ATC personnel or ground personnel; and the sixth, machines that take action on their own to rectify the error, i.e., the DC-9-82's autoslat and stick pusher systems. With regard to the first line of defense, the professor testified that it was, "of course, normal procedures, and that is the crew doing the right thing, supported by checklist, training, experience, manuals, discipline, check airmen, and what not."

With regard to checklist presentations, the management sciences professor testified that he did not know of any human factors research on how a checklist should be designed and that he could not find anything in his library on the subject. "There are a couple of human engineering handbooks and under 'checklist' about all they said was the type ought to be visible and it ought to be easy to handle . . ."

A National Aeronautics and Space Administration (NASA) research psychologist testified about the observations made by a group investigating the effects of interpersonal relationships on the performance of cockpit duties. He testified that, beginning in the late seventies, NASA began placing volunteer flightcrews from several airlines in "a high fidelity flight simulator and trying to replicate every aspect of [their] real world [flight environment] in a very highly controlled setting in order to determine some of the factors that did effect successful crew performance." The NASA psychologist testified that the project was not completed, that the research is still in progress, and that the research group had neither arrived at nor released any conclusions. The NASA psychologist's observations cited herein are limited to those areas which the Safety Board considered germane to this report.

The NASA psychologist discussed the effect of role structure in the cockpit environment. He testified that the term "role structure" refers basically to the degree and specificity of the structure of a groups activities. "With cockpit crews you would have a very well defined role structure, each position being well defined and having specific responsibilities in the cockpit." He testified that role structure performs a very valuable function and that, "the safety of the system, I think, in many ways is a testament to how well defined and how functional the roles are in the cockpit. But one of the other characteristics of a well defined role structure is it significantly reduces ambiguity about who is going to do what and at what particular time."

The NASA psychologist testified that the simulation studies have disclosed crews whose performances could be classified as "effective" or "less effective," that a number of differences which they have seen "between the so-called effective crews and the so-called less effective crews are very reliable and appear time and time again." He testified that with regard to the highly effective crews, "there is much more communication in general . . . but there are also differences in the type of communication . . . You see much more task oriented communication." He testified that one of the patterns we tend to see, "is what we call the information acknowledgment sequence . . . We find that (with) crews that are highly effective . . . we tend to see many more acknowledgments to anything that is said."

The NASA psychologist testified that the manner in which the subject flightcrews used their checklists also was evaluated. He testified that it was rare to see a checklist ignored completely or not done but that this had occurred from time to time during various phases of flight in the simulator. There was a lot of variation with regard to checklist usage and it varied from the conduct described above to a "very clearly read challenge/response methodology."

The NASA psychologist testified that evidence suggested that the way the checklists were used were directly related to the number of errors made by the flightcrews. The flightcrews that performed their checklist duties "by the book, challenge (and) response methodology . . . tend to perform more effectively." He testified that he was not familiar with any body of research relating to the construction and presentation of checklists, but it was his opinion that, "there are probably many ways to do a checklist correctly. What's important is that everyone agrees on how it should be done, and then it's done the same way every time by all the people that are concerned."

An article in the Boeing Airliner Magazine 10/ concerning flightcrew-caused accidents and citing the Boeing fleet over a 10-year period as an example stated that:

> 16 percent of the operators have crew-caused accident rates higher than the fleet average, and these operators account for over 80 percent of the total accidents.
>
> Conversely, 80 percent of the operators had no crew-caused accidents over the same period . . .

The authors of the article contacted a small group of operators, "most of which had better than average crew-caused accident history" with a view to obtaining information on the policies and techniques that contributed to their safe operations. They found that:

> Management recognizes the need for aircrews performing in a standardized way and the importance of cockpit discipline in providing the environment for proper crew coordination.

With regard to check airman, the article notes that a strong check airman program acts as a continuous quality control check on the training department and that methods exist for assuring the uniformity of check pilot techniques and instruction.

In the area of cockpit discipline and procedures some of the procedures used by these operators were as follows:

10/ L.G. Lautman and P.L. Gallimore, "Control of the Crew-Caused Accident" Airliner Magazine, Boeing Commercial Airplane Company, April-June 1987.

> There is a firm requirement for in-depth takeoff and approach briefings for each flight segment . . . One operator requires an RTO [rejected takeoff] touch drill in which each control used during the RTO is sequentially touched by the pilot making the takeoff.
>
> Cockpit procedural language is tightly controlled to maintain consistency and to avoid confusion from non-standard callouts, which can result from crewmembers using differing phraseology. Callouts and responses are done verbatim. The recurrent training program and check pilot system rigidly enforce this requirement.

1.17.6 FAA Surveillance

FAA ACDO No. 34 held the respective certificates and was responsible for surveillance and oversight of the former Northwest and Republic Airlines.

The principal operations inspector (POI) assigned to the current Northwest operation was also the pre-merger Northwest POI, a duty which he assumed in January 1985. He is assigned only to Northwest and is responsible for the oversight of the operational procedures and training relevant to the carrier's total fleet.

During February 1986, the FAA assigned an aircrew program manager (APM) to the Northwest DC-9 fleet to assist the POI. The APM is rated in the DC-9, -10, -30, -50, and -82 airplanes. The APM works for the POI and serves as his technical expert on the DC-9 fleet and on how Northwest operates it. He has no additional oversight for any other airplanes in the Northwest fleet nor for any other carrier.

The APM duties include monitoring proficiency checks, training programs, designated flight examiners, manual changes, procedures, and surveillance. Currently, five examiners assist him. Between October 1986 and August 1987, the FAA conducted 1,493 operations inspections, 819 maintenance inspections, and 293 avionics inspections on the Northwest DC-9. The APM surveillance activities are further assisted by 174 FAA-approved DC-9 check airmen who are qualified to conduct line checks and proficiency checks in the DC-9 airplanes and simulators.

1.18 Useful or Effective Investigative Techniques

Recorded LLWSAS Wind Sensor Data

On March 25, 1983, the Safety Board recommended that the FAA record output data from all installed LLWAS sensors "and retain such data for an appropriate period for use in reconstructing pertinent windshear events as a basis for studies to effect systems improvements." 11/ The FAA agreed with the recommendations and began installing recording capability on selected LLWAS. Detroit-Metro's LLWAS recording equipment was commissioned on November 3, 1986, and the equipment was operating at the time of the accident.

Since using the Detroit LLWAS to reproduce the recorded wind data would have required removing the entire system from operation for 2 hours, the recordings were taken to the Program Engineering and Maintenance Service facility at the FAA's Aeronautical Center, Oklahoma City, Oklahoma, where the data were reproduced and read out, and the wind directions and speeds recorded by the system's sensors were obtained. The recorded LLWAS data were instrumental in allowing the Safety Board to determine the wind conditions which existed at Detroit-Metro Airport at the time of the accident.

11/ Safety Recommendation A-83-15.

2. ANALYSIS

2.1 General

The captain and the first officer were qualified in accordance with applicable Federal aviation regulations, company regulations, and procedures to operate the airplane.

The airplane's maintenance records disclosed that it had been maintained and operated in accordance with applicable Federal aviation regulations and company operations specifications, rules, and procedures. Except for the possible failure of the takeoff warning system to provide an aural warning for an improper takeoff configuration, there was no evidence of any preexisting malfunctions or failures of any airplane structures or systems which would have been a causal factor to the accident. The analysis of the performance of the takeoff warning system will be discussed in greater detail herein.

The changeover of Detroit-Metro's runway operation from a runway 21 to a runway 3 configuration was accomplished in accordance with published ATC procedures. The decision to change the direction of traffic was based on the tower supervisor's judgment that the wind direction was changing from southwest to northwest. The LLWAS's recorded data confirmed the supervisor's description of the wind shift. At 2029:31, about 1 minute 31 seconds after the runway change, the LLWAS centerfield wind was 290° M at 20 to 21 knots. On runway 3C, this wind would have produced crosswind and tailwind components of about 19 and 5 knots, respectively. The direction of the wind continued to shift toward the northwest. About 2045, based on NWS records and LLWAS data, the most likely range of winds would have been from 305° M at 12 to 16 knots. On runway 3C, these winds would have produced crosswind components between 11.8 and 16 knots and headwind components between 0 and 2.8 knots. Since runway 27 was closed, the wind shift was producing winds which favored slightly the runway 3 configuration. Based on these data, the Safety Board concludes that the supervisor's decision was reasonable.

The light pole struck by flight 255 was 2.2 feet higher than the 40-foot height that was approved in the FAA's aeronautical study. However, the 42.2-foot-high pole did not penetrate any civil airport imaginary surface, and the impact point on the pole was 37 feet agl. Therefore, the Safety Board concludes that the pole's additional height was not a causal factor.

When the left wing struck the light pole the wing's fuel tanks were ruptured and released fuel. The fire observed by some witnesses during this part of the accident sequence was caused when the left engine torched after it ingested the fuel. The carbon deposits inside the engine's front accessory case further corroborate this occurrence.

Given the fact that the deaths of the passengers and crew on flight 255 were the result of multiple blunt force trauma, the fact that the airplane disintegrated during the impact sequence, and the fact that the crash forces destroyed the livable volume of the cabin, it was obvious that these forces exceeded the limits of human tolerance to abrupt acceleration. Therefore, the Safety Board concludes that this was a nonsurvivable accident. The survival of the 4-year-old female child can only be attributed to a combination of fortuitous circumstances.

The CVR transcript showed that the first officer made the required callouts during the takeoff roll. Therefore, the Safety Board concludes that the captain was flying the airplane at the time of the accident.

2.2 The Accident

The evidence showed that windshear alerts had occurred at Detroit-Metro and that windshears had been reported near the airport by pilots during the 30 minutes before the accident.

In addition, the evidence showed that flight 255's stall warning stick shaker had activated immediately after liftoff and that, thereafter, the flight failed to either match or approach its predicted climb profile. This evidence suggested initially that the airplane encountered a windshear that decreased significantly its performance capability. A loss of an airplane's climb performance can be caused by a strong downdraft or a rapidly decreasing head windshear. Therefore, the Safety Board first sought to determine whether flight 255 had encountered such a shear.

The performance loss of an airplane that encounters a significant windshear during takeoff is discernible from the parameters recorded on the airplane's DFDR. As the airplane enters the shear, a change in the airspeed vector as measured by indicated airspeed and the angle of attack occurs without corresponding changes to the measured inertial acceleration parameters. Stall warning devices will activate at the expected angle of attack for the airplane's configuration.

However, examination of the CVR and DFDR data readouts showed immediately that the airplane had not encountered a decreasing headwind type of windshear. The DFDR data showed that, at liftoff, the airplane's airspeed was about 169 KIAS and that instead of decelerating over the last 14 seconds of the flight, the airplane accelerated to about 184 KIAS and climbed about 48 feet. This performance was not consistent with the expected performance of an airplane that is caught in a decreasing head windshear. The fact that the airplane did not encounter a windshear was further corroborated by the lack of divergence between the airplane's ground speed and indicated airspeed during the time it was airborne.

The correlated CVR and DFDR readouts showed that during the 14-second flight, the airplane's stick shaker remained activated continuously, and its SSRS activated four times. With the flaps at 11° and the slats in the mid-sealed position, the airplane's stall speed was about 121 KIAS; if the flaps were retracted and the slats remained in the mid-sealed position, the stall speed would increase to 128 KIAS. Despite the fact that the 169 to 184 KIAS recorded during the flight exceeded the worst of the two stall speeds by 36 to 56 KIAS, the stall warnings persisted. The investigation indicated that the only wing configuration that would continue to activate the stall warnings between 169 and 184 KIAS was a wing that was in cruise configuration, i.e., slats and flaps retracted. Consequently, the Safety Board concluded that the airplane had not encountered a windshear and directed its investigation to determine the configuration of the airplane during the takeoff roll. The following areas of evidence were available to the Safety Board for this analysis: the DFDR readouts and, where applicable, the CVR recording; the airplane performance study; and the physical evidence at the impact site.

2.3 The DFDR Readout and Airplane Performance Study

Examination of the recovered flap sensors, the DFGC memories, and the fact that those airplane systems whose performances would have been adversely affected by a malfunctioning slat position sensor(s) performed within prescribed parameters showed that the information received by the DFDR accurately reflected the positions of the wing flaps and slats.

The DFDR readout of the accident flight covered the entire period between pushback from the gate and impact, except for two intervals where the data stream was interrupted because the airplane's parking brakes were set. The first interruption occurred after the airplane was pushed back from the gate. At 2034:25, the captain told maintenance personnel "Brakes are set," and the power to the DFDR ceased. At 2034:57, after the tow bar was removed, the flight acknowledged its taxi clearance, and, at 2035:03, power was restored to the DFDR. The second interruption began at 2043:18 after the flight had taken the runway, turned to the runway heading, and was holding in position awaiting takeoff clearance. At 2044:04, the local controller cleared flight 255 for takeoff, and, at 2044:14.8, the CVR transcript contained a "(sound similar to parking brake released.)" At 2044:20, power was restored to the DFDR. The DFDR readout showed that the recorded values for the flaps and slats were identical at the beginning and at the end of each of these two data stream interruptions. The recorded values showed that the flaps and slats were in the retracted position and that there was no disagreement between the slat position and the flap handle position. In addition, the DFDR readout showed that, from pushback to impact, during the entire period that power was on the DFDR, the flaps were always retracted, the slats were always retracted, and there was no disagreement between the positions of the flap handle and slats.

The only position of the flap handle that will place and keep the slats in the retracted position is the UP/RET detent. Moving the flap handle to any other select position on the flap handle track will move the slats out of the retract position to either the mid-sealed or the extended position as the case may be. Had the flap handle been moved from the UP/RET detent to another detent, the DFDR readout would have shown the slats in transit and a disagreement between the flap handle and slat positions until the slats had reached their new commanded position. Throughout the entire readout, the recorded data showed that the slats never moved from the retracted position and that the flap handle position never disagreed with the slat position. Therefore, the Safety Board concludes that the DFDR data showed that the flap handle was never moved out of the UP/RET detent.

The Safety Board's airplane performance study also showed that flight 255 was not configured properly for takeoff. The recorded DFDR data showed that both engines were operating at or above takeoff power and, that although the acceleration up to and through Vr was in accordance with predicted rates, the airplane did not lift off at the predicted pitch attitude. Assuming proper takeoff configuration, the airplane should have lifted off between a 6° and 8° noseup pitch attitude. In this instance, the airplane rotated to an 11° noseup attitude, stabilized at that attitude, and accelerated to a higher airspeed before liftoff. The liftoff speed provided further evidence that the airplane was not configured properly. With both engines operating at takeoff power, a properly configured airplane typically should have been at V2 + 10 KIAS (163 KIAS) by the time it climbed through 35 feet agl. However, the accident airplane did not lift off until it accelerated to about 169 KIAS.

The Safety Board's performance study examined the climb profiles depicting the DC-9-82's ability to clear the obstacles beyond the end of runway 3C. The profiles showed that only the flaps and slats retracted takeoff configuration placed the airplane within dangerous proximity of the first light pole. The profiles also showed that with either slats in the mid-sealed position and flaps 11°, or with the flaps retracted and the slats in the mid-sealed position, the airplane would have cleared the light pole by 400 to 600 feet.

The information contained in the performance study corroborated the DFDR data that the takeoff was made with the flaps and slats retracted.

2.4 The Physical Evidence

The Trailing Edge Flap System.--The measurements of the extensions of the flap system's hydraulic actuators were inconsistent because the hydraulic lines to the actuators were broken, and there was no pressure available to hold the actuators in place throughout the entire impact sequence. However, other physical evidence was examined to determine the flap position at the time the airplane struck the railroad embankment.

The wing's trailing edge flaps are supported and guided at their inboard ends by curved tracks that travel along rollers mounted to the fuselage. When the airplane struck the ground, both flaps broke from the airplane and damaged their tracks. The shapes of the damaged areas on the flanges of each track matched the shape of the fuselage-mounted rollers, and the distance between the damaged points was the same as the distance between the rollers. In additions, the locations of the damaged areas on the flanges corresponded to the position that the rollers would have been in the tracks when the flaps are fully retracted.

Before assessing the reliability of this evidence, the Safety Board considered the scenario that the flaps were extended to 11° and that the initial impacts with the light standard and the rental car facility damaged the hydraulic lines and allowed the air loads to retract the flaps before the airplane struck the ground and they were broken from the airplane. The airplane's initial impact with the light standard did not break any hydraulic lines, but, thereafter, when the airplane struck the rental car facility, it is likely that the hydraulic lines to the left outboard spoiler and the outboard actuator of the left outboard flap ruptured. Since the neutral position of the flap control valve would have isolated the flap actuators from the remainder of the hydraulic systems, the rupture of the spoiler lines would not have immediately affected the flaps. While the rupture of the lines to the aforementioned actuator would have resulted in the loss of left hydraulic system pressure to the flaps, the right hydraulic system remained intact and its pressure alone was sufficient to prevent flap retraction from airloads.

In addition, pressure from the right hydraulic system should have prevented any movement of the left flap followup cable. Movement of this cable could bias the flap control valve and initiate flap retraction. The airplane traversed the distance between the rental car facility and the initial impact site in 1.5 seconds. Based on the flaps' normal rate of movement, it would have taken 6 seconds for them to retract from 11° to full up; therefore, even if the left flap followup cable had moved, the flaps could not have retracted from 11° to the up position in 1.5 seconds. The Safety Board concludes that the damaged areas on the inboard flap tracks presented a reliable portrayal of the position of the flaps when they were torn from the airplane, and, considering the 1.5-second interval between the impacts with the building and railroad embankment, the Board also concludes that the flaps were up when the airplane hit the building.

The flap handle was in the UP/RET position when it was found in the wreckage. The disassembly of the flap handle module showed that its right side was displaced to the left, forcing the flap handle to the left and against the fixed detent track. The handle's fixed detent pin was intact in the UP/RET detent, and there was a circular impact mark in the side of the detent which matched the end of the fixed detent pin. The orientation of a raised metal lip around the end of the detent pin matched the circular impact mark in the UP/RET detent.

The flap takeoff selector (dial-a-flap) movable detent was stowed and the cam finger detent mechanisms were scratched. The scratch most probably was produced by the dial-a-flap detent pin as the flap handle was displaced downward during impact.

There was no damage to the fixed detent pin and fixed detent track that indicated the flap handle had been in another detent during takeoff and was forced to the UP/RET detent during the impact sequence. Had the flap handle been positioned in the 11° detent and then forced forward during impact, the detent pin would have sheared and the fixed detent track most probably would have been damaged significantly.

Physical evidence supports the conclusion that the flaps were in the retracted position during the breakup of the airplane and that the flap handle was positioned in the UP/RET detent before impact.

The Leading Edge Slat System.--Except for a portion of the No. 5 slat which had remained attached to the 18-foot section of left wing which separated on initial contact with the light pole, the slat surfaces were destroyed. The examination of some of the recovered components of the slat actuation system produced contradictory evidence as to their positions at impact. However, the Safety Board believes that significant and reliable physical evidence depicting the position of the slats at impact was contained within the separated 18-foot section of the left wing.

The 18-foot wing section contained the drive cables from the slat drive drum to the transition drum of the No. 5 slats. The cables, which were routed just aft of the wing's leading edge, had been broken. When the slats were placed in the extended position, the cable breaks were 15.5 inches apart and neither of the breaks then matched the plane of the wing's fracture. However, when the cable breaks were aligned with each other, they aligned with the plane of the wing's fracture and the slats were in the retracted position. The Safety Board believes this evidence was most significant in determining the position of the leading edge slat before the initial impact. Given the location of the cables within the wing and the speed at which the airplane was traveling, the impact with the pole would have damaged the wing and the cables almost simultaneously. Since this damage was inflicted by the first object to strike the airplane, it showed that the slats were retracted at that time. This conclusion is further supported by the position of the flap handle.

In summary, the most reliable physical evidence of flap and slat position was the damaged inboard flap roller tracks and the breaks in the drive cables to the No. 5 slat transition drum. These items showed that the flaps and slats were fully retracted when the damage occurred. The slat cable damage was caused by the very first object the airplane struck, thus, showing that the slats were retracted when the left wing struck the light pole. During normal operation, the flaps cannot extend without the slats extending first; therefore, it can be concluded that the flaps also were retracted before the airplane hit the light pole. The damage to the flap handle and the significant impact damage to the UP/RET detent and adjacent area also supports this conclusion. The lack of damage elsewhere in the flap handle module further corroborated that the handle was in UP/RET detent before impact, rather than being forced to that position by impact forces. The most reliable physical evidence showed that the flaps and slats were retracted and in agreement with the full forward position of the flap handle at the start of the impact sequence.

The Safety Board also considered the statements of two Northwest first officers that flight 255's flaps and slats were extended. Their recollections were based on observations of an event which occurred after sunset, during twilight, and about 15 minutes before the time of official darkness. The Safety Board concludes that the recorded DFDR data, the physical evidence, and the resultant aerodynamic performance of the airplane during the takeoff were the more reliable evidence of the airplane's configuration.

Since only the flightcrew could extend the airplane's flaps and slats after it was pushed back from the gate, the Safety Board also concludes that the flightcrew did not extend the flaps and slats and did not configure the airplane properly for takeoff. However, the CVR transcript showed that the takeoff warning system, which was designed to warn the flightcrew that the airplane was not configured properly for takeoff, failed to provide the proper warning to the crew. Consequently, the Safety Board sought to determine the reason for this failure before analyzing the operational aspects of the accident.

2.5 The Central Aural Warning System

Except for the left wing slat's position sensors and the oleo switch on the nose landing gear, the Safety Board was able to examine and perform functional tests on every recovered component which provided information and electrical power to the CAWS unit. The examinations and testing showed that, at the time of the accident, these components functioned as designed. Both throttle switches were mounted in their separate switch bank units and functioned normally during these tests. However, destruction of the wiring harnesses precluded positive verification of complete circuit continuity. The throttle switches in the DC-9-82 are wired in parallel so either or both throttles will activate the warning and no single circuit failure can affect the system adversely. Therefore, two separate circuits would had to have been open to disable the system. Since the wires are routed in separate bundles to two different connectors, the Safety Board believes that this scenario is improbable.

The missing left oleo switch controls the left ground shift system which deactivates the takeoff warning system when the nose landing gear extends; thus, a malfunction of this switch could have disabled the takeoff warning system. However, the left ground shift system also provided air-ground logic to the DFDR, and the DFDR would have recorded continuously while the airplane was on the ground if the switch had malfunctioned. Since the DFDR, as designed, ceased recording when the parking brakes were engaged while the airplane was holding in the takeoff position, the Safety Board concludes that this switch also functioned properly.

A fail light is mounted on the front of the CAWS unit which will illuminate when the unit's self-monitor detects an internal failure. The fail light is operated by a latching-type relay and once lit, the relay latches and the light remains lit until the unit is removed, opened, and the relay reset. The CAWS unit was virtually undamaged when it was recovered. The latchable relay fault light on the front face of the unit was not latched indicating that the unit had not failed any portion of its internal self-monitoring test before the accident. The testimony of a Northwest first officer who rode in the jump seat from Detroit to Saginaw indicated that the takeoff warning system had functioned after the airplane landed at Saginaw.

The sound spectrum analysis testing conducted in the Safety Board's audio laboratory permitted the Board to identify the takeoff warning's failure mode. Of primary importance to this analysis was the fact that the two SSRS alarms are connected to different power supplies in the CAWS unit: SSRS-2, the first officer's alarm, was connected to CAWS power supply-3; and SSRS-1, the captain's alarm, was connected to CAWS power supply-2. The takeoff warning system also was connected to power supply-2.

When both SSRSs operate, an echo effect will be heard. The sound spectrum analysis of the actual warning generated by the accident airplane's CAWS unit showed that there was no echo effects, that only one SSRS had provided the alarm, and that, based on the frequency components of the word, SSRS-2 provided the alarm recorded by the CVR. This conclusion was further corroborated by the facts that no significant damage was noted on the filaments of either of the captain's bulbs; however, stretching, typical of an impact while the bulb filament is hot, was found on both bulbs of the first officer's warning light.

The evidence showed that the stall alarm was generated from power supply-3 of the CAWS unit's, and that, based on the facts that the takeoff warning system and SSRS-1 did not operate, power supply-2 of the unit was inoperative. Had the output from power supply-2 failed while the 28V d.c. input power from the airplane's electrical system was still available, the fail light on the CAWS unit would have illuminated, and, more importantly, its internal relay would have latched and remained latched until released by maintenance personnel; this relay was found not latched after the accident. Therefore, the Safety Board concludes that the loss of the takeoff warning system was caused by the lack of 28V d.c. input power from the airplane to power supply-2.

Power supply-2 of the CAWS unit receives power from the left 28V d.c. bus through the P-40 circuit breaker. Loss of the airplane's left 28V d.c. bus must be ruled out as the source of the loss of power to power supply-2 because its loss would have been readily apparent to the flightcrew. Numerous indicating lights and gauges would have been lost. The loss of the bus would have been annunciated on the cockpit's overhead annunciator panel, the master caution light would have illuminated, and the loss of the bus would have caused failures which would have affected information recorded by the DFDR. The fact that the DFDR did not record any information indicative of these types of failure further confirms that the left 28V d.c. bus was powered throughout the flight. Since the bus was powered and the wiring from the P-40 circuit breaker to the CAWS unit was intact, but power supply-2 of the CAWS unit was not functioning, the process of elimination leads to the only remaining component in the input circuit where a power interruption most logically could occur--the P-40 circuit breaker.

Because the P-40 circuit breaker was badly damaged during the accident, it was impossible for the Safety Board to determine positively its preimpact condition. There were three possible conditions that would have caused power to be interrupted at the P-40 circuit breaker: the circuit breaker was intentionally opened by either the flightcrew or maintenance personnel, the circuit breaker tripped because of a transient overload and the flightcrew did not detect the open circuit breaker, or the circuit breaker did not allow current to flow to the CAWS power supply and did not annunciate the condition by tripping.

The Safety Board considered the possibility that the system was disabled by operating the P-40 circuit breaker as a switch and opening it intentionally. This might occur if any of the warnings operated by power supply-2 were producing nuisance warnings that annoyed or distracted the flightcrew. The testimony of the Northwest first officer who rode in the cockpit jumpseat from Detroit to Saginaw indicated that power supply-2 was operational at Saginaw, when he heard the words "flaps, flaps" annunciate. Also, no nuisance warning was recorded by the CVR between the beginning of the recording at 2013:27 and its end at 2045:24.7. The DFDR recording showed that both engines were operating during the taxi from the gate at Saginaw and to the gate at Detroit-Metro. Therefore, not only was it unlikely that a nuisance takeoff warning would have been generated by a prolonged high engine power setting, but power settings of this magnitude were not recorded. However the SSRS-1, landing gear, auto-pilot disconnect, cabin altitude, and speedbrake warnings also are generated by power supply-2. Thus, it was possible that the power supply could have been disabled by the flightcrew for a nuisance warning other than the takeoff warning. The Safety Board cannot rule out this possibility. In addition, there was no evidence that any person who would have reason to open or close the circuit breaker had done so between the time the airplane landed at Saginaw and departed the gate at Detroit-Metro.

The second possibility considered was that the circuit breaker opened electrically due to an undetermined transient overload condition, and that the crew did not detect the tripped circuit breaker. In this case, there would be no warning that such a condition existed and the location of the circuit breaker is such that a tripped breaker might not be visually detected, especially in low ambient light conditions. Although flightcrew members normally check the circuit breaker panels on entering the cockpit, the sixth item on the BEFORE START checklist requires a circuit breaker inspection and both crewmembers are required to accomplish this step and are required to respond to the challenge.

The P-40 circuit breaker, as well as the other two circuit breakers on the input power circuits to the CAWS power supplies, are located directly behind the captain's seat and can best be inspected by the first officer. At 2029:28, the first officer said "Circuit breakers, are ah . . . " At 2029:30, the captain responded, "Checked," and, at 2029:31, the first officer said, "Auto-land is checked radio altimeters and flight director."

The CVR showed that the first officer, with regard to the circuit breakers, did not respond properly to the challenge and response aspects of the checklist and that his inspection of the upper and lower circuit breaker panels behind the captain was completed within 2 seconds. Given the time expended by the first officer, the thoroughness of his check of the circuit breaker panels had to have been limited. In addition, the P-40 circuit breaker might have opened after the check while the airplane was being taxied. Under those circumstances, it was very likely that its condition would have gone undetected.

The third possibility examined was that the P-40 circuit breaker, for undetermined reasons, did not allow current to flow even though the latch appeared mechanically closed to the flightcrew. Typically, this anomaly occurs when the breaker is cycled open and is subsequently closed, such as might occur if a crewmember closes a breaker that has tripped open. In this case, foreign objects may lodge between the breaker contacts preventing full closure, as was evidenced by the examination of two of the circuit breakers at TI. Another means by which current could be impeded is the formation of a dielectric film that could build up on the contact surfaces through airborne contaminants flowing into the vented circuit breaker case. When the contacts are closed, the contact make-point may rest on the surface of the film, preventing current flow. These films are typically tenuous in nature, and the behavior of the two circuit breakers that originally were open and then were metered after little or no disturbance suggests that the presence of such a film was responsible for the open circuit displayed by these devices.

The stationary contacts of the two circuit breakers mentioned above were similar in conductivity to those of the bus bar stationary contact of the P-40 circuit breaker from flight 255, i.e., these contacts exhibited random areas of intermittency about the outer periphery of the contacts when continuity was tested with 1.5 volts. The bus bar contact of the P-40 breaker had been exposed to the environment for several weeks after the accident; thus, the possibility existed that the silver sulfide layer resulted from this exposure. However, other contacts on the same bus, which were similarly exposed to the environment, did not exhibit the silver sulfide tarnish. In addition, the contacts from about 70 circuit breakers in the accident airplane were examined and silver sulfide tarnish was found on contacts that were not exposed to the environment. Silver sulfide tarnish also was present on the stationary contacts of the two breakers that were analyzed at Klixon and were suspected of not conducting current due to the presence of a dielectric film. The silver sulfide tarnish buildup on the P-40 contact from flight 255 appeared among the heaviest encountered during the examination. Therefore, the Safety Board concludes that much, if not all, of the silver sulfide tarnish existed on the contact before the accident. The evidence makes it impossible for the Safety Board to rule out that the current flow through the P-40 circuit breaker was inhibited by the presence of a dielectric film on the bus bar contact.

Personnel at Klixon stated that they are unaware of an instance where a closed and conducting circuit breaker suddenly stopped conducting and did not annunciate the condition to the flightcrew by tripping. The Safety Board agrees that this possibility seems remote given the design of the circuit breaker. Further, there is no information currently available regarding the in-service reliability of the devices, since service difficulties encountered regarding circuit breakers are seldom reported. However, testimony at the public hearing by nearly every pilot witness disclosed that periodically throughout their careers, they had regained the use of a system or component by opening and resetting the applicable circuit breaker. Possible failure modes for this scenario remain unidentified since the anomaly disappears once the circuit breaker is reset. Naturally, the type of system involved has some bearing on this behavior, and it may be in some cases that the circuit breaker is not responsible for the loss of the system. Nonetheless, the existing evidence suggests that circuit breakers may occasionally disable functioning systems for reasons that are not clear. Since this type of failure may not be readily apparent to flightcrews and may occur in critical systems, the Safety Board believes that the FAA should conduct a directed safety investigation to determine the reliability of circuit breakers and the mechanisms by which failures internal to the circuit breaker can disable operating systems, and to identify corrective actions as necessary.

The evidence did not permit the Safety Board to determine which of the three possible reasons interrupted the flow of current and caused the failure of the P-40 circuit breaker to power supply-2 of the CAWS unit.

The Safety Board supports the change to the MD-80 checklist contained in the Douglas telex as well as the efforts of the FAA to include flightcrew procedures in airplane checklists that will allow crewmembers to validate the operational capability of takeoff warning systems. Until such time as warning systems can, through the operation of internal self-testing equipment, furnish notice to a flightcrew that they are inoperative, these checklist procedures will enhance the flightcrew's ability to detect and deal with a failed takeoff warning system.

The evidence developed by the Safety Board during its investigation of the loss of power to the P-40 circuit breaker illuminated another area of concern. The evidence showed that the CAWS fail light was installed on the DC-9-82 to facilitate maintenance. The manufacturer believed that an increased level of dispatch reliability could be achieved if the flightcrew were made aware of in-flight CAWS anomalies and could notify maintenance personnel before landing. Maintenance could then meet the airplane with a replacement CAWS unit and facilitate airplane turn-around procedures. It was for this reason that the self-monitoring capability was built into the unit.

The CAWS unit's self-monitoring capability was also the reason that the CAWS fail light was not designed to annunciate the loss of 28V d.c. input power. Trouble-shooting can be limited to replacement of the CAWS unit if the only discrepancy that will illuminate the light is internal to the unit. However, from a safety viewpoint, this feature could be improved by modifying the design so that the CAWS fail light will illuminate not only with an internal failure, but with the loss of input power to the unit. This modification would change the behavior of the system so that it would perform in the manner reflected by the original FMEA that was approved by the FAA during the original certification of the airplane and system. The Safety Board believes that this type of warning is important to the concept of centralized aural warning since the loss of one power supply results in a number of disabled warnings, some of which may not be immediately recognizable to the crew.

As the number of required warnings is likely to increase in the future due to increasing complexity and automation, and the concept of centralized aural warnings is likely to be employed to a greater degree, a standardized approach to the design and certification of these systems should be developed. This should also include a standardized approach to the determination of the type of warning to be provided and the criticality of these warnings, such that similar systems in different jet transport category airplanes are afforded the same degree of self-monitoring and failure annunciations. Currently, there is no structured method by which to approach these evaluations, with the final outcome often determined through negotiation between the manufacturer and the FAA. Consequently, there is a wide variation in the results of these evaluations, not only from manufacturer to manufacturer, but between a single manufacturer's product lines. No regulations exist addressing the concept of the CAWS or the level of criticality of warning systems. The Safety Board believes that the determination and dissemination of guidance for the design of CAWS would be beneficial in the certification and operation of future transport airplanes.

The Safety Board also notes that some DC-9-82 operators have changed their checklist procedures. Flightcrews on these carriers are now required to check the performance of the takeoff warning system before every flight. While this procedure will verify the status of the takeoff warning system and the CAWS power supply-2, it will not apprise the flightcrew of a subsequent failure nor will it alert them of input power losses to the other power supplies of the CAWS.

The takeoff warning system alerts the flightcrew to an existing fault. It is the flightcrew's duty and responsibility to configure the airplane for takeoff and to ensure that they have done this correctly. Therefore, the Safety Board sought to determine why the flightcrew had not accomplished this basic task.

2.6 Flightcrew Checklist Performance

The CVR recording showed that the flightcrew neither called for nor accomplished the TAXI checklist. The first item on the TAXI checklist required both pilots, in response to the checklist's challenge, to check and verify orally that the flaps and slats were positioned correctly. This item was not performed, and the flightcrew did not discover that the airplane was configured improperly for takeoff. The omission of the TAXI checklist was further corroborated by the flightcrew's inability to engage the autothrottles at the start of the takeoff because they did not, as required by the TAXI checklist place the TCI in the "T.O." mode. However, they were able to rectify this omission by the time the airplane accelerated to 100 KIAS. Once the takeoff began, however, there was little chance they would detect any of the visual cues--the flap indicators in the up position, the absence of the blue takeoff light on the slat indicator light panel, and the absence of the ART ready light--that might have alerted them to the fact that the airplane was not configured properly. All of the visual cues relating to the flaps and slats were located outside, or on the perimeter of, those areas normally monitored by the captain and the first officer during takeoff. The Safety Board concludes that the failure of the flightcrew to accomplish the TAXI checklist in accordance with required procedures was the probable cause of this accident. Therefore, the Safety Board sought to determine how this omission could have occurred.

The Safety Board could not determine conclusively why the first officer did not lower the flaps. Northwest procedures authorized first officers to extend the flaps after the airplane begins to taxi and has cleared the parking ramp and its associated obstacles. The CVR recording showed that at the time the first officer was authorized to extend the flaps, several intervening events might have diverted his attention. Almost immediately after receipt of the taxi clearance and about the time the airplane began moving, the first officer had to select the ATIS radio frequency and listen to and copy the contents of the ATIS message. After receiving the message, he then had to get the takeoff performance chart and verify if they could use runway 3C for takeoff. Thus, the possibility existed that he might have intentionally delayed lowering the flaps, perhaps anticipating a different flap setting due to the runway change. The testimony of and interviews with Northwest flight personnel indicated that the flap extension procedure had become a very strong habit pattern among the DC-9 first officers. As such, the first officer may never have experienced an occasion when he had either inadvertently failed to extend flaps or had failed to extend them when the airplane began taxiing. The habit pattern of extending the flaps may have caused a lessening of his awareness of the omission, because by the time the first officer completed copying the ATIS message and analyzing the takeoff weight data, the airplane had taxied well beyond the point where he would have routinely extended the flaps. Based on this well developed habit pattern of extending the flaps, the first officer might have believed that this task, which was always completed shortly after the captain began to taxi or by the time the airplane departed the terminal ramps, had been completed as it always was.

The flap extension procedure did not require the captain to be either notified or to approve repositioning the flaps and slats. Therefore, unless he happened to either observe the first officer move the flap handle, or observe the movement of the flap indicator or the illumination of the slat advisory lights, he would not know that the procedure had been accomplished. In addition, the same habit pattern concerning the flap extension procedure would apply to the captain. Since there was no requirement to advise him, it was even more likely that he would assume that the first officer had extended the flaps at the place and time that they had always been extended. Consequently, the TAXI checklist became the only procedural means available to the flightcrew to ensure that the airplane was configured properly.

Northwest procedures defined clearly the flightcrew's duties and responsibilities as to how checklists were to be initiated and completed. During ground operations, the captain is to initiate each checklist by calling for it by name; if the captain does not call for the checklist, the first officer is required to ask the captain if he is ready to run the checklist. This procedure establishes a positive entry into a checklist for both crewmembers and provides crew backup to the memory-based initiation of a checklist. This design is particularly critical in initiating the TAXI checklist on which the flaps are the first item since the actual lowering of the flaps is solely the first officer's responsibility. After each checklist is completed, the first officer is required to identify the checklist by name and state that it was "complete." The statement that a specific checklist is complete provides closure to checklist conduct by acknowledging checklist completion. This statement enables both crewmembers to mentally move from the checklist to other areas of the operation with the assurance that the checklist has been accomplished. These requirements were met only once during the pretakeoff checklists. The closest approach to these standards was the BEFORE START checklist. At 2029:10, the first officer challenged "Brakes," the first item on this checklist. The captain did not respond to the challenge; however, at 2029:18, the captain said, "Lets do the checklist." At 2032:54, the first officer announced, "The BEFORE START checklist is complete."

However, even within the performance of this checklist, there were failures to comply with company standard procedures. Checklist items which require actions by and responses from the captain were read and responded to by the first officer. The captain did not call for the AFTER START, TAXI, or BEFORE TAKEOFF checklists, nor did the first officer ask the captain if he was ready to perform any of these checklists before reading the items.

The Safety Board believes that the design of the checklist procedures establishes a process wherein both crewmembers actively participate in checklist initiation. When by manner of practice, the captain yields his responsibility for checklist initiation, or the first officer actively or aggressively takes sole responsibility for checklist initiation, the redundancy afforded by mutual checklist entry is eliminated. By not adhering to the procedural framework, the crewmembers compromised the structure which was designed to support them and thereby placed a greater burden on the memory or habit pattern of an individual crewmember, in this case the first officer. This breakdown rendered the crew more susceptible to distractions or memory lapses.

The Taxi Checklist.--The Safety Board believes that the initiation of the TAXI checklist presented a problem to the flightcrew that did not exist with regard to the other checklists which are performed during ground operations before takeoff and which all have fairly definite keys or sequences that the crewmember can use to initiate the checklists. Two of these checklists, the BEFORE START and BEFORE TAKEOFF, constitute a condition precedent which must be eliminated before further airplane operations can be conducted. The BEFORE START checklist can be keyed by the final closing of the cabin door; the AFTER START checklist is cued by the completion of the last engine start; and, the BEFORE TAKEOFF checklist has the runway hold short line or the flight's takeoff sequence as cues. By contrast, the TAXI checklist can reasonably be initiated and accomplished any time after the captain begins to taxi or during any phase of ensuing taxi to the takeoff runway.

Testimony from other Northwest flightcrew members showed that they usually complete the TAXI checklist within the first 1 to 2 minutes of taxi. However, during this time they are also establishing radio contact with ATC, being sequenced with other traffic, and receiving other ground control instructions. All of these factors are potential distractors or delayers of the checklist. Therefore, crew-coordination and work-load management play a vital role in the accomplishment of both routine and intervening tasks that occur during taxi. The Safety Board believes that the nonstandard manner in which the crew initiated checklists, with the first officer bearing the load for checklist initiation and accomplishment, increased the crew's vulnerability to the problems associated with conducting checklists during taxi operations.

Since the TAXI checklist was almost always performed early in the taxi operation, it is possible that the flightcrews become conditioned to having completed the checklist by the time the flight has taxied for more than a few minutes. If there are interruptions and the checklist has not been initiated normally, when the airplane reaches a point in the taxi where the TAXI checklist typically has been completed, it is possible that the flightcrew will believe that the checklist was completed.

The captain and first officer on flight 255 had accomplished those items on the TAXI checklist which could be completed upon receipt of the final weight, such as stabilizer trim, airspeed settings, and the insertion of the c.g. and takeoff flap setting into the takeoff condition computer. At 2036:37 and 2036:40, while the airplane was taxiing, the CVR recording contains two comments concerning takeoff speeds and trim settings, the third and second items, respectively, on the TAXI checklist. The Safety Board's CVR group could not identify who made the 2036:37 comment, but the captain made the second comment. It is possible that the first officer and captain were either in a preparatory stage preceding the initiation of the TAXI checklist or were updating what they thought was a completed checklist. However, immediately thereafter, the captain questioned whether runway 3C could be used for takeoff and taxied past taxiway Charlie precipitating an almost

2-minute digression from matters relevant to the checklist. By this time the airplane's location on the airport was such that the external cues and references available to the flightcrew were not those normally associated with the initiation of the TAXI checklist at Detroit-Metro. In fact, with reference to the time of taxi and the airplane's location, the flightcrew had progressed into a frame of reference where the TAXI checklist would have been completed. Since no further action was taken concerning any other TAXI checklist items, the Safety Board believes that by this time, the flightcrew thought the checklist had been completed.

The Safety Board recognizes that the TAXI checklist must, at times, either be initiated or accomplished while flightcrews are establishing radio contact with ATC, taxiing through congested ramp areas, being sequenced with other taxiing airplanes, and receiving other ground control instructions. All of these factors are potential distractors and may even reach levels which may require a captain to delay initiating the checklist. The sequence of events involving flight 255's departure from Detroit indicated that these and other potentially distracting factors were present. The flight was operating behind schedule with the crew facing a curfew problem for their arrival in Santa Ana. Weather in the local area could have caused further delay if the storm arrived before their departure. There were reports of windshear by other crews and ATIS "hotel" windshear advisories. The runway change required the first officer to reference the takeoff performance manual.

The Safety Board believes that while the occurrence of these events presented the crew with distractions in addition to routine duty requirements, none represented extraordinary circumstances. The flightcrew was competent, qualified, highly experienced, and well regarded in their abilities by their peers. As such, none of the events they encountered should have been new to them and were circumstances with which they had successfully dealt in the past. While it is apparent that some combination of these events induced sufficient disruption to cause inadvertent omissions by a flightcrew using nonstandard procedures, the Safety Board sought to determine if other procedural areas might have contributed to flight 255's flightcrew's failure to perform the TAXI checklist.

<u>Cockpit Discipline</u>.-- A NASA psychologist testified that a well defined role structure in the cockpit reduces ambiguity about each crewmember's responsibility and when he will do it. He testified that the "lack of a well defined role structure is as devastating as one that is overly strong." The statements indicated that he believed there is a middle ground which the crew must occupy in effecting the desirable aspects of role or command structure. Too many commands or commands issued in a too authoritarian manner may inhibit crew effectiveness.

The psychologist testified that based on his observations of flightcrew performance during the simulator flights, he found, in general, that "commands were associated with a lower incidence of flying errors . . . and often communications of this type seem to assure the proper delegation of cockpit duties and facilitate coordination and planning."

The Safety Board believes that it is the captain's responsibility to structure the manner in which his crew will accomplish its duties. While he must be open to information input from his crew, he must set the tone for how this information will be proffered. Except for the BEFORE START CHECKLIST, he did not call for any of the other checklists nor did he point out to the first officer that checklists were not being accomplished in accordance with company procedures. After pushback, the captain initiated three conversations which were not germane to duty requirements and which diverted the crew's attention from task-related activities.

The evidence indicated that the first officer was either given, or assumed he had been given, the duties of leading the crew's task-related activities up to and including the signing of the flight release, a responsibility assigned to the captain by regulation. 12/ While it is possible the captain intended to discuss this problem with the first officer, he made no move to point out to the agent, for the agent's future knowledge, that only the captain is authorized to sign the release. The first officer's assumption of the role of leader placed him in a position of structuring the crew's approach to activities while at the same time trying to satisfy the captain that he was carrying out his subordinate role in a satisfactory manner. In the area of checklist initiation, the first officer's assumption of initiation responsibilities greatly increased his work and planning load and relegated the captain's function to that of observer. The evidence also indicated that deference by a captain to a first officer also can inhibit crew effectiveness because the captain cannot presume that the first officer will always assume all of the captain's responsibilities. The captain appears to have become dependent upon checklist initiation by the first officer instead of on his own active initiation responsibilities. Therefore, when the first officer became distracted, the captain's passive involvement with checklist initiation did not provide a backup to the first officer's memory.

An examination of the flightcrew's performance patterns during the flight into Detroit and during their departure from the terminal and taxi to the takeoff runway showed numerous examples of less than standard performance.

- After landing at Detroit-Metro, the flightcrew taxied by the entrance to their assigned gate and had to turn 180° to return to the gate.

- The airplane's weather radar is normally turned off during the AFTER LANDING checklist which is normally accomplished shortly after clearing the active runway. However, flight 255's weather radar was still on when the airplane was in proximity to the gate and after a lengthy taxi. While the possibility existed that the flightcrew intentionally did not turn the radar off, the greater possibility was that the flightcrew had not yet performed the checklist or had missed turning it off during the performance of the checklist.

- During the taxi-out at Detroit-Metro, ground control directed the crew to taxi to runway 3C, to change radio frequencies, and to contact ground control on the new radio frequency. The first officer did not change frequencies, and ground control was unable to contact the flight when it taxied past taxiway Charlie.

- The first officer had reiterated the ATC taxi clearance and route and the takeoff runway assignment to the captain at least twice. The captain did not question either the radio transmission or the first officer's reiteration of the transmission. Although the captain had flown to and from Detroit-Metro many times, he failed to turn off at Charlie and expressed doubt as to where it was located.

In essence, when these deviations are assessed together with the flightcrew's checklist performance, the Safety Board believes that their performance was below the standards of an air carrier flightcrew.

The Safety Board recognizes that human performance is subject to considerable change and variation and that flightcrews are not immune to having "off days" in which their performance is below the standards they have set for themselves and which others expect of them. Because

12/ Title 14 CFR 121.663 states in part, "The pilot in command and an authorized dispatcher shall sign the release only if they both believe the flight can be made safely.

factors which can contribute to substandard performance are often subtle, difficult to recognize, and individual in nature, crewmembers may not be aware of the reasons which underlie below-par performance. Management cannot monitor, on a daily basis, the individual's ability to deal with job requirements. It is for these reasons that standard operating procedures are developed. Applying these procedures as they are written provides a firm foundation on which they can depend for support. Routine operating procedures when applied in a disciplined, standardized manner provide crewmembers with a firm foundation which they can depend upon for support during those times when they are subject to less than optimum levels of performance. This support is provided when the crew fully recognizes the necessity to function as a coordinated team while applying routine procedures in a disciplined and standardized manner.

Flightcrew Standardization.--It was clearly evident in this accident that the flightcrew did not perform checklist procedures in the manner prescribed in the company's APH. There are two avenues of approach in analyzing the crew's nonstandard application of checklist procedures. Either the crew was acting in a totally anomalous fashion or their performance was consistent with their routine behavior.

The captain gave no indication that he was uncomfortable with, or disapproved of, the first officer initiating checklists without his command or without first inquiring whether the captain was ready to start a particular checklist. The first officer's actions did not seem to generate any confusion on the part of either man and tends to indicate the checklists were being operated in a manner familiar to both of them and accepted by both as a proper alternative to standard company procedure. Had either been uncomfortable with this manner of operation one would assume that the aberrant actions by either crewmember would have been brought to the other's attention and corrected. This performance by two crewmembers whose performance was described by peers as standard, meticulous, and professional seems to indicate that this manner of checklist performance was one to which each had been exposed and become familiar with over a lengthy period. For the flightcrew to gain the level of comfort and acceptance which was demonstrated indicates that this manner of application was accepted and used by other crewmembers with whom they had flown.

The Safety Board could not positively conclude that the performance of the accident crew was representative of the standards of performance used by a significant number of the carrier's flightcrews. Nor does the Safety Board have direct evidence to support the contention that this type of nonstandard performance is an industry-wide problem. Nevertheless, the Safety Board recognizes there are similarities between Northwest and the published operational procedures, aircraft, and checklist concept used by many air carriers. Therefore, the Safety Board believes that the FAA should require its operations inspectors and designated check airmen to emphasize the importance of disciplined application of operating procedures and rigorous adherence to prescribed checklist procedures. The Safety Board also believes that the standards and procedures used by the management of carriers cited in the Boeing Airliner Magazine are indicative of procedures that would foster an improved degree of standardizaton and safety.

The Safety Board believes that the use of company check airmen has advantages in that it expands the surveillance of the FAA and, as structured within the former Republic Airlines organization, serves as quality control to the training department. Check airmen are selected by management based upon their high level of professional performance and are given ground school and specialized training before designation by the FAA. Evidence indicates that the company had established a program to address standardization of crew performance. The Safety Board believes, however, that check airmen are also susceptible to erosion of standardization. Procedural differences that are subtle and which demonstrate no readily apparent flaw may lead to a check airman's loss of sensitivity to the relaxation of adherence to standards or at least prompt hesitancy in correcting such crew performance. While this loss of sensitivity may have existed within the check airmen of the company, the Safety Board does not view this as an indictment of the concept of the check airman program. The Safety Board believes that the program is necessary and is successful because of the air carrier's self interest in conducting safety operations.

Checklist Presentation.--While the applicable regulations require that carriers furnish checklists to their flightcrews and establish procedures for using the checklist, the regulations do not establish how the information contained on the checklist is to be presented. Some carriers present their checklists on an 8- by 11-inch laminated card; each side of the card contains several sections of the checklist. The U.S. Air Force presents the checklists of its Lockheed C-141s and C-5s on scrolls. After completing the items in view on a lubber line in the window of the scroll case, the user rotates the scroll to position the next checklist item on the lubber line for accomplishment. One U.S. carrier uses the laminated card to present all but its before takeoff and landing checklists; the carrier presents these two checklists on a mechanical slide checklist. As each item on the mechanical checklist is completed, a slide is moved over and covers the completed item. In later model airplanes, the checklist is displayed electrically. When the desired checklist is selected, all items on the list are illuminated. As the checklist item is completed, a switch is moved and the light beneath the completed item is extinguished. Both the mechanical and electrical checklists are affixed permanently to the cockpit structure.

The Northwest DC-9-82 checklist is printed on a 6 3/4- by 11-inch card which is divided into thirds by dashed lines. When folded, one section of the card includes the TAXI, DELAYED ENGINE START, BEFORE TAKEOFF, CLIMB, and IN RANGE checklists. During the accident flight operational sequence, after completing the AFTER START checklist, the flightcrew would have had to turn over the card and would have had to affix it to the control wheel to expose the TAXI checklist.

The presentation and organization of the checklist card does not, of itself, allow visual differentiation between accomplished and nonaccomplished checklists. The TAXI and BEFORE TAKEOFF checklists are arranged in sequential order of operations and, as such, the checklist card requires no manual manipulation to transfer attention from one checklist to the other. Also, the checklist card does not provide a visual alert to a nonaccomplished checklist.

The presentation on the Northwest checklist does not differ in any substantial degree from the checklist presentations by other carriers on 8- by 11-inch laminated cards. Both presentations require some manipulation because all of the checklists cannot be presented legibly on one side of the card. Although the places where manual manipulation on each chart is required may differ, neither presentation requires manual manipulation to transfer attention from each individual checklist segment to another and neither provides a visual alert to a nonaccomplished checklist.

The evidence developed during the Safety Board's investigation showed that adherence to flightcrew procedures is paramount in accomplishing a checklist properly. The testimony of the NASA psychologist corroborated this conclusion as did that of the management sciences professor.

However, the management sciences professor testified that he "did not know of any human factors research on how a checklist should be designed and he could not find anything in his library on the subject." The Safety Board believes that the facts and circumstances of this accident contain compelling reasons for conducting human performance research on checklist presentation. The Safety Board believes that the FAA should convene a human performance research group of personnel from NASA, industry, and pilot groups to determine if there is any type or method of presenting a checklist which produces better performance on the part of user personnel.

2.7 Training

The Safety Board notes that both crewmembers received single-crewmember training during their last simulator training and proficiency checks. When such training is performed, the instructor occupies the other pilot seat and also operates the simulator. The Safety Board believes this manner of training significantly limits the opportunity for the instructor to observe and to critique nonstandard practices because he is part of the operating process. The Safety Board realizes that providing recurrent training to captains and first officers separately was not the policy of the Northwest Airlines DC-9-82 training department. Rather, the single-crewmember training sessions for the captain and first officer of flight 255 occurred as a result of nonroutine scheduling difficulties or other unforeseen circumstances. When training is conducted using a complete crew, the instructor is able to observe the manner in which the two crewmembers perform their duties. By observing the interaction of the crew, the instructor is better able to identify problems relating to communication, checklist usage, and standardization.

Historically, the industry in general, and the FAR's in particular, have emphasized during training and proficiency checks individual piloting skills as a measure of performance. This emphasis on individual performance pays insufficient attention to the importance of the crew functioning as a team. The Safety Board believes that training individuals to an individual level of performance does not necessarily provide for an effective, coordinated cockpit team.

The Safety Board believes line-oriented flight training (LOFT) and training in the management of crew coordinated activities provides the opportunity to more fully train flightcrews in a team-oriented manner. LOFT focuses the training environment on the conduct of the entire crew; as such, it expands the training incorporated during the performance of individual maneuvers. Training crewmembers in management and communication skills will expand the crew's ability to more effectively coordinate information processing requirements.

Since 1968, the Safety Board has issued 22 recommendations to the FAA which addressed, in varying degrees, cockpit resource management (CRM). On April 15, 1985, the Safety Board recommended that the FAA:

A-85-27

Conduct research to determine the most effective means to train all flightcrew members in cockpit resource management, and require air carriers to apply the findings of the research to pilot training programs.

The FAA, in its December 1986 response to Safety Recommendation A-85-27, stated it had:

Initiated a program in the area of Aviation Behaviorial Technology which is intended to develop and apply advanced behaviorial analysis and technology to improve flight safety. The program includes projects on optimized line-oriented training to enhance cockpit resource management, improve cockpit/cabin communication and coordination, and improved pilot decision making training program.

The FAA further commented that this program would be a "long-term effort."

The Safety Board supports these efforts of the FAA and hopes that a priority will be given to this program that will allow its benefits to be incorporated in air carrier training programs as expeditiously as possible.

While the Safety Board believes there are benefits to be derived from any meaningful discussion on CRM, it also believes there is evidence that would indicate CRM training given solely in a quasi-classroom environment with diminished frequency will not provide to flightcrews the appropriate emphasis and hence the long-term follow through that is intended.

Republic Airlines began training crews for CRM in the fall of 1983. It was presented in the recurrent ground school and was followed with instruction presented in Recurrent Training Bulletins (RTB) 83-3 and 83-4, and each RTB in 1984.

The flightcrew members on the accident flight received 3.5 hours of CRM training during their respective ground schools (general) in 1983. This was the last CRM training that each crewmember received.

The Safety Board believes that the absence of leadership and coordination demonstrated by the accident crew suggests there is strong evidence to support that the CRM training they did receive was deficient and that future programs must go beyond the scope of a limited and traditional classroom forum.

The Safety Board is aware that the Republic Airlines training program will be integrated into the Northwest Airlines training program. The carrier thus has the opportunity to assure that flightcrew coordination, cockpit resource management, and standardization of operational procedures will be given adequate emphasis during training.

2.8 Automated Systems Use

The Safety Board found no indication that the flightcrew's failure to configure the airplane for takeoff was attributable to their reliance on an automated system which would warn them of their omission. The Safety Board's concern over this matter was aroused when Northwest flightcrews testified that some DC-9-82 crews used the takeoff warning system to check their airplane configuration while taxiing out for takeoff. Pilots stated that during taxi and after the airplane has been configured for takeoff, one or more throttles are sometimes advanced to see if the takeoff warning annunciates. If there is no warning, they assume the airplane to be configured for takeoff. The evidence showed that this practice was brought about by the sensitive relationship of the airplane trim setting to the adjustable center of gravity index. Crewmembers stated that they had experienced occasions when the trim setting appeared to be set properly but was apparently misset a slight amount causing the takeoff warning to sound when power was applied for takeoff. When this occurred on the runway, the crew would have to reject the takeoff, exit the runway, and delay departure while they analyzed the cause of the problem. Therefore, to preclude this late discovery, flightcrews began checking for a warning before taking the active runway. A Northwest check airman stated that he recommended this procedures to flightcrews during line checks.

While the use of this procedure to check specifically for a slightly-out-of-tolerance trim setting before starting a takeoff may be good, the Safety Board is concerned that the practice may cause flightcrews to believe that they are also performing a functional check of the takeoff warning system when, in fact, they are not. If the takeoff warning system had failed as it did in the accident flight then regardless of the airplane configuration, the flightcrew will receive no warning. Operation of the takeoff warning system can only be checked properly by performing the functional test contained in the checklist or by advancing the throttles beyond the throttle switches with a known parameter out-of-tolerance.

2.9 Flightcrew Actions After Takeoff

Even though the Safety Board determined that the flightcrew failed to configure the airplane properly for takeoff, the Safety Board examined the flightcrew's actions after takeoff to see if they could have prevented the accident.

By the time the airplane lifted off, the captain had rotated it to a 11° to 12° nose-up pitch attitude. The stick shaker activated at liftoff and continued to operate throughout the flight. After liftoff, the captain rotated the airplane to a 13° to 14° noseup pitch attitude, and, 4.5 seconds after liftoff, the SSRS alarm activated and the airplane began to roll. The subsequent rolls and control inputs required to recover from them decreased the airplane's climb capability by about 20 percent. Between the start of the first roll and initial impact, the airplane's pitch attitude varied between 13° to 14° noseup and these pitch attitudes were either at or just below the angle of attack which activated the SSRS.

The Safety Board's performance calculations showed that the airplane would have cleared the light pole if the roll oscillations were eliminated and the captain could have avoided them by lowering the nose of the airplane and maintaining a pitch angle that would have positioned it at or just below the stick shaker's angle of attack. Given the configuration of the wing, flaps and slats retracted, the stick shaker would have initiated at an angle of attack of about 11°, 2° below the SSRS's angle of attack and below the angle of attack at which the airplane's roll stability was compromised. Had the captain flown the airplane at a constant 11° angle of attack, he would have avoided the roll oscillations and the airplane would have cleared the light pole by about 80 feet.

Three Northwest DC-9-82 captains stated that, during an encounter with a windshear, they would consider flying the airplane above the pitch angle that would cause the SSRS to begin. They stated that the airplane was not stalled at that pitch angle. One of these captains stated that he "would not be completely uncomfortable in the supplementary stall warning region if necessary for recovery." Although the captain of flight 255 flew the airplane at and just below the angle of attack which activated the SSRS warning, there was no evidence to indicate that the captain of flight 255 entertained similar conclusions as to the airplane's performance capabilities in this flight regime.

The evidence does not provide a sufficient basis for the Safety Board to conclude that his entrance into this area of flight was intentional. The airplane lifted off the runway with the stick shaker activated and at about a 11° to 12° noseup pitch attitude. To silence the stick shaker, the captain would have had to release the back pressure on the control column and allow the nose to lower about 2°. Given the facts that the airplane had just taken off, that its climb rate was virtually negligible, and that the stick shaker was operating continuously, the Safety Board believes that it would be almost impossible to expect the captain to introduce control inputs which threatened to reverse the airplane's negligible rate of climb. Throughout the entire flight, the airplane was operating in proximity to the ground. The Safety Board believes that one possible explanation for the manner in which the airplane was flown was that the control inputs of the captain were merely a reflex action on his part to avoid recontacting the ground.

Any evaluation of the captain's flight techniques must start with a conclusion as to what the captain and first officer believed the configuration of the airplane was. Since they both believed that the airplane was configured as required for takeoff before they began the takeoff, the fact that the takeoff warning did not sound in accordance with their expectations would have further reinforced their belief that the flaps were at 11° and that the slats were extended to the mid-sealed position. During the time they had been in the airplane, there had been numerous communications concerning windshear and microbursts in proximity to the airport. Also, thunderstorms, which might reinforce the possibilities of windshear or gust were in sight north and west of the airport. When the immediate nature and strength of repetition, both verbally and visually, of the possibility of windshear is combined with the reasons for the crew's belief in a properly configured airplane, the Safety Board believes that it is reasonable to conclude that the flightcrew thought they had encountered a windshear when the stall warnings began after liftoff and focused their attention on escaping from a windshear encounter. Windshear recovery procedures do not call for a configuration change. Instead, they call for power and attitude adjustments to prevent the airplane from striking the ground and, thereafter, to try and establish a rate of climb. The DFDR indicated that the captain was trying to maximize the performance of the airplane with pitch attitude adjustments. In addition, the rolling of the airplane also would have been indicative of the type of turbulence that can accompany a low altitude windshear or microburst. The fact that the pitch adjustments exceeded those recommended for use during windshear encounters and placed the airplane at angles of attack which activated the SSRS alarm could be attributed to reflex actions by the captain to clear the oncoming light poles.

The stall recovery procedures contained in the Northwest APH stated, in part, that if a stall were encountered with the airplane configured for takeoff the pilot flying the airplane should apply and call "Max power, flaps 15" while simultaneously relaxing the back pressure enough to stop the stick shaker or buffeting. The pilot not flying will select the flaps and trim the throttles to maximum power. The DFDR recording indicated that maximum power was applied; however, the CVR showed that the captain did not call for the flaps to be set to 15°. The fact that the captain did not try to use this procedure could further indicate that he believed he had encountered a windshear.

The total amount of time that the airplane was flyable was 14 seconds. Even if the crew had recognized that the increasing airspeed was inconsistent with a decreasing performance windshear, the short period of time for them to completely and accurately assess what was happening to the airplane was probably inadequate. The combination of airplane rolling, the stall warnings, and the possibility of imminent ground contact were probably powerful enough stimuli to focus the crew's attention completely on the factors relevant to avoiding ground contact and to maintaining airplane control and did not allow them sufficient flexibility to expand their attention to include all the factors that were required to more completely assess the airplane's condition.

The Safety Board believes that the captain's bracketing of the SSRS alarm was a reflexive action to the adverse visual cues presented to him. However, the continued operation at the higher SSRS angle of attack instead of the stick shaker angle of attack resulted in the onset of roll oscillations and the loss of critical climb capability.

All DC-9 series airplanes that have leading edge wing slat systems are equipped with an SSRS. The SSRS system is unique in that it provides an indication of the stall angle of attack; therefore, it may lead to over-confidence while operating above the normally accepted upper limit of stick shaker angle of attack. The Safety Board found that some DC-9-82 captains expressed no concern about operating at the SSRS angle of attack. Only one captain who was interviewed stated that "he would not try to go into the supplementary stall warning area." It appears that some captains did not recognize the SSRS as an announcement of stall. They viewed the SSRS alarm as a warning with some margin as is the case with the stick shaker where there is a margin. In addition, these captains expressed no concern about the loss of lateral control at SSRS and the resultant degradation of climb performance procedure taught by most airlines for windshear. Actually, the crew were maintaining pitch at or near the SSRS and should have been maintaining a lower angle at stick shaker.

The possible reasons for these beliefs about the SSRS are either that training is inadequate or that the simulators do not accurately model the decreased roll stability at angles near to or greater than the SSRS angle of attack, thus giving a false sense of security. MD-80 flightcrews should be trained on the lateral control hazards that exist while operating at the SSRS angle of attack and the fact that the additional climb performance capability that exists above the stick shaker angle of attack is minimal and easily negated when small roll oscillations commence. MD-80 pilots should be trained to operate at or below the onset of stick shaker activation and to avoid the activation of the stick shaker except in those conditions beyond their control.

The Safety Board cannot determine if the selection of the go-around mode resulted from an inadvertent actuation of the TOGA switch when the captain advanced the throttles after liftoff or whether the TOGA switch was activated intentionally. However, there is no normal, abnormal, or emergency procedure in the Northwest APH which recommends that the F/D be transferred from the takeoff mode to the go-around mode under the conditions of flight that existed when the transfer occurred.

The simulations of the F/D's theoretical design performance for the condition of the accident takeoff demonstrated that, had the F/D remained in the takeoff mode and had the captain been able to follow the guidance provided by the command bar, the airplane theoretically would have been flown at pitch attitudes below the stick shaker's angle of attack. Flight in this regime would have increased the airplane's roll stability. Consequently, the airplane's climb performance would not have been degraded by roll oscillations and spoiler deflections and the airplane would have cleared the light pole.

2.10 The Captain's Hearing

The captain's hearing aid was fitted for his left ear, the same ear that he would have used for his radio receiver. The captain's hearing aid was not found at the accident site, and it was also doubtful that he would have used the hearing aid at the same time he would have worn the radio receiver's molded ear piece. Therefore, the Safety Board concludes that the captain was probably not wearing his hearing aid at the time of the accident.

Examination of the CVR transcript showed a few instances where the captain appeared not to have heard either a radio transmission or an intracockpit remark; however, the instances are separated widely and no pattern of consistency that could be attributed to a hearing deficiency was discernible.

3. CONCLUSIONS

3.1 Findings

1. Flight 255 did not encounter windshear either during the takeoff roll or after liftoff.

2. Flight 255 took off with its wing's trailing edge flaps and leading edge slats retracted.

3. The flightcrew did not extend the airplane's flaps and slats.

4. The flightcrew did not perform the airplane's checklists in accordance with the prescribed procedures contained in the Northwest Airplane Pilots Handbook. The flightcrew did not accomplish the TAXI checklist and therefore did not check the configuration of the airplane.

5. The airplane's climb performance was severely limited by the flightcrew's failure to properly configure the wing for takeoff.

6. The airplane would have cleared the light pole by 500 feet with only its wings slats extended.

7. The roll stability of the airplane was decreased as a result of flying it at or below the SSRS alarm and near the stall angle of attack. The resultant rolling of the airplane degraded its climb performance.

8. If the airplane had been flown at or below the stick shaker angle of attack, the roll stability would have been increased and the airplane would have cleared the light pole.

9. The CAWS unit's takeoff warning system was inoperative and, therefore, did not warn the flightcrew that the airplane was not configured properly for takeoff.

10. The failure of the takeoff warning system was caused by the loss of input 28V d.c. electric power between the airplane's left dc. bus and the CAWS unit.

11. The interruption of the input power to the CAWS occurred at the P-40 circuit breaker. The mode of interruption could not be determined.

13. The light poles at the impact site did not exceed the limiting standards contained in 14 CFR Part 77.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's failure to use the taxi checklist to ensure that the flaps and slats were extended for takeoff. Contributing to the accident was the absence of electrical power to the airplane takeoff warning system which thus did not warn the flightcrew that the airplane was not configured properly for takeoff. The reason for the absence of electrical power could not be determined.

4. RECOMMENDATIONS

As a result of its investigation, the National Transportation Safety Board made the following recommendations:

--to the Federal Aviation Administration:

Conduct a directed safety investigation to determine the reliability of circuit breakers and the mechanisms by which failures internal to the circuit breakers can disable operating systems and to identify appropriate corrective actions as necessary. (Class II, Priority Action) (A-88-64)

Require the modification of the DC-9-80 series airplanes to illuminate the existing central aural warning system (CAWS) fail light on the overhead annunciator panel in the event of CAWS input circuit power loss so that the airplane conforms to the original certification configuration. (Class II, Priority Action) (A-88-65)

Develop and disseminate guidelines for the design of central aural warning systems to include a determination of the warning to be provided, the criticality of the provided warning, and the degree of system self-monitoring. (Class II, Priority Action) (A-88-66)

Require that all Parts 121 and 135 operators and principal operations inspectors emphasize the importance of disciplined application of standard operating procedures and, in particular, emphasize rigorous adherence to prescribed checklist procedures. (Class II, Priority Action) (A-88-67)

Convene a human performance research group of personnel from the National Aeronautics and Space Administration, industry, and pilot groups to determine if there is any type or method of presenting a checklist which produces better performance on the part of user personnel. (Class II, Priority Action) (A-88-68)

Expedite the issuance of guidance materials for use by Parts 121 and 135 operators in the implementation of team-oriented flightcrew training techniques, such as cockpit resources management, line-oriented flight training, or other techniques which emphasize crew coordination and management principles. (Class II, Priority Action) (A-88-69)

training, or other techniques which emphasize crew coordination and management principles. (Class II, Priority Action) (A-88-69)

Issue an Air Carrier Operations Bulletin-Part 121 directing all principal operations inspectors to emphasize in MD-80 initial and recurrent training programs on stall and windshear recovery the airplane's lateral control characteristics, potential loss of climb capability, simulator limitations, and flight guidance system limitations when operating near the supplemental stall recognition system activation point (stall angle of attack). (Class II, Priority Action) (A-88-70)

--to all Part 121 Air Carriers:

Review initial and recurrent flightcrew training programs to ensure that they include simulator or aircraft training exercises which involve cockpit resource management and active coordination of all crewmember trainees and which will permit evaluation of crew performance and adherence to those crew coordination procedures. (Class II, Priority Action) (A-88-71)

ICAO Note.— Figures 1 and 2, and Appendices A to E were not reproduced.

ICAO Ref.: 119/87

No. 3

Boeing 737-200, HS-TBC, accident in the Andaman Sea near Phuket Airport, Thailand, on 31 August 1987. Report released by the Aircraft Accident Investigation Committee, Ministry of Transports and Communications, Thailand.

SYNOPSIS

A THAI AIRWAYS COMPANY AIRCRAFT, BOEING 737-200 OF THAI NATIONALITY AND REGISTRATION , HS-TBC, FLIGHT NUMBER THAI AIR 365, ON A SCHEDULED DOMESTIC PASSENGER FLIGHT, CRASHED IN THE ANDAMAN SEA NEAR PHUKET AIRPORT ON AUGUST 31, 1987. IT WAS A NON-SURVIVABLE ACCIDENT.

THE AIRCRAFT ACCIDENT INVESTIGATION COMMITTEE DETERMINES THAT THE PROBABLE CAUSE OF ACCIDENT WAS: THE PILOT SLOWED THE AIRCRAFT AND IT STALLED WHILE THE PILOT PREPARED TO BE NUMBER ONE ON LANDING AS ADVISED BY PHUKET APPROACH CONTROL. IT APPEARS THAT HE WAS WORRYING AND NOT SURE WHETHER HE COULD MAKE NUMBER ONE LANDING BECAUSE THE PILOT OF NUMBER TWO AIRCRAFT IN SEQUENCE GAVE WARNING THAT THE NUMBER ONE AIRCRAFT AHEAD WAS ABOVE HIM AND COULD NOT DESCEND PASSING THROUGH HIS LEVEL. THE PILOT ADDED POWER AND RAISED THE GEAR AFTER STICK SHAKER ACTIVATED BUT DID NOT EXECUTE A RECOVERY BEFORE HITTING THE SEA.

ALL TIMES IN THIS REPORT ARE UTC

1.1 HISTORY OF THE FLIGHT

ON AUGUST 31,1987, AT 05:15:00 HRS, DRAGON AIR 203, WITH EIGHT FLIGHT CREW MEMBERS AND FIFTY THREE PASSENGERS PLUS ONE INFANT ONBOARD, DEPARTED FROM THE HONGKONG INTERNATIONAL AIRPORT ON AN IFR FLIGHT TO THE PHUKET AIRPORT IN THAILAND VIA A 901 DANANG, A1 UBON, W1 BANGKOK, W 10 SURAT, W 18 PHUKET, AT FL 350. IT PROCEEDED VIA ITS FLIGHT PLANNED ROUTE AND WAS TRANSFERED TO THE BANGKOK AREA CONTROL CENTRE WHEN IT WAS OVER BUTRA, AT THE BANGKOK FLIGHT INFORMATION BOUNDARY.

AT 08:10:00 HRS, THAI AIR 365, WITH NINE FLIGHT CREW MEMBERS AND SEVENTY FOUR PASSENGERS ONBOARD, DEPARTED FROM HAT-YAI AIRPORT IN THAILAND ON AN IFR FLIGHT TO THE PHUKET AIRPORT VIA W14 , AT FL 180. SHORTLY AFTER AIRBORNE, THAI AIR 365 BEGAN TO CONTACT THE BANGKOK AREA CONTROL CENTRE WHEN IT WAS AT 13 NAUTICAL MILES FROM HAT-YAI VOR/DME, ON RADIAL 299 , AT ALTITUDE 11,000 FEET. IT WAS CLEARED TO CLIMB UP TO FL 180.

THE TWO AIRCRAFT WERE MAKING THE VOR/DME APPROACH TO LAND ON RUNWAY 27 AT PHUKET AIRPORT. BOTH WERE CONVERGING ON THE INITIAL APPROACH FIX, 12 NAUTICAL MILES FROM THE VOR/DME. THEY WERE THAI AIRWAYS COMPANY AIRCRAFT, HS-TBC, BOEING 737-200, FLIGHT NUMBER THAI AIR 365 ON SCHEDULED DOMESTIC PASSENGER FLIGHT AND DRAGON AIRLINES LTD. AIRCRAFT, VR-HYL, BOEING 737-200, FLIGHT NUMBER DRAGON AIR 203 ON A SCHEDULED INTERNATIONAL PASSENGER FLIGHT.

THE SEQUENCE OF EVENTS BELOW DERIVED FROM THE COCKPIT VOICE RECORDER OF THAI AIR 365 AND THE PHUKET APPROACH CONTROL RECORDED AIR TRAFFIC COMMUNICATION:

AT 08:10:00 HRS, DRAGON AIR 203 REQUESTED BANGKOK AREA CONTROL TO DEVIATE TO THE WEST OF ITS PRESENT ASSIGNED TRACK ON INBOUND RADIAL 038 IN ORDER TO AVOID THUNDERSTORM CLOUDS OVER SURATTANEE. BANGKOK AREA CONTROL APPROVED AND ASKED DRAGON AIR 203 TO ADVISE WHEN IT WAS CLEARED OUT OFF THUNDERSTORM CLOUDS AND TO INFORM THEM OF ITS INBOUND RADIAL TO PHUKET VOR/DME.

AT 08:15:00 HRS, DRAGON AIR 203 REPORTED TO BANGKOK AREA CONTROL THAT THE FLIGHT WAS AT FL 350 AND WOULD BE ABLE TO ESTABLISH

ITSELF ON THE RADIAL 025 INBOUND TO PHUKET VOR/DME, AND REQUESTED DESCENT CLEARANCE. BANGKOK AREA CONTROL THEN CLEARED DRAGON AIR 203 TO PHUKET VOR/DME ON THE INBOUND RADIAL 025 AND TO DESCEND AND MAINTAIN FL 190, DUE TO THE FAILURE OF DIRECT SPEECH CIRCUIT BETWEEN BANGKOK AREA CONTROL AND PHUKET APPROACH CONTROL, THEN

AT 08:17:00 HRS, BANGKOK AREA CONTROL REQUESTED DRAGON AIR 203 TO CONTACT PHUKET APPROACH CONTROL FOR THEM TO OBTAIN CLEARANCE FOR DRAGON AIR 203 TO PROCEED INBOUND ON RADIAL 025 TO PHUKET VOR/DME. PILOT OF DRAGON AIR 203 CARRIED OUT THE BANGKOK AREA CONTROL REQUEST AND REPORTED BACK TO BANGKOK AREA CONTROL THAT HE HAD BEEN ADVISED BY PHUKET APPROACH CONTROL THAT THERE WAS NO CONFLICTING TRAFFIC AT PHUKET.

AT 08:18:00 HRS, DRAGON AIR 203 REPORTED TO BANGKOK AREA CONTROL THAT IT WAS AT 82 NAUTICAL MILES FROM PHUKET VOR/DME AND, IT WAS DESCENDING FROM FL 275. BANGKOK AREA CONTROL CLEARED DRAGON AIR 203 TO DESCEND TO FL 130 AND TO CROSS NORTH OF PHUKET AIRPORT 30 NAUTICAL MILES FROM PHUKET VOR/DME.

AT 08:19:00 HRS, THAI AIR 365 REPORTED REACHING FL 180 AND WAS CLEARED BY BANGKOK AREA CONTROL TO PHUKET VOR/DME ON RADIAL 119.

AT 08:20:00 HRS, THAI AIR 365 WAS AT 90 NAUTICAL MILES FROM PHUKET VOR/DME AND THE PILOT-IN-COMMAND BRIEFED HIS CO-PILOT, CONCERNING THE PHUKET VOR/DME APPROACH PROCEDURES.

AT 08:23:00 HRS, BANGKOK AREA CONTROL CLEARED THAI AIR 365 TO DESCEND AND MAINTAIN FL 140.

AT 08:24:00 HRS, DRAGON AIR 203 REPORTED THAT IT WAS 'CLEARED OUT OFF THUNDERSTORM CLOUDS AND COULD REESTABLISH, ON RADIAL 038 AGAIN. BANGKOK AREA CONTROL ASKED DRAGON AIR 203 TO CONFIRM ITS PRESENT RADIAL AND DRAGON AIR 203 CONFIRMED THAT IT WAS ON RADIAL 025 AND COULD REESTABLISH ON RADIAL 038 . BANGKOK AREA CONTROL THEN CLEARED DRAGON AIR 203 TO CONTINUE ON RADIAL 025 TO PHUKET VOR/DME.

AT 08:25:00 HRS, DRAGON AIR 203 REPORTED DESCENDING FROM FL 140 AND WAS INSTRUCTED TO CONTACT PHUKET APPROACH CONTROL ON 126.2 MHZ.

AT 08:26:00 HRS, BANGKOK AREA CONTROL CLEARED THAI AIR 365 TO MAINTAIN FL 140 AND ASKED THAI AIR 365 TO CONTACT PHUKET APPROACH CONTROL ON 126.2 MHZ. AND REPORT BACK AGAIN WHEN IT WAS CLEARED BY PHUKET APPROACH CONTROL TO DESCEND BELOW FL 140 AND WHEN IT PASSED FL 130.

AT 08:26:47 HRS, DRAGON AIR 203 REPORTED ITS POSITION TO PHUKET APPROACH CONTROL AT 35 NAUTICAL MILES FROM PHUKET VOR/DME, REACHING FL 130. IT WAS CLEARED TO THE PHUKET INITIAL APPROACH FIX (14 NAUTICAL MILES FROM PHUKET VOR/DME) AND TO DESCEND AND MAINTAIN ALTITUDE 4,500 FEET, AND TOLD TO EXPECT TO LAND ON RUNWAY 27. THE QNH GIVEN TO DRAGON AIR 203 WAS 1010 MILLIBARS.

AT 08:27:18 HRS, THAI AIR 365 MADE INITIAL CONTACT WITH PHUKET APPROACH CONTROL THAT IT WAS AT 50 NAUTICAL MILES FROM PHUKET VOR/DME, DESCENDING FROM FL 150 TO FL 140. IT WAS INSTRUCTED TO REPORT AGAIN AT FL 140, AND TOLD TO EXPECT TO LAND ON RUNWAY 27.

AT 08:27:39 HRS, THAI AIR 365 REPORTED REACHING FL 140 AND WAS CLEARED TO PHUKET VOR/DME CLEARANCE LIMIT ON W14 AND TO DESCEND AND MAINTAIN ALTITUDE 7,000 FEET .

AT 08:28:08 HRS, THAI AIR 365 REPORTED BACK TO BANGKOK AREA CONTROL THAT IT WAS CLEARED TO DESCEND TO ALTITUDE 7,000 FEET AND IT WAS PASSING FL 130.

AT 08:28:15 HRS, DRAGON AIR 203 WAS AT 27 NAUTICAL MILES FROM PHUKET VOR/DME AT ALTITUDE 11,000 FEET. THE FLIGHT WAS PERMITTED BY PHUKET APPROACH CONTROL TO EXECUTE A 12 NAUTICAL MILES DME ARC WHEN IT REACHED 14 NAUTICAL MILES FROM PHUKET VOR/DME.

AT 08:29:38 HRS, DRAGON AIR 203 REQUESTED INFORMATION ON LOCAL LOWER CLOUD BASE. THE CLOUD INFORMATION GIVEN TO DRAGON AIR 203 WAS 2/8 CUMULUS AT 1,800 FEET.

AT 08:30:51 HRS, THAI AIR 365 WAS CLEARED TO DESCEND FROM ALTITUDE 7,000 FEET TO ALTITUDE 5,000 FEET.

AT 08:31:08 HRS, DRAGON AIR 203 WAS AT 14 NAUTICAL MILES FROM PHUKET VOR/DME. IT WAS CLEARED TO DESCEND TO ALTITUDE .2,500 FEET AND TO REPORT AGAIN ON INBOUND FINAL TO RUNWAY 27. DRACON AIR 203 ACKNOWLEDGED THE DESCENT CLEARANCE.

AT 08:31:28 HRS, PHUKET APPROACH CONTROL REQUESTED THE DISTANCE OF THAI AIR 365 FROM PHUKET VOR/DME AND IT WAS INFORMED THAT THAI AIR 365 WAS AT 25 NAUTICAL MILES FROM PHUKET VOR/DME. PHUKET APPROACH CONTROL THEN ASSIGNED THAI AIR 365 TO BE NUMBER TWO TO LAND FOLLOWING DRAGON AIR 203. FROM CVR READ OUT, PILOT-IN -COMMAND OF THAI AIR 365 STATED TO HIS CO-PILOT THAT "DRAGON AIR, IT HAS TO MAKE AN APPROACH AGAIN".

AT 08:31:56 HRS, THAI AIR 365 ACKNOWLEDGED THE ASSIGMENT OF NUMBER TWO TO LAND.

AT 08:32:28 HRS, THAI AIR 365 REPORTED APPROACHING ALTITUDE 5,000 FEET AND PHUKET APPROACH CONTROL INFORMED THAI AIR 365 TO STANDBY.

AT 08:32:39 HRS, DRAGON AIR 203 WAS AT ALTITUDE 4,000 FEET. IT WAS CLEARED TO DESCEND FROM ALTITUDE 4.000 FEET TO ALTITUDE 2,500 FEET. LATER ON PHUKET APPROACH CONTROL CLEARED THAI AIR 365 TO DESCEND TO ALTITUDE 4,000 FEET. THE DESCENT CLEARANCE WAS ACKNOWLEDGED BY THE THAI AIR 365 FIRST OFFICER. WHILE SIMULTANEOUSLY THE PILOT-IN-COMMAND OF THAI AIR 365 CALLED OUT APPROACH SPEED (REF+5) 127,131 .

AT 08:33:26 HRS, DRAGON AIR 203 WAS REQUESTED TO REPORT WHEN REACHING ALTITUDE 2,500 FEET.

AT 08:33:42 HRS, THAI AIR 365 REPORTED REACHING ALTITUDE 4,000 FEET AND IT WAS REQUESTED TO REPORT ITS DISTANCE FROM PHUKET VOR/DME . THE REPORTED DISTANCE GIVEN BY THAI AIR 365 WAS 16 NAUTICAL MILES FROM PHUKET VOR/DME.

AT 08:34:09 HRS, DRAGON AIR 203 REPORTED THAT IT WAS AT 11 NAUTICAL MILES FROM THE PHUKET VOR/DME ON RADIAL 090 AT ALTITUDE 2,500 FEET. PHUKET APPROACH CONTROL INSTRUCTED DRAGON AIR 203 TO REPORT

AGAIN AT 5 NAUTICAL MILES FROM THE PHUKET VOR/DME ON FINAL TO RUNWAY 27.

AT 08:34:33 HRS, PHUKET APPROACH CLEARED THAI AIR 365 TO DESCEND TO ALTITUDE 3,000 FEET. THE DESCENT CLEARANCE WAS ACKNOWLEDGED BY THAI AIR 365.

AT 08:34:41 HRS, DRAGON AIR 203 ASKED "WHAT IS THE TRAFFIC DME FROM PHUKET ?" AND THAI AIR 365 REPLIED IMMEDIATELY, "13 VOR/DME".

AT 08:34:49 HRS, DRAGON AIR 203 INFORMED THAI AIR 365 "COPY WE ARE AT 2,500 FEET WE HAVE GOT YOU IN OUR ONE O'CLOCK". DRAGON AIR 203 ALSO INFORMED PHUKET APPROACH CONTROL "WE HAVE THE TRAFFIC AHEAD OF US ONE O'CLOCK ABOUT 5 MILES LEFT TO RIGHT". FROM COCKPIT CONVERSATION OF CVR READOUT, CO-PILOT OF THAI AIR 365 STATED THAT "IT IS BEHIND US!".

AT 08:35:25 HRS, PHUKET APPROACH CONTROL REQUESTED POSITION OF DRAGON AIR 203 AND IT WAS INFORMED THAT DRAGON AIR 203 WAS TURNING RIGHT AT 12 NAUTICAL MILES FROM PHUKET VOR/DME. AT THAT MOMENT THE CO-PILOT AND PILOT-IN-COMMAND OF THAI AIR 365 BEGAN NEARLY AT THE SAME TIME SPEAKING IN COLLOQUIAL THAI WHICH HAD VARIOUS MEANINGS, E.G. DRAGON AIR 203 TRIED TO CUT CORNER OR SNEAKED IN OR MAKE A FALSE POSITION REPORT IN ORDER TO GET FIRST PRIORITY FOR LANDING.

AT 08:35:39 HRS, PHUKET APPROACH CONTROL REQUESTED DRAGON AIR 203 TO CONFIRM ITS 12 NAUTICAL MILES DME POSITION AND IT WAS CONFIRMED THAT DRAGON AIR 203 WAS AT 12 NAUTICAL MILES FROM PHUKET VOR/DME AT ALTITUDE 2,500 FEET.

AT 08:35:48 HRS, PHUKET APPROACH CONTROL REQUESTED POSITION OF THAI AIR 365 AND PILOT-IN-COMMAND OF THAI AIR 365 REPLIED HURRIEDLY IN VERY FAST WORDS "8 DME 8 DME INBOUND". FROM COCKPIT CONVERSATION AT THAT MOMENT CO-PILOT OF THAI AIR 365 EXCLAIMED "OH" FOLLOWED BY THE PILOT-IN-COMMAND'S VOICE "365 REQUEST VISUAL".

AT 08:35:57 HRS, PHUKET APPROACH CONTROL REASSIGNED THAI AIR 365 TO BE NUMBER ONE TO LAND AND DRAGON AIR 203 TO BE NUMBER TWO TO LAND. PILOT OF THAI AIR 365 IMMEDIATELY REPLIED GEARS DOWN .

AT 08:36:06 HRS, DRAGON AIR 203 GAVE WARNING TO PHUKET APPROACH CONTROL "DRAGON AIR 203 WE ARE 2,500 FEET THE TRAFFIC AHEAD IS ABOVE US AND CANNOT DESCEND THROUGH OUR LEVEL , WE ARE IFR". FROM COCKPIT CONVERSATION OF THAI AIR 365 AN UNCLEAR VOICE FORM CO-PILOT WAS HEARD FROM CVR RECORDING WHICH SOUNDED LIKE "WE'D BETTER GO" THEN THE PILOT-IN-COMMAND SAID "WAIT A MINUTE, WAIT A MINUTE, IT IS IFR" SIMULTANEOUSLY A TRIM SOUND WAS HEARD.

AT 08:36:28 HRS, PILOT-IN-COMMAND OF THAI AIR 365 ASKED PHUKET APPROACH CONTROL "WHO IS GOING TO LAND FIRST ?" SHORTLY AFTERWARD A STACCATO SOUND AND AN INCREASE IN THE SOUND OF THE ENGINE WAS HEARD AND THE PILOT CALLED GEARS UP, CHIMED SOUND WAS HEARD FOLLOWED BY THE GROUND PROXIMITY WARNING SOUND

AT 08:36:31 HRS, PHUKET APPROACH CONTROL ASKED THAI AIR 365 IN THAI MEANING "OK THAI AIR 365 DO YOU SEE OTHER TRAFFIC BOEING 737,HONG KONG ?" DURING WHICH TIME THE PILOT FROM DRAGON AIR 203 SAID," DRAGON AIR 203 WE ARE TWO-FIVE " AFTER THAT THERE WAS AN EXCLAMATION FROM THE THAI AIR 365 PILOT "OY!"

AT 08:36:47 HRS, PHUKET APPROACH CONTROL CALLED, "DRAGON AIR 203 ROGER 2,500 FEET, REQUEST DME INBOUND FROM PHUKET ?" .

AT 08:36:55 HRS, DRAGON AIR 203 REPORTED TO PHUKET APPROACH CONTROL SIGHTING THAI AIR 365 CRASH INTO THE SEA

THE ACCIDENT SITE WAS AT LATITUDE 08 06 00 NORTH, LONGITUDE 98 27 10 EAST, APPROXIMATELY EIGHT NAUTICAL MILES FROM RUNWAY 27 AT THE PHUKET AIRPORT. THE TIME OF THE ACCIDENT WAS AT 08:36:52 HRS. (DAY TIME)

1.2 INJURIES TO PERSONS

INJURIES	CREW	PASSENGER	OTHERS
FATAL	9	74	-
SERIOUS	-	-	-
MINOR/NONE	-	-	

1.3 DAMAGE TO AIRCRAFT

THE AIRCRAFT WAS DESTROYED.

1.4 OTHER DAMAGE

THERE WAS NO OTHER DAMAGE.

1.5 PERSONNEL INFORMATION

1.5.1 **THE PILOT-IN-COMMAND,** AGED 53, HELD AN AIRLINE TRANSPORT PILOT LICENCE NO. D-0054 ISSUED BY DEPARTMENT OF AVIATION OF THAILAND, VALID UNTIL 7 DECEMBER B.E. 2530 (A.D.1987) WITH AIRCRAFT RATINGS IN AEROPLANE; SINGLE AND MULTI-ENGINE LAND; CO-PILOT FOR DC-3 AND HS-748 AND PILOT FOR BOEING 737. HE ALSO HAD INSTRUMENT RATING. HE HAD PASSED HIS LAST PROFICIENCY CHECK AND LAST INSTRUMENT RATING CHECK ON 21 JUNE B.E. 2530 (A.D.1987). HE HAD ACCUMULATED THE FOLLOWING FLIGHT TIME :

TOTAL FLIGHT TIME	19,538:08	HRS,
FLIGHT TIME WITH BOEING 737	5,576:30	HRS,
FLIGHT TIME IN THE LAST 90 DAYS	244:50	HRS,
FLIGHT TIME IN THE LAST 30 DAYS	80:00	HRS,
FLIGHT TIME IN THE LAST 24 HRS,	5:20	HRS.

HE WAS A ROUTE TRAINING PILOT FOR BOEING 737.

HIS LAST MEDICAL EXAMINATION WAS DONE ON JUNE 8, B.E. 2530 (A.D. 1987) AT THE ROYAL THAI AIR FORCE AVIATION MEDICINE INSTITUTE. HIS MEDICAL CERTIFICATE WAS VALID UNTIL DECEMBER 7, B.E. 2530 (A.D. 1987) WITH LIMITATIONS ENDORSED ON THE CERTIFICATE THAT THE HOLDER OF THE LICENCE MUST WEAR CORRECTIVE LENS FOR DISTANCE AND NEAR VISION WHILE PERFORMING HIS DUTY.

1.5.2 **THE CO-PILOT,** AGED 37, HELD A COMMERCIAL PILOT LICENCE NO. C-0337 ISSUE BY DEPARTMENT OF AVIATION OF THAILAND VALID UNTIL MAY 25, B.E. 2531 (A.D.1988) WITH AIRCRAFT RATINGS IN AEROPLANE, SINGLE AND MULTI-ENGINE LAND; CO-PILOT FOR SHORT SD3-30 AND HS-748. HE HAD PASSED AN APPROVED GROUND TRAINING COURSE EXAMINATION FOR BOEING 737 CONDUCTED BY THAI AIRWAYS COMPANY. HE ALSO HAD PASSED A FLIGHT TEST FOR THE BOEING 737 CONDUCTED BY THE THAI AIRWAYS COMPANY UNDER SUPERVISION OF A DEPARTMENT OF AVIATION PILOT EXAMINER. THE CO-PILOT HELD A TEMPORARY BOEING 737 AIRCRAFT TYPE RATING ISSUED BY THE THAI AIRWAYS COMPANY DELEGATED BY THE DEPARTMENT OF AVIATION. HE HAD PASSED HIS LAST PROFICIECNY CHECK IN THE BOEING 737 ON 21 JUNE B.E. 2530 (A.D.1987), HE HAD ACCUMULATED FLIGHT TIME AS FOLLOWS:

TOTAL FLIGHT TIME	5,951:27 HRS,
FLIGHT TIME WITH BOEING 737	156:26 HRS,
FLIGHT TIME IN THE LAST 90 DAYS	156:26 HRS,
FLIGHT TIME IN THE LAST 30 DAYS	65:54 HRS,
FLIGHT TIME IN THE LAST 24 HRS,	5:20 HRS,

THE CO-PILOT LAST MEDICAL EXAMINATION WAS DONE ON MAY 26, B.E. 2530 (A.D. 1987) AT THE ROYAL THAI AIR FORCE AVIATION MEDICINE INSTITUTE. HIS MEDICAL CERTIFICATE WAS VALID UNTIL MAY 25, B.E. 2531 (A.D. 1988). THERE WAS NO LIMITATION ENDORSED ON HIS LICENCE.

1.5.3 **THE AIR TRAFFIC CONTROLLER AT PHUKET AIRPORT,**

AGED 39, HELD AN AIR TRAFFIC CONTROL LICENCE NO.130 ISSUED BY THE DEPARTMENT OF AVIATION OF THAILAND VALID UNTIL MAY 3, B.E. 2531 (A.D.1988) WITH RATINGS IN AERODROME CONTROL AND APPROACH CONTROL AT PHUKET AIRPORT. HE HAD BEEN WITH THE DEPARTMENT OF AVIATION SINCE MAY, 1 1967, AND HAD ABOUT 10 YEARS EXPERIENCE AS AN AIR TRAFFIC CONTROLLER.

HIS LAST MEDICAL EXAMINATION WAS DONE ON MAY 4, B.E. 2529 (A.D.1986) AT THE ROYAL THAI AIR FORCE AVIATION MEDICINE INSTITUTE. HIS MEDICAL CERTIFICATE WAS VALID UNTIL MAY 3, B.E. 2531 (A.D. 1988).

1.6 AIRCRAFT INFORMATION

1.6.1 THE BOEING 737-200, HS-TBC, SERIAL NUMBER 22267, WAS MANUFACTURED BY THE BOEING COMMERCIAL AIRCRAFT COMPANY LTD., SEATTLE, WASHINGTON, U.S.A. IN B.E. 2523 (A.D. 1980). IT WAS PURCHASED NEW BY THAI AIRWAYS COMPANY AND REGISTERED IN THAILAND ON AUGUST 18, B.E. 2523 (A.D.1980). THE AIRCRAFT WAS OWNED, OPERATED AND MAINTAINED BY THAI AIRWAYS COMPANY FROM THE DATE OF PURCHASE UNTIL THE TIME OF THE ACCIDENT. THE AIRCRAFT HAD A VALID CERTIFICATE OF AIRWORTHINESS ISSUED BY THE DEPARTMENT OF AVIATION OF THAILAND. IT ACCUMULATED A TOTAL TIME OF 16.963:48 HRS, AT THE TIME OF THE ACCIDENT WITH 20,864 TOTAL NUMBER OF LANDINGS. IT HAD A TIME FROM LAST OVERHAUL OF 2,754:11 HRS, SINCE JUNE 16, B.E. 2529 (A.D. 1986). THE LAST 100 HRS PERIODIC INSPECTION (A-CHECK) WAS DONE ON AUGUST 10, B.E. 2530 (A.D. 1987).

1.6.2 THE AIRCRAFT WAS EQUIPPED WITH TWO PRATT AND WHITNEY JT8D-7 TURBO FAN ENGINES. MAINTENANCE HAD BEEN CURRENT AND IN COMPLIANCE WITH COMPANY AND OFFICIAL REQUIREMENTS. DETAILS ARE AS FOLLOW:

1.6.2.1 NUMBER 1 ENGINE, SERIAL NUMBER P 702821B HAD BEEN MANUFACTURED ON OCTOBER 13, B.E.2523 (A.D.1980). IT HAD A TOTAL OPERATIONAL TIME OF 10,509:05 HRS, SINCE NEW AND 2,528:19 HRS, SINCE LAST OVERHAUL.

1.6.2.2 NUMBER 2 ENGINE, SERIAL NUMBER P 702897B HAD BEEN MANUFACTURED ON NOVEMBER 14, B.E.2523 (A.D.1980). IT HAD A TOTAL OPERATIONAL TIME OF 10,839:27 HRS, SINCE NEW AND 3,768:04 HRS, SINCE LAST OVERHAUL.

1.7 METEOROLOGICAL INFORMATION

THE WEATHER AT THE SITE OF THE OCCURRENCE AS OBSERVED INFLIGHT BY THE PILOT OF DRAGON AIR 203 WAS SCATTERD CUMULUS OVER THE AIRPORT AND THE AREA TO THE WEST OF THE AIRPORT. THE LET-DOWN AREA WAS CLEAR WITH GOOD FLIGHT VISIBILITY.

METAR 08:30:00 HRS, AT PHUKET AIRPORT WAS AS FOLLOWS;

METAR	310830 HRS, VTSP
WIND	290/09
VISIBILITY	9.000 METRES
WEATHER	LIGHT MIST (10BR)
CLOUDS	2CU018 3SC030 6CI 300
TEMP/DEW PT.	31/25
QNH	1010 MBS.

1.8 AIDS TO NAVIGATION

PHUKET AIRPORT WAS EQUIPPED WITH CONVENTIONAL VOR/DME, DOPPLER VOR/DME AND NDB. THERE WAS PAPI AT RUNWAY 09 AND T VASIS AT RUNWAY 27. THEY RECEIVED PROPER PERIODIC FLIGHT INSPECTIONS. THERE IS NO RADAR AT THE AIRPORT AND NO PRECISION APPROACH FACILITIES. IT HAS A VOR/DME AND ADF APPROACH PROCEDURES. A DOPPLER VOR/DME WAS COMMISSIONED ON THE AIRPORT. A NOTAM HAS BEEN DISTRIBUTED TO ALL CONCERNS BUT NO DOPPLER VOR/DME APPROACH PROCEDURE HAS YET BEEN ESTABLISHED.

1.9 COMMUNICATIONS

TWO-WAY R/T COMMUNICATION BETWEEN BOTH AIRCRAFT AND PHUKET APPROACH CONTROL WERE OPERATING NORMALLY.

1.10 AERODROME INFORMATION

PHUKET AIRPORT IS A LICENSED AIRPORT, OPERATED AND CONTROLLED BY THE DEPARTMENT OF AVIATION. THE AIRPORT IS LOCATED ON THE ISLAND AT AN ELEVATION OF 69 FEET ABOVE MEAN SEA LEVEL. THE RUNWAY DIRECTION IS 09/27. IT HAS THREE TAXIWAYS, TAXIWAY A, TAXIWAY B AND TAXIWAY C. THE RUNWAY CONSISTS OF ASPHALT AND CONCRETE. THERE WERE NO UNUSUAL AIRPORT OR GROUND FACILITY ACTIVITIES OR CONDITIONS AT PHUKET AIRPORT DURING THE ACCIDENT OF THAI AIR 365.

1.11 FLIGHT RECORDERS

1.11.1 THE HS-TBC WAS EQUIPPED WITH FAIRCHILD FLIGHT RECORDERS. THEY WERE INSTALLED IN THE TAIL SECTION OF THE AIRCRAFT. THE FLIGHT DATA RECORDER WAS A

MODEL 5424, SERIAL NUMBER 6357. IT WAS RETRIEVED FROM THE SEA TWO DAYS AFTER THE ACCIDENT. THE COCKPIT VOICE RECORDER WAS A MODEL A-100. IT WAS RETRIEVED FROM THE SEA FOUR DAYS AFTER THE ACCIDENT. BOTH RECORDERS WERE DAMAGE BY IMPACT FORCES. THE MAGAZINES CONTAINING THE STEEL FOIL RECORDING MEDIUM AND MAGNETIC TAPE RECORDING MEDIUM HAD BEEN REMOVED FROM THE RECORDERS FOLLOWING RECOVERY FROM THE SEA AND WERE BROUGHT TO THE LABORATORIES OF THE U.S. NATIONAL TRANSPORTATION SAFETY BOARD FOR READOUT AND TRANSCRIPTIONS. THE COCKPIT VOICE RECORDER TAPE WAS IN GOOD CONDITION. A NORMAL READOUT OF THE TAPE WAS OBTAINED. THE FDR STEEL FOIL MEDIUM WAS ALSO IN GOOD CONDITION. THE ALTITUDE TRACE READOUT SHOWED THAT THE DESCENT OF HS-TBC TO PHUKET AIRPORT APPEARED TO BE HIGHER THAN THE ALTITUDE WHICH THE PILOT REPORTED TO PHUKET APPROACH CONTROL. ADJUSTMENT OF THE FDR READOUT ALTITUDE TRACE COINCIDED WITH THE PILOT'S REPORTED ALTITUDE.

1.11.2 THE VR-HYL WAS EQUIPPED WITH FLIGHT RECORDERS. THE COCKPIT VOICE RECORDING OF THE EVENTS SURROUDING THE ACCIDENT WAS ERASED ON THE AIRCRAFT'S RETURN FLIGHT TO HONG KONG.

1.12 *WRECKAGE*

THE AIRCRAFT CRASHED INTO THE WATER AT ABOUT A 40 DEGREE FLIGHT PATH ANGLE WITH CONSIDERABLE FORCE, AND SUBMERGED TO THE BOTTOM OF THE SEA. IT DISINTEGRATED ON IMPACT. VERY FEW PARTS OF THE WRECKAGE WERE RETRIEVED. THEY CONSISTED OF LOWER WING SKIN, PART OF EMPENNAGE WITH REAR PRESSURE BULKHEAD AND VERTICAL FIN ATTACHED, APU AND TAILCONE, APU EXHAUST DUCT, SMALL PIECES OF FUSELAGE, EMERGENCY EXIT DOOR, CLOCK, ALTIMETER, CO-PILOT WHEEL, TIRES, UNIDENTIFIED PIECES OF FLAPS AND SPOILER, FACE OF AIRSPEED INDICATOR, FDR AND CVR. THE WRECKAGE WAS RETRIEVED FROM 60 FEET OF WATER AND THE BOTTOM WAS FLAT.

1.13 MEDICAL AND PATHOLOGICAL INFORMATION

BODIES OF PERSONS ON BOARD WERE RECOVERED FROM THE SEA A FEW DAYS AFTER THE ACCIDENT. THE BODIES WERE SEVERELY TRAUMATIZED. MOST OF THE FACES WERE MUTILATED.

1.14 FIRE

NO EVIDENCE OF FIRE IN FLIGHT WAS FOUND.

1.15 SURVIVAL ASPECT

THE PILOT OF DRAGON AIR 203 HAD BEEN KEEPING THAI AIR 365 IN SIGHT. HE SAW THAI AIR 365 PITCH VIOLENTLY NOSE DOWN AND STRIKE THE WATER. HE REPORTED HIS OBSERVATIONS AND THE LOCATION OF THE CRASH TO PHUKET APPROACH CONTROL. HE PROCEEDED TO THE CRASH SITE AND ORBITED THE AREA. AFTER SIGHTING SOME FLOATING DEBRIS, HE DECIDED TO LAND. HE WENT TO CONTROL TOWER AFTERWARD ON A LARGE-SCALE MAP. AND SHOWED THE POSITION OF CRASH SITE TO THE AIR TRAFFIC CONTROLLER. PHUKET TOWER CALLED THE NEARBY MARINE POLICE UNIT, PHUKET PROVINCIAL OFFICE AND LOCAL FACILITIES TO RENDER RESCUE ASSISTANCE. THIS ACCIDENT WAS NOT SURVIVABLE TO THE PERSONNEL ON THE AIRCRAFT. ALL OF THE FATALLY INJURED WERE RETRIEVED FROM THE SEA IN FEW DAYS AFTER THE DATE OF ACCIDENT AND MOVED TO THE HOSPITAL FOR AUTOPSY AND INDENTIFICATION.

1.16 TEST AND RESEARCH

1.16.1 THE AIRSPEED AND THE ALTITUDE INDICATORS WERE SENT TO THE LABORATORY OF U.S. NATIONAL TRANSPORTATION SAFETY BOARD FOR EXAMINATION. THE RESULT OF EXAMINATION COULD NOT REVEAL ANY INFORMATION FOR THE INVESTIGATION.

1.16.2 SIMULATION FLIGHTS ON AN ENGINEERING SIMULATOR AT THE BOEING COMMERCIAL AIRCRAFT COMPANY, SEATTLE, WASHINGTON, U.S.A. WERE CONDUCTED BY THAI AND BOEING COMPANY FLIGHT TEST PILOTS. THE SIMULATOR WAS FLOWN TO DUPLICATE THE FLIGHT OF THAI AIR 365. THE SIMULATION WAS BASED ON THE PRELIMINARY FLIGHT RECORDER DATA PROVIDED BY THE U.S. NATIONAL TRANSPORTATION SAFETY BOARD (U.S. NTSB). DURING THE SIMULATOR SESSION SEVERAL CONFIGURATIONS AT 98,000 LBS WERE FLOWN ,FLAP UP, GEAR UP, GEAR DOWN, AND GEAR DOWN WITH SPEEDBRAKES. EACH CONFIGURATION WAS FLOWN WITH VARYING AMOUNS OF POWER. HOWEVER, NO DEFINITE CONCLUSIONS ABOUT THE PROBABLE CONFIGURATION OF THE AIRCRAFT PRIOR TO IMPACT COULD BE DRAWN BY SIMPLE COMPARISON OF THE SUMULATOR TIME HISTORIES WITH THE FDR DATA.

2. ANALYSIS

2.1 THE AIRCRAFT WAS CERTIFICATED, EQUIPPED AND MAINTAINED ACCORDING TO REGULATIONS. THE WEIGHT AND BALANCE WERE WITHIN PRESCRIBED LIMITS. THE PILOT-IN-COMMAND AND CO-PILOT WERE CERTIFIED IN ACCORDANCE WITH GOVERNMENTAL AND COMPANY REGULATIONS.

2.2 THE WEATHER AT THE SITE OF THE ACCIDENT WAS FAIR AND WAS NOT IN ANYWAY A FACTOR IN THE ACCIDENT. ANALYSIS OF FDR AND CVR DATA FROM THE THAI AIR 365 FLIGHT REVEALED NO EVIDENCE OF A MALFUNCTIONING OF AIRCRAFT'S SYSTEMS OR ITS POWERPLANTS. THE SOUND OF THE ENGINES WAS AUDIBLE ON CVR TAPE RECORDING BUT THE SOUND OF FLAP AND SPEED BRAKE EXTENSION COULD NOT BE HEARD, NOR WAS A COMMAND GIVEN BY THE CAPTAIN TO EXTEND THEM. ONLY THE SOUND OF GEAR EXTENSION AND THE CHIME WAS HEARD IMMEDIATELY AFTER PHUKET APPROACH CONTROL ADVISED THAI AIR 365 TO BE NUMBER ONE TO LAND.

2.3 ANALYSIS OF THE FLIGHT PROFILE FROM THE FDR READOUT ,SHOWED THAT THAI AIR 365 FIRST CONTACTED PHUKET APPROACH CONTROL AT 08:27:18 HRS. WHEN IT WAS DESCENDING FROM FL 150 INBOUND TO THE PHUKET AIRPORT. THE RATE OF DESCENT VARIED BETWEEN 1,500 FEET AND 2,400 FEET PER MINUTE, AND THE SPEED DURING THE DESCENT VARIED BETWEEN 290 KNOTS AND 270 KNOTS. THE SPEED BEGAN TO DECREASE AS THE AIRCRAFT REACHED ALTITUDE 4,000 FEET, AT 08:33:30 HRS. AT 08:34:49 HRS,THE SPEED WAS 220 KNOTS, AND THAT SPEED WAS MAINTAINED FOR ABOUT 25 SECONDS UNTIL 08:35:10 HRS, WHEN THE AIRCRAFT REACHED ITS LAST ASSIGNED ALTITUDE OF 3,000 FEET. AFTER THAT POINT THE SPEED BEGAN DECREASING AGAIN. ATABOUT 08:36:34 HRS, THE SPEED FINALLY DROPPED TO 152 KNOTS, AND THE AIRCRAFT ENTERED INTO A STALL. THE AIRCRAFT IMPACTED THE WATER AT ABOUT 08:36:52 HRS.

2.4 CONSIDERING THE VALUE IN THE LOAD MESSAGE AND BALANCE SHEET PREPARED BY THAI AIRWAYS COMPANY PERSONNEL, THE COMPUTED LANDING WEIGHT OF THAI AIR 365 ON ARRIVING AT PHUKET AIRPORT WAS 98,418 POUNDS.

THEREFORE THAI AIR 365 GROSS WEIGHT AT THE TIME OF THE ACCIDENT WAS

APPROXIMATELY THE SAME AS ITS LANDING WEIGHT. THE INTERPOLATION OF THE BOEING-737 AIRCRAFT PERFORMANCE CHART SHOWED A STALL SPEED OF ABOUT 105 KNOTS AT A GROSS WEIGHT OF 98,418 POUNDS WITH 15 DEGREES OF LANDING FLAPS, LANDING GEAR DOWN, AND SPEED BRAKES DOWN (RETRACTED). SIMULATOR TESTS SHOWED THAT THE STICK SHAKER ACTIVATION SPEED WAS 161 KNOTS AT AND ENTRY RATE OF 1 KNOT PER SECOND WITH THE FLAPS UP , LANDING GEAR DOWN, SPEEDBRAKES DOWN AT C.G. SIMILAR TO THE ACCIDENT AIRCRAFT. ALSO, SIMULATOR TESTS FLOWN WITH THE SPEEDBRAKES UP (EXTENDED) SHOWED THAT THE STALL SPEEDS WERE CONSISTENTLY HIGHER, BETWEEN 169 AND 174 KNOTS. HOWEVER, THE FLIGHT RECORDER DATA SHOWED THAT THE STICK SHAKER ACTIVATED AT 163 KNOTS AND THE AIRCRAFT STALLED AT 152 KNOTS WHILE IT WAS IN LEVEL FLIGHT AT 3,000 FEET. THEREFORE, IT IS CONCLUDED THAT THE AIRCRAFT WAS NOT IN PROPER LANDING CONFIGURATION, WITH THE FLAPS EXTENDED, NOR IS IT BELIEVED THAT THE SPEEDBRAKES WERE USED TO SLOW THE AIRCRAFT IN PREPARATION FOR LANDING.

2.5 IN CONSIDERATION OF BOTH FLIGHTS , THEY WERE ON CONVERGING FLIGHT PATHS WHILE ATTENDING TO LAND AT PHUKET AIRPORT. DRAGON AIR 203 WAS APPROACHING FROM NORTHEAST OF PHUKET AIRPORT ON RADIAL 025 WHILE THAI AIR 365 WAS APPROACHING FROM SOUTHEAST ON RADIAL 119. DRAGON AIR 203 WAS MAKING A RIGHT 12 DME ARC TURN AND THAI AIR 365 WAS MAKING A STRAIGHT-IN APPROACH PROCEEDING TO ITS ASSIGNED CLEARANCE LIMIT PHUKET VOR/DME IN ORDER TO MAKE A PROCEDURE TURN OVER PHUKET VOR/DME. BUT WHEN THE AIRCRAFT WAS ADVISED TO BE NUMBER ONE TO LAND, THE PILOT THEN LOWERED LANDING GEAR IN ORDER TO LAND. BOTH AIRCRAFT WERE APPROACHING TO LAND ON RUNWAY 27 OF PHUKET AIRPORT IN FOLLOWING SEQUENCES :

2.5.1 EVENT

- DRAGON AIR 203 FIRST CONTACTED PHUKET APPROACH CONTROL AT 08:18:34 HRS, DESCENDING FORM FL 190 INBOUND TO PHUKET AIRPORT ON RADIAL 025 AT 08:26:51 HRS. IT WAS AT 35 NAUTICAL MILES FROM PHUKET VOR/DME AND WAS CLEARED TO DESCEND TO ALTITUDE 4,500 FEET.

- THAI AIR 365 FIRST CONTACTED PHUKET APPROACH CONTROL AT 08:27:22 HRS, DESCENDING FROM FL 150 TO FL 140 INBOUND ON RADIAL 119 AT 50 NAUTICAL MILES FROM PHUKET VOR/DME AND IT WAS REQUESTED TO REPORT AGAIN AT FL 140.

AT 08:27:39 HRS, THAI AIR 365 REPORTED REACHING FL 140. AT 08:27:49 HRS, IT WAS CLEARED TO PHUKET VOR/DME AND TO DESCEND AND MAINTAIN ALTITUDE 7,000 FEET

CONSIDERATION

- (FROM FDR READOUT) DRAGON AIR 203 WAS AT 35 NAUTICAL MILES OF PHUKET VOR/DME AT 08:26:51 HRS. AT THAT TIME, SPEED OF THAI AIR 365 WAS 280 KNOTS. AT 08:27:12 HRS, THAI AIR 365 WAS AT 50 NAUTICAL MILES OF PHUKET VOR/DME AND THE SPEED WAS ALSO AT 280 KNOTS. SO THAT AT 08:26:51 HRS, WHEN DRAGON AIR 203 WAS AT 35 NAUTICAL MILES OF PHUKET VOR/DME , THAI AIR 365 SHOULD HAVE BEEN AT 52 NAUTICAL MILES FROM PHUKET VOR/DME. IT WAS 17 NAUTICAL MILES BEHIND DRAGON AIR 203 .

2.5.2 EVENT

- AT 08:28:15 HRS, DRAGON AIR 203 WAS AT 27 NAUTICAL MILES FROM PHUKET VOR/DME, PASSING FL 110, THE PILOT REQUESTED AND WAS GIVEN PERMISSION TO FLY TO 12 DME ARC. AT 08:31:08 HRS, DRAGONAIR 203 REPORTED AT 14 NAUTICAL MILES FROM PHUKET VOR/DME AND WAS CLEARED TO DESCEND TO ALTITUDE 2,500 FEET.
- AT 08:31:35 HRS, THAI AIR 365 WAS AT 25 NAUTICAL MILES FROM PHUKET VOR/DME AND WAS ASSIGNED TO BE NUMBER TWO TO LAND FOLLOWING DRAGON AIR 203. IT WAS ALSO CLEARED TO DESCEND TO ALTITUDE 5,000 FEET. FROM COCKPIT CONVERSATION. DURING THAT TIME PILOT OF THAI AIR 365 SAID, "DRAGON AIR 203, IT HAS TO MAKE AN APPROACH AGAIN"
- AT 08:33:59 HRS, THAI AIR 365 WAS AT 16 NAUTICAL MILES OF PHUKET VOR/DME AT ALTITUDE 4,000 FEET.
- AT 08:34:09 HRS, DRAGON AIR 203 REPORTED IT WAS AT 11 NAUTICAL MILES FROM PHUKET VOR/DME ON RADIAL 090 AT ALTITUDE ABOUT 2,500 FEET. IT WAS REQUESTED TO REPORT AGAIN AT 5 NAUTICAL MILES FROM PHUKET VOR/DME ON FINAL FOR RUNWAY 27.
- AT 08:34:33 HRS, PHUKET APPROACH CONTROL CLEARED THAI AIR 365 TO DESCEND TO ALTITUDE 3,000 FEET.

CONSIDERATION

- ACCORDING TO FLIGHT CREW OF DRAGON AIR 203 INTERVIEW , THEY SAID THAT AT THAT TIME THEY SAW THAT THAI AIR 365 WAS HIGH IN ITS WIND SCREEN AND MOVIN FROM LEFT TO RIGHT AT ABOUT FIVE MILES AHEAD OF THEM . THEY THOUGHT THAI AIR

365 WAS FLYING FAST AND WOULD HAVE CONTINUED TO THE VOR TO MAKE VOR APPROACH. (FROM FDR READOUT) THE SPEED OF THAI AIR 365 AT THAT TIME AT ALTITUDE 4,200 FEET WAS ABOUT 270 KNOTS . BY INTERPOLATION OF BOEING 737 OPERATIONS MANUAL THE HOLDING SPEED OF BOEING 737 AT A GROSS WEIGHT OF 100,000 POUNDS AT ALTITUDE 5,000 FEET WAS AT 210 KNOTS. SO, THE SPEED OF THAI AIR 365 AT 16 NAUTICAL MILES FROM PHUKET VOR/DME, AT ALTITUDE 4,200 FEET SHOULD HAVE BEEN DECREASING TO AT 210 KNOTS. THE SPEED OF THAI AIR 365 AT THAT TIME WAS 60 KNOTS FASTER THAN ITS NORMAL SPEED. AS THAI AIR 365 WAS ADVISED TO BE NUMBER TWO TO LAND FOLLOWING DRAGON AIR 203 BUT SPEED OF THAI 365 WAS VERY FAST , LATER ON IT WAS AHEAD OF DRAGON AIR 203 . PHUKET APPROACH CONTROL PROVIDED VERTICAL SEPARATION FOR BOTH AIRCRAFT AT 500 FEET. IT WAS BELOW MINIMUM SEPARATION PRESCRIBED BY DOC 4444 (RULES OF THE AIR AND AIR TRAFFIC SERVICES). THE MINIMUM VERTICAL SEPARATION AS PRESCRIBED BY THE DOCUMENT WAS AT 1,000 FEET.

2.5.3 EVENT

- AT 08:34:41 HRS, DRAGON AIR 203 ASKED PHUKET APPROACH CONTROL" WHAT IS THE TRAFFIC'S DME FROM PHUKET" THAI AIR 365 REPORTED TO DRAGON AIR 203 DIRECTLY, "13 DME VOR". DRAGON AIR 203 THEN INFORMED THAI AIR 365, "COPY WE ARE 2,500 FEET, WE HAVE GOT YOU IN OUR ONE O'CLOCK."
- AT 08:35:57 HRS, THAI AIR 365 REPORTED POSITION AT 8 NAUTICAL MILES OF PHUKET VOR/DME AND REQUESTED VISUAL LANDING. ABOUT NINE SECONDS LATER, IT WAS REASSIGNED TO BE NUMBER ONE TO LAND AND DRAGON AIR 203 WAS TO BE NUMBER TWO. THE PILOT OF THAI AIR 365 THEN IMMEDIATELY LOWERED LANDING GEARS IN ORDER TO LAND.
- AT 08:36:17 HRS, DRAGON AIR 203 GAVE CAUTION TO PHUKET APPROACH CONTROL " DRAGON AIR 203, WE ARE AT 2,500 FEET. THE TRAFFIC AHEAD IS ABOVE US AND CAN NOT DESCEND THROUGH OUR LEVEL . WE ARE IFR. " DURING THAT TIME IT IS BELIEVED THAT CO-PILOT OF THAI AIR 365 STATED TO HIS PILOT-IN-COMMAND, "WE'D BETTER GO" AND THE PILOT-IN-COMMAND SAID "IT IS IFR, WAIT A MINUTE, WAIT A MINUTE," FOLLOWED BY THE SOUND OF STABILIZER TRIM OPERATING.

- AT 08:36:28 HRS, PILOT OF THAI AIR 365 ASKED PHUKET APPROACH CONTROL "WHO IS GOING TO LAND FIRST ?" THIS WAS IMMEDIATELY FOLLOWED BY SEVERAL SECONDS OF A STACCATO SOUND IDENTIFIED AS THE STICK SHAKER, AND THE PILOT-IN-COMMAND CALLING FOR GEARS UP AND THE SOUND OF THE CHIME, ALSO AN INCREASE IN ENGINE SOUND WAS HEARD, FOLLOWED BY THE PILOT'S EXCLAMATION. "OY!" AND GROUND PROXIMITY WARNING SOUND. DURING THAT TIME PHUKET APPROACH CONTROL ASKED PILOT OF THAI AIR 365 WHETHER HE HAD SIGHTED DRAGON 203

CONSIDERATION

DRAGON AIR 203 HAD ALREADY ESTABLISHED 12 DME ARC AT ALTITUDE 2,500 FEET AND WAS GOING TO TURN TO INBOUND ON FINAL FOR RUNWAY 27. IT HAD FIRST PRIORITY IN APPROACH SEQUENCE AND THAI AIR 365 HAD SECOND PRIORITY.BUT THE PILOT OF THAI AIR 365 TRIED TO OVERTAKE DRAGON AIR 203 BY INCREASING THE SPEED OF THE AIRCRAFT AND REQUESTED VISUAL LANDING. THIS ASSUMPTION IS SUPPORTED BY FOLLOWING REASONS,

(1) COCKPIT CONVERSATION AT 08:31:35 HRS, SINCE THE PILOT OF THAI AIR 365 SAID, "DRAGON AIR HAS TO MAKE AN APPROACH AGAIN".

(2) AT 08:34:49 HRS, AFTER DRAGON AIR 203 REPORTED SIGHTING THAI AIR 365 AT "ONE O'CLOCK ABOUT 5 MILES LEFT TO RIGHT," THE THAI AIR 365 COPILOT BELIEVED THAT DRAGON AIR 203 WAS BEHIND THEM.

(3) AT 08:35:25 HRS, DRAGON AIR 203 REPORTED IT WAS TURNING RIGHT AT 12 NM, THE THAI AIR 365 FLIGHTCREW SURMISED THAT DRAGON AIR 203 MADE A FLASE POSITION REPORT TO GAIN LANDING PRIORITY. THIS EVIDENTLY PROMPTED THE THAI AIR 365 PILOT-IN-COMMAND TO HURRIEDLY REPORT HIS POSITION AS 8 DME, AT 08:35:48. HOWEVER, THE TIME INTERVAL BETWEEN HIS POSITION REPORT AT 13 DME, AT 08:34:41, AND HIS 8 DME REPORT COMPUTES TO A SPEED OF 270 KNOTS, BUT FDR DATA SHOWED THE AIRCRAFT'S ACTUAL SPEED AT 220 KNOTS. THEREFORE, THE PILOT-IN-COMMAND INTENTIONALLY MISLED THE CONTROLLER WHICH RESULTED IN THE CHANGE OF LANDING SEQUENCE.

THE WORDS "REQUEST VISUAL LANDING" COULD NOT BE HEARD BY PHUKET APPROACH CONTROL BECAUSE AT THAT MOMENT PHUKET APPROACH CONTROL WAS IN CONTACT WITH DRAGON AIR 203. SINCE DRAGON AIR 203 HAD FIRST PRIORITY, PHUKET

APPROACH CONTROL SHOULD NOT HAVE REASSIGNED THAI AIR 365 TO BE NUMBER ONE TO LAND. HE SHOULD HAVE LET THAI AIR 365 PROCEED TO ITS CLEARANCE LIMIT OF THE PHUKET VOR/DME OR HE SHOULD HAVE HELD THAI AIR 365 AT 14 DME IAF.

2.6 THE FAILURE IN THE DIRECT COMMUNICATION LINK BETWEEN BANGKOK AREA CONTROL AND PHUKET APPROACH CONTROL WAS NOT A FACTOR IN THE ACCIDENT DUE TO BEFORE THE ACCIDENT TOOK PLACE THE TWO AIRCRAFT HAD ALREADY TRANSFERED TO THE CONTROL OF PHUKET APPROACH CONTROL.

2.7 AFTER PILOT OF THAI AIR 365 LOWERED LANDING GEARS, THE AIRCRAFT WAS STILL MAINTAINING ALTITUDE 3,000 FEET. THEN THE SPEED OF THE AIRCRAFT CONTINOUSLY DECREASED AFTERWARD UNTIL THE AIRCRAFT STALLED. IT IS PROBABLE THAT THE CO-PILOT DID NOT MONITOR THE AIRCRAFT INSTRUMENTS BECAUSE HE WAS CONCENTRATING ON THE CONFLICTING TRAFFIC.

2.8 FROM CVR RECORDING, THE CO-PILOT OF THAI AIR 365 WAS IN COMMUNICATION WITH AIR TRAFFIC CONTROL UNITS , SO THE PILOT-IN-COMMAND WAS PILOTING THE AIRCRAFT.

2.9 ACCORDING TO BOEING SIMULATOR FLIGHT TESTS, THE AIRCRAFT WAS AT A GROSS WEIGHT OF 98,418 POUNDS AT IDLE THRUST WITH FLAPS UP AND LANDING GEARS DOWN. THE STICK SHAKER SPEED WAS AT 161 KNOTS . FROM THAI AIR 365 FDR READ OUT, THE STICK SHAKER SPEED OF THAI AIR 365 WAS AT ABOUT 163 KNOTS NEARLY THE SAME AS THE SIMULATOR FLIGHT TEST. THE BOEING COMPANY COMMENCED THAT MOST LIKELY AIRCRAFT CONFIGURATION APPROXIMATES STICK SHAKER SPEED AT FLAPS UP IS BETWEEN 159 TO 163 KNOTS AND THERE IS NO FLAPS SELECTION AUDIBLE ON CVR OF THAI AIR 365. STICK SHAKER SPEED OF THAI AIR 365 BEGAN TO ACTIVATE AT ABOUT 08:36:28 HRS, AND THE AIRCRAFT ENTERED INTO STALL AT ABOUT 08:36:38 HRS,. IT BEGAN ACTIVATE ABOUT 10 SECONDS BEFORE STALL.

2.10 DURING THE SIMULATOR FLIGHT TEST OF BOEING 737 AT THE BOEING AIRCRAFT COMPANY. THE FLIGHT TEST PILOT COULD RECOVER FROM STALL AT ALTITUDE 3,000 FEET.

IN CASE OF THAI AIR 365, THE PILOT COULD NOT MADE STALL RECOVERING DUE TO THE FOLLOWING REASONS;

2.10.1 THE PILOT OF THAI AIR 365 PREOCCUPIED HIS ATTENTION WITH ANOTHER AIRCRAFT SO THAT HE MADE A STALL RECOVERY LATER THAN THE TEST PILOT DID IN SIMULATOR FLIGHT TEST.

2.10.2 ACCORDING TO FDR READOUT, THE FLIGHT CHARACTERISTIC OF THAI AIR 365 DURING STALL WAS DIFFERENT FROM SIMULATOR. THAI AIR 365 PITCHED VIOLENTLY FROM 320 DEGREES TO 180 DEGREES AND BACK TO 260 DEGREES.

2.10.3 AN ANALYSIS OF CVR READOUT REVEALED THAT THE INCREASE OF BOTH ENGINES NOISE DIFFERED WITH 2.5 SECONDS WHICH MIGHT HAVE CAUSED THE AIRCRAFT PITCH VIOLENTLY.

3. CONCLUSIONS

3.1 FINDINGS

3.1.1 THE AIRCRAFT WAS CERTIFICATED AND MAINTAINED ACCORDING TO APPROVED PROCEDURE

3.1.2 THE PILOT-IN-COMMAND AND THE CO-PILOT WERE CERTIFIED AND QUALIFIED FOR THE FLIGHT.

3.1.3 WEIGHTS AND BALANCE OF THE AIRCRAFT WERE WITHIN PRESCRIBED LIMIT.

3.1.4 THERE WAS NO EVIDENCE OF POWERPLANTS OR OTHER SYSTEMS FAILURE DURING THE TIM OF ACCIDENT.

3.1.5 THE WEATHER AT THE SITE OF ACCIDENT WAS FAIR.

3.1.6 TWO WAY RADIO COMMUNICATIONS BETWEEN PHUKET APPROACH CONTROL AND BOTH AIRCRA WERE NORMAL.

3.1.7 THE FAILURE IN THE DIRECT COMMUNICATION LINK BETWEEN BANGKOK AREA CONTROL AN PHUKET APPROACH WAS NOT A FACTOR IN THE ACCIDENT.

3.1.8 THERE IS NO EVIDENCE THAT FLAPS AND SPEEDBRAKES WERE EXTENDED PRIOR TO THE STALL.

3.1.9 BOTH AIRCRAFT WERE ON CONVERGING FLIGHT PATHS TO LAND AT PHUKET AIRPORT.

3.1.10 DRAGON AIR 203 WAS CLEARED TO PHUKET APPROACH FIX AND THAI AIR 365 WAS CLEARE TO PHUKET VOR/DME.

3.1.11 AT INITIAL CONTACT, DRAGON AIR 203 ESTIMATED TO BE OVER PHUKET AIRPORT BEFORE THAI AIR 365.

3.1.12 AT FIRST PHUKET APPROACH CONTROL INSTRUCTED THAI AIR 365 TO BE NUMBER TWO TO LAND FOLLOWING DRAGON AIR 203.

3.1.13 LATER ON THAI AIR 365 BECAME AHEAD OF DRAGON AIR 203.

3.1.14 PHUKET APPROACH CONTROL THEN REASSIGNED THAI AIR 365 TO BE NUMBER ONE TO LAND AND DRAGON AIR 203 TO BE NUMBER TWO.

3.1.15 HAVING BEEN REASSIGNED TO BE NUMBER ONE TO LAND, PILOT OF THAI AIR 365 LOWERED LANDING GEARS.

3.1.16 AFTER LANDING GEARS WENT DOWN, THAI AIR 365 WAS STILL MAINTAINING ALTITUDE AT 3,000 FEET.

3.1.17 AFTER PHUKET APPROACH CONTROL REASSIGNED THAI AIR 365 TO BE NUMBER ONE TO LAND AND DRAGON AIR 203 TO BE NUMBER TWO, THE PILOT OF DRAGON AIR 203 GAVE CAUTION TO PHUKET APPROACH CONTROL BY STATING "DRAGON AIR 203, WE ARE 2,500 FEET, THE TRAFFIC AHEAD IS ABOVE US AND CAN NOT DESCEND THROUGH OUR LEVEL, WE ARE IFR"

3.1.18 PILOT OF THAI AIR 365 ASKED PHUKET APPROACH CONTROL "WHO IS GOING TO LAND FIRST ?"

3.1.19 PHUKET APPROACH CONTROL THEN ASKED PILOT OF THAI AIR 365 WHETER HE SIGHTED DRAGON AIR 203.

3.1.20 AFTER LANDINGS GEARS WENT DOWN, THAI AIR 365 WAS STILL MAINTAINING ALTUTUDE AT 3,000 FEET AND THE SPEED GRADUALLY DECREASED FROM 210 KNOTS TO 150 KNOTS AND THEN THE AIRCRAFT BEGAN TO STALL. THE PILOT APPLIED GEARS UP AND TRIED TO RECOVER FROM STALL BUT THE ALTITUDE WAS LOW THE AIRCRAFT THEN CRASHED INTO THE SEA.

3.1.21 THE THAI AIR FLIGHTCREW BECAME CONFUSED OVER THE EXACT LOCATION OF DRAGON AIR DURING THE APPROACH.

3.1.22 THE DECISION BY THE APPROACH CONTROLLER TO CHANGE THE LANDING SEQUENCE ADDED TO THE CONFUSION OVER WHO TO HAVE LANDING PRIORITY.

3.1.23 THE THAI AIR PILOT-IN-COMMAND BECAME DISTRACTED AT A CRITICAL TIME IN THE INITIAL APPROACH AND FAILED TO REACT IN TIME TO PREVENT THE AIRCRAFT FROM STALLING.

3.2 PROBABLE CAUSE

THE AIRCRAFT ACCIDENT INVESTIGATION COMMITTEE DETERMINES THAT THE PROBABLE CAUSE ACCIDENT WAS: THE PILOT SLOWED THE AIRCRAFT AND IT STALLED WHILE THE PILOT PREPARED BE NUMBER ONE ON LANDING AS ADVISED BY PHUKET APPROACH CONTROL. IT APPEARS THAT HE WAS WORRYING AND NOT SURE WHETHER HE COULD MAKE NUMBER ONE LANDING BECAUSE THE PILOT OF NUMBER TWO AIRCRAFT IN SEQUENCE GAVE WARNING THAT THE NUMBER ONE AIRCRAFT AHEAD WAS ABOVE HIM AND COULD NOT DESCEND PASSING THROUGH HIS LEVEL. THE PILOT ADDED POWER AND RAISED THE GEAR AFTER STICK SHAKER ACTIVATED BUT DID NOT EXECUTE A RECOVERY BEFORE HITTING THE SEA.

4. SAFETY RECOMMENDATION

AIR TRAFFIC CONTROL RADAR SHOULD BE INSTALLED AT PHUKET AIRPORT.

ICAO Note.— Names of personnel were deleted. The attachments were not reproduced.

ICAO Ref.: 230/87

No. 4

Boeing 747-244/B Combi, ZS-SAS, accident in the Indian Ocean, 134 NM NE of Mauritius, on 28 November 1987. Report released by the Board of Inquiry, Republic of South Africa.

SYNOPSIS

Note: Save where otherwise expressly indicated all times stated in this report are in Co-ordinated Universal Time (UTC).

SYNOPSIS

On November 27th 1987 at 14:23, flight SA 295, a Boeing 747-244B Combi of South African Airways, departed from Taipei's Chiang Kai Shek Airport for Mauritius' Plaisance Airport with 159 persons on board. In the main deck cargo hold 6 pallets of cargo had been loaded. Some 9 hours out and some 46 minutes before the estimated time of arrival at Plaisance the flight deck informed the approach control at Plaisance that there was a smoke problem in the aeroplane and that an emergency descent to flight level (FL) 140 had been initiated. The last radio communication was at 00:04 on November 28th 1987. At about 00:07 the aeroplane crashed into the sea. The wreckage, consisting of thousands of fragments, sank to the ocean bottom at depths of the order of 15 000 feet (about 4,5 kilometers), although many of the lighter materials floated away on the currents. Some of the latter items were recovered from the sea, or from the sea-shores where they had been washed up far from the scene of the crash. Months later one such item was found on a beach in Natal, over 2 000 nautical miles away. There are clear indications that a fire developed in the right hand front pallet in the main deck cargo hold, that the fire got out of control and that it eventually led to the crash.

There were no survivors.

The State of Registry, the Republic of South Africa (RSA), was notified of the accident by Plaisance Air Traffic Control (Mauritius) at 01:15 on November 28th 1987.

As the accident had occurred outside the territory of any State, the investigation of the accident was conducted by the State of Registry in terms of paragraph 5.3 of Annex 13 to the Convention on International Civil Aviation. This was agreed to by the Government of Mauritius.

1. FACTUAL INFORMATION

1.1 History of the Flight

On November 27th 1987 flight SA 295 was scheduled to depart from *Taipei's Chiang Kai Shek Airport* at *13:00* for Mauritius' Plaisance Airport on a scheduled international air transport service. Due to adverse weather and the late arrival of a connecting flight the departure time was delayed and the aeroplane took off at 14:23 with 149 000 kg of fuel, 43 225 kg of baggage and cargo, 140 passengers and a crew comprising 5 flight crew members *(including an extra co-pilot and an extra flight engineer)* and 14 cabin crew members. The calculated flight time was 10 hours 14 minutes. According to the tape recording of the radio communication with Taipei Approach Control the take-off was normal in all respects. At 14:56:04 the crew communicated with Hong Kong radar and thereafter routine position reports were given to the *flight information centres (FICs)* at Hong Kong, Bangkok, Kuala Lumpur, Colombo, Cocos Islands and Mauritius. At 15:55:18 a routine report was made to the Operator's base at Jan Smuts (ZUR). The information given was that the aeroplane had taken off from Taipei at 14:23, was flying at FL 310 and that the arrival time at Mauritius was estimated as 00:35. The ZUR radio operator informed *flight SA 295 that the selective calling system (SELCAL)* was unserviceable and requested that the next call be at 18:00. SELCAL is a coded system whereby a radio station can call an individual aircraft. The flight crew's attention is drawn to a call by audio and visual means. In fact there was no further contact between ZUR and the aircraft, although the latter continued to have routine communications with the FICs en route. For further details of the omission to call ZUR, see paragraphs 1.9 and 2.16 below.

At about 22:30:00 the pilot called Mauritius FIC, using HF radio on frequency 3476 KHz, and advised that the aircraft had been at position 070° East at 22:29:00 at FL 350 and that the time at position 065° East was estimated as 23:12:00. At 23:13:27 the position report of 065° East at FL 350 was given to Mauritius FIC. The estimated time of arrival (ETA) over position 060° East was given as 23:58:00. As it can be accepted that the aircraft was on track, the position given as 065° East would have been at latitude 15°40'12" South and position 060° East at latitude 18°57'54" South.

There is no suggestion whatsoever of any distress in the routine HF radio transmissions which ended at 23:14:00.

On the tape of the 30 minute cycle CVR (see paragraph 1.11 below), which had no time injection, much of the first 28 minutes period was unintelligible.

Sufficient data was, however, recovered to indicate that the conversation was on purely personal topics and did not relate to the flight in any way. The Board acceded to a request by the representative of IFALPA not to publish details of this purely personal conversation. That ruling was in accord with the Board's understanding of the general practice in accident inquiries. The character of the flight deck conversation changed abruptly 28 minutes 30 seconds after commencement of the recording cycle, when the master fire warning alarm sounded. Somebody, probably the pilot, inquired where the warning had come from and received the reply that it had come from the main deck cargo. The pilot then asked that the check list be read. Some 30 seconds later somebody on the flight deck uttered an oath. This was followed by the CVR 800 Hz test tone on all four channels which ended in a warble at 29 minutes 52 seconds after commencement of the recording. These sounds indicate that the audio input and test signal wiring were being affected by the fire. It is assumed that the recorded cockpit conversation had commenced very shortly after the HF communication with Mauritius FIC at 23:14:00 and ended shortly before the VHF communication with Mauritius Approach Control at 23:48:51, reporting trouble.

According to the Plaisance tower tape recording (a full rendering of which is given in paragraph 1.9 below) the pilot called Mauritius Approach Control at 23:48:51 on 119.1 MHz. At 23:49:07 he said that they had a smoke problem and were doing an emergency descent to FL 140. The approach controller gave clearance for the descent and the pilot asked that the fire services be alerted. The controller asked if full emergency services were required to which the pilot replied in the affirmative. At 23:51:02 the approach controller asked the pilot for his actual position. The pilot replied: "Now we have lost a lot of electrics, we haven't got anything on the ... aircraft now". At 23:52:33 the approach controller asked for an ETA at Plaisance and was given the time of 00:30. At 23:52:50 the pilot made an inadvertent transmission when he said to the senior flight engineer: "Hey Joe, shut down the oxygen left". From this time until 00:01:34 there was a period of silence lasting 8 minutes and 44 seconds. From 00:01:34 until 00:02:14 the pilot inadvertently transmitted instructions, apparently to the senior flight engineer, in an excited tone of voice. Most of the phrases are unintelligible. At 00:02:43 the pilot gave a distance report as 65 nautical miles. This was understood by the approach controller to be the distance to the Airport. In fact it was the distance to the next way-point, Xagal. The distance to the Airport at that point was approximately 145 nautical miles. At 00:02:50 the approach controller recleared the flight to FL 50 and at 00;03:00 gave information on the actual weather conditions at Plaisance Airport, which the pilot acknowledged. When the approach controller asked the pilot at 00:03:43 which runway he intended to use he replied one three but was corrected when the controller asked him to confirm one four. This is no reflection on the pilot for what was one three had recently been changed to one four in conformity with a change of magnetic variation. At 00:03:56 the controller cleared the flight for a direct approach to the Flic-en-Flac (FF) non-directional beacon and requested the pilot to report on approaching FL 50. At 00:04:02 the pilot said: "Kay". From 00:08:00 to 00:30:00 the approach controller called the aircraft repeatedly but there was no reply.

The aeroplane crashed into the Indian Ocean at a position determined to be about 19°10' S and 59°38' E. The accident occurred at night, in darkness, at about 00:07. The local time was 04:07. This time was determined from 2 damaged wrist watches recovered from hand baggage.

Two persons who were on the South-Eastern shore of Flat Island, situated approximately 6 nautical miles North of Mauritius, stated that at about the time of the accident (04:07 local time) they had seen a red and yellow coloured object coming down rapidly from an estimated height of 6 to 7 feet above the horizon and disappearing behind

Round Island. This evidence emerged only after some days, and, when tested, did not tally with the facts. The direction was different, and the wreckage of the aircraft and the undersea photographs established that there was no "torching", i.e. no flames ouside the aircraft. It would appear that they had probably seen a meteorite.

1.2 Injuries to Persons

INJURIES	CREW	PASSENGERS	OTHERS
FATAL	19	140	nil
SERIOUS	nil	nil	nil
MINOR/ NONE	nil	nil	

1.3 Damage to Aircraft

The aeroplane was totally destroyed. Thousands of wreckage pieces were found scattered on the ocean floor.

1.4 Other Damage

There was no damage to property outside the aircraft.

* 1.5 Personnel Information

* *ICAO Note.*— Section 1.5 was not reproduced.

1.6 Aircraft Information

The type certification of the aeroplane had been approved on December 23rd 1970 under the airworthiness requirements current at the time. The aeroplane was imported into the RSA in November 1980 as a new aircraft. The certificate of airworthiness (C of A) in categories (a), (c), (d), (e) and (f) was issued on December 5th 1980 and was based on the submission of an USA export C of A in accordance with the bilateral agreement between the USA and the RSA. No recertification was required. Nor were any certification data requested or provided. FAA standards were accepted in good faith. The RSA C of A was continuously valid provided that the conditions prescribed therein were observed.

The aeroplane had flown 26 743,48 hours and completed 4 877 operating cycles since new. It had flown 360 hours since the last Phase A inspection, which was required by the approved maintenance schedule to be carried out at 430 flying hours intervals, and 81 hours since the last terminal inspection which was required at 120 flying hour intervals.

An inspection of the aircraft's maintenance records revealed that it had been maintained in accordance with the requirements of the approved maintenance schedule and the applicable Air Navigation Regulations. There were no known defects when the aircraft departed on the last flight. A certificate of safety for flight was issued on October 16th 1987 and was valid for another 70 flying hours, that is until 26 814,09 flying hours had been reached.

Because of the in-flight fire which occurred in the main deck cargo compartment, special attention has been paid by the technical investigation team to the maintenance history of the smoke detection system in that compartment.

During the periods August 11th to October 21st 1987 and November 10th to November 14th 1987 several defects relating to the main deck cargo compartment smoke detection system were recorded in the on-board technical defect log. Rectification actions included the replacement of no 2B and no 3A smoke detectors and a differential pressure switch. The recovered cockpit voice recording provided conclusive proof that the smoke detection systems of the main deck cargo compartment functioned.

The approved maintenance schedule prescribes that the orifices in the smoke detection sampling manifolds be inspected for obstructions at every tenth Phase A inspection, i.e. at 4 300 hour intervals. Such an inspection was carried out on February 2nd 1987 at 24 394 total hours i.e. 2 349 flying hours before the accident.

The aircraft's empty mass and balance were last determined on January 23rd 1984 at which time the basic empty mass was 166 129 kg and the centre of gravity (CG) position 34,1226 m (1343,41 inches) aft of the datum. This equals 26.1% of the mean aerodynamic chord (MAC) . The structural maximum certificated mass was 377 842 kg for take-off and 285 762 kg for landing.

The aircraft's mass at the time of the accident was calculated as 242 855 kg and the CG position estimated as 28,78% MAC. The CG limits at this mass are 13% and 33% MAC. The aircraft was thus correctly loaded.

The underwater inspection of the stabiliser trim actuator jackscrew revealed that 9 screw threads were exposed above the ball nut and 4 threads below the nut. No noticeable bending of the jack-screw had occurred. This suggests that the break in this area may have occurred flush with the ball nut on impact and that the jackscrew may have moved during the break-up following the impact. The actuator setting as found, equates to a CG position of 27% MAC. If the break had occurred flush with the ball nut and if the aeroplane was trimmed for level flight, the CG position would have been 21,47%. Both CG positions are within the safe cruising trim range. With all 159 occupants concentrated in the most forward passenger compartment the CG position would have been 21,5% MAC.

The quantity of aviation turbine fuel in the aircraft at the time of the impact was calculated as approximately 24 370 kg.

Of the 43 225 kg of cargo and baggage carried in the aircraft, 14 588 kg of cargo was loaded on 6 pallets in the main deck cargo compartment. This cargo consisted mainly of electrical components and parts, electronic components and parts, hardware, paper articles, textiles, medicines and sports equipment. Some articles from the main deck cargo which were recovered showed evidence of fire damage. None of the observed cargo from the lower holds had any signs of fire or heat.

Extensive investigations have been made into rumours that the cargo included a quantity of fireworks. The results have been negative. The South African Bureau of Standards (SABS) conducted numerous tests to determine whether signs of nitrates and/or ferrites were present, but the evidence is inconclusive. Pallet PR, in which the fire started, could not have carried a large quantity of fireworks because almost all the contents of that pallet were accounted for. But even a very small quantity could have provided a source of ignition because of the instability of the chemicals used and their responsiveness to heat.

1.7 Meteorological Information

Very little information on the actual weather conditions at the accident site is available. From the actual condition at Mauritius and Rodrigues together with the 03:00 satellite picture, the following weather conditions were estimated :

Upper wind FL 140 : 160/5-8 kt

Visiblity : 10 km or more

Cloud : Scattered cumulus and stratocumulus at 5 000 ft

No medium level cloud at FL 140.

The night was dark. The moon had set at 20:16 on November 27th 1987.

1.8 Aids to Navigation

The aeroplane was equipped with the following navigational aids and associated displays :

3 inertial navigation systems (INS)
2 weather and mapping radars with 300 nm range.
2 radio magnetic indicators (RMI)
1 standby compass
2 automatic direction finders (ADF)
3 very high frequency omni range (VOR) units
3 distance measuring units (DME)
3 instrument landing systems (ILS)

Plaisance Airport was equipped with the following terminal navigational aids :

2 VOR stations
2 DME stations
2 NDB stations

Runway 14 was equipped with an ILS system.
The ground stations were serviceable.

1.9 Communications

The aeroplane was equipped with 2 high frequency (HF) and 3 very high frequency (VHF) transmitter-receiver radio sets. Interphone (sometimes referred to as intercom) and passenger address systems were also provided.

The take-off and departure communications with Taipei departure control were normal in all respects.

Some 34 minutes after departure from Taipei, SA 295 called Hong Kong Radar at 14:56:04 and obtained direct clearance from ELATO to ISBAN. Normal position reporting was made over ELATO at 15:03:25; SUNEK at 15:53:52; ADMARK at 16:09:54 and SUKAR at 16:34:47. At 15:55:18 a routine report was made to the Operator's base station at Jan Smuts (ZUR). The crew was asked to report again at 18:00 as the selective calling system (SELCAL) was unserviceable. The communication with ZUR ended at 15:56:55. *The ZUR tape recording ran until about* 16:34. As the follow-on tape was apparently later mislaid or inadvertently re-used, there is no further communication between SA 295 and ZUR on record. The ZUR operator confirmed that there was no other communication. The ZUR log shows that at 04:48 on November 28th flight MK 057 had asked the ZUR radio officer when he last had contact with flight SA 295 and was informed "1600 UTC on 27". The ZUR episode is analysed in paragraph 2.16 below, and the Board's findings are to be found in paragraph 4.17 below. From 16:49:41 to 21:43:00 position reports were made to Bangkok, Colombo and the Cocos. The first HF call to Mauritius on 3476 KHz was made at about 21:46:00 when the crew reported the time at the Mauritius FIR boundary as 21:43:00. At about 22:30 a report of crossing longitude 070° East was made. At 23:13:27 a position report of 065° East at FL 350 was made to Mauritius. From 15:41:06 until 23:14:00 all position reporting was by means of high frequency transmissions. At 23:48:51 the pilot called Mauritius approach control on VHF. The communication which followed has been transcribed from the Plaisance control tower tape recording and is set out below. Free translations of Afrikaans phrases are in brackets. While most of the words were clearly recorded and could be easily transcribed, some of them and some of the unintentional transmissions from SA 295 cannot be made out clearly. In the transcription below the best available interpretation has been given to these passages, based on the conclusions of an expert on eletronic recordings, Dr , and of an experienced airline captain, Capt , who listened to the recording repeatedly and became acquainted with the voices of some of the crew.

KEY

295 : PILOT IN COMMAND OF FLIGHT SA 295

MRU : MAURITIUS APPROACH CONTROL

TIME	SPEAKER	RECORDED INFORMATION
23:48:51	295	Eh, Mauritius, Mauritius, Springbok Two Niner Five
23:49:00	MRU	Springbok Two Niner Fife, eh, Mauritius, eh, good morning, eh, go ahead

TIME	SPEAKER	RECORDED INFORMATION
23:49:07	295	Eh, good morning, we have, eh, a smoke, eh, eh, problem and we're doing emergency descent to level one five, eh, one four zero
23:49:18	MRU	Confirm you wish to descend to flight level one four zero
23:49:20	295	Ya, we have already commenced, eh, due to a smoke problem in the aeroplane
23:49:25	MRU	Eh, roger, you are clear to descend immediately to flight level one four zero
23:49:30	295	Roger, we will appreciate if you can alert, eh, fire, eh, eh, eh, eh
23:49:40	MRU	Do you wish to, eh, do you request a full emergency?
23:49:48	295	Okay Joe, kan jy ... vir ons (Okay Joe can you ... for us)
23:49:51	MRU	Springbok Two Nine Five, Plaisance
23:49:54	295	Sorry, go ahead
23:49:56	MRU	Do you, eh, request a full emergency please a full emergency?
23:50:00	295	Affirmative, that's Charlie Charlie
23:50:02	MRU	Roger, I declare a full emergency, roger
23:50:04	295	Thank you
23:50:40	MRU	Springbok Two Nine Five, Plaisance
23:50:44	295	Eh, go ahead
23:50:46	MRU	Request your actual position please and your DME distance
23:50:51	295	Eh, we haven't got the DME yet
23:50:55	MRU	Eh, roger and your actual position please
23:51:00	295	Eh, say again
23:51:02	MRU	Your actual position

TIME	SPEAKER	RECORDED INFORMATION
23:51:08	295	Now we've lost a lot of electrics, we haven't got anything on the on the aircraft now
23:51:12	MRU	Eh, roger, I declare a full emergency immediately
23:51:15	295	Affirmative
23:51:18	MRU	Roger
23:52:19	MRU	Eh, Springbok Two Nine Five, do you have an Echo Tango Alfa Plaisance please
23:52:30	MRU	Springbok Two Nine Five, Plaisance
23:52:32	295	Ya, Plaisance
23:52:33	MRU	Do you have an Echo Tango Alfa Plaisance please?
23:52:36	295	Ya, eh, zero zero, eh eh eh three zero
23:52:40	MRU	Roger, zero zero three zero, thank you
23:52:50	295	Hey Joe, shut down the oxygen left
23:52:52	MRU	Sorry say again please
00:01:34	295	Eh Plaisance, Springbok Two Nine Five, we've opened the door(s) to see if we (can?) ... we should be okay
00:01:36	295	Look there (?)
		(Exclamation by somebody else, and is said over the last part of the previous sentence)
00:01:45	295	Donner se deur t... (Close the bloody door) (?)
00:01:57	295	Joe, switch up quickly, then close the hole on your side
00:02:10	295	Pressure (?) twelve thousand
00:02:14	295	... ... Genoeg is ... Anderster kan ons vlug verongeluk (is enough ... Otherwise our flight could come to grief)

TIME	SPEAKER	RECORDED INFORMATION
00:02:25	295	Carrier wave only
00:02:38	295	Eh Plaisance, Springbok Two Nine Five, do (did) you copy
00:02:41	MRU	Eh negative, Two Nine Five, say again please, say again
00:02:43	295	We're now sixty five miles
00:02:45	MRU	Confirm sixty five miles
00:02:47	295	Ya, affirmative Charlie Charlie
00:02:50	MRU	Eh, Roger, Springbok eh Two Nine Five, eh re you're recleared flight level five zero. Recleared flight level five zero
00:02:58	295	Roger, five zero
00:03:00	MRU	And, Springbok Two Nine Five copy actual weather Plaisance Copy actual weather Plaisance. The wind one one zero degrees zero five knots. The visibility above one zero kilometres. And we have a precipitation in sight to the north. Clouds, five octas one six zero zero, one octa five thousand feet. Temperature is twenty two, two two. And the QNH one zero one eight hectopascals, one zero one eight over
00:03:28	295	Roger, one zero one eight
00:03:31	MRU	Affirmative, eh and both runways available if you wish
00:03:43	MRU	And two nine five, I request pilots intention
00:03:46	295	Eh we'd like to track in eh, on eh one three
00:03:51	MRU	Confirm runway one four
00:03:54	295	Charlie Charlie
00:03:56	MRU	Affirmative and you're cleared, eh direct to Foxtrot Foxtrot. You report approaching five zero
00:04:02	295	Kay

TIME	SPEAKER	RECORDED INFORMATION
00:08:00	MRU	Two Nine Five, Plaisance
00:08:11	MRU	Springbok Two Nine Five, Plaisance
00:08:35	MRU	Springbok Two Nine Five, Plaisance

(NO ANSWER)

A NTSB human performance expert commented as follows on the pilot's last VHF communication with the approach controller :

"The air traffic recording is generally of very good audio quality. After screening it, I had a definite impression that there were changes in the stress level of the speaker (who was identified to me as the captain) over the course of the tape. From 23:48:51 to 23:49:30 the speaker sounds relatively calm, speaking slowly and courteously (although the seriousness of his communication is clear from its content). At 23:49:30 he fails to complete the sentence, and there is a definite impression that someone or something in the cockpit is distracting him due to the growing emergency. From this point until the end he definitely sounds more agitated, is definitely more distracted, and appears to be talking more quickly. Several of the transmissions, for example from 00:01:34 to 00:02:14, appear to have the high levels of fundamental frequency, speaking rate, and amplitude which are generally characteristic of great psychological stress (the statement at 00:01:45 seems so high it is close to screaming). It should be noted, however, that these statements appear to be inadvertent transmissions meant for the on-board crew and that the speaker may be yelling partly to be heard through his oxygen mask and above the background noise in the cockpit. In the final section, from 00:02:38 to the end, the speaker appears to be more composed and responsive than he was in the preceding section. It seems possible that he has calmed down somewhat and feels that the emergency is more under control at this point than it was at earlier points. These comments are based on simply reviewing the tape and do not reflect scientific measurement for psychological stress."

1.10 Aerodrome Information

The emergency services at Plaisance Airport conformed to category 8 standards as laid down in ICAO's Annex 14. All navigational, landing and communication aids were functioning normally. At 00:25 everything was ready to receive the aircraft in distress and everybody was on alert. The aerodrome was not equipped with surveillance radar and only runway 14 was equipped with an ILS.

1.11 Flight Recorders

The following recorders were fitted :

(1) Penny and Giles quick access recorder (QAR) type D50761 for logging flight data. The QAR was mounted in the main equipment bay just forward of the lower cargo hold at station 460. This recorder was not recovered.

(2) Lockheed model 209F digital flight data recorder (DFDR) Part no. 10077 A500 - 803 fitted with a Dukane N15F210B underwater locator beacon. The DFDR was mounted on top of a stowage facility in the left hand rear side of the main deck cargo compartment at station 2320. This recorder was not recovered.

(3) Collins type 642 C-1 cockpit voice recorder (CVR) Part no. 522 - 4057 -002 fitted with a Dukane N15F210B underwater locator beacon. The CVR was mounted next to the DFDR and was the only recorder found and recovered from the sea bed.

After the CVR was found it was handled with great care and all possible precautions were taken to ensure that the recorded information would be retained. To prevent the formation of air bubbles on the tape and hence a deposit of sea water chemicals, the transfer from the lifting tackle to the transport container was performed under the water. Once on board the ship the sea water was replaced with de-ionised water whilst ensuring non-entry of air into the recorder unit. Ice made from de-ionised water was progressively added to maintain the temperature within the range of 4 to 12°C. The CVR, in the transport container, was then flown to the Operator's suitably equipped laboratory for removal of the tape. All metal tools used for this process were de-magnetised. The tape was removed with the unit submerged in de-ionised water and cleaned in such water by winding it from one reel to another after which it was dried in a vacuum chamber with periodic nitrogen purging. After drying the tape was hand carried to a NTSB laboratory in Washington DC for copying and analysis.

Examination of the recorder revealed impact damage to the outer casing. It had been exposed to heat as evidenced by blistering of the paint. The insulation of electrical wiring found attached to the mounting rack plug was scorched. The solder of some electrical wire joints had melted which was a further indication that the unit had been exposed to heat. The melting point of the solder is 183°C. The interior of the unit was covered with an oily soot, ingress of which was probably through an aperture in the front cover. The plastic blanking plug of this aperture had melted. The signal and control wiring was routed along the top left hand side of the main deck cargo compartment in raceway G and was next to the DFDR wiring. The power supply cable was routed along the top right hand side in raceway H.

The CVR locator beacon was examined by the manufacturer who concluded that the unit had been subjected to external heat in excess of 190°C. This temperature caused the solder surrounding the water switch spring to reflow and hold the switch in the compressed position. This high temperature also damaged the potting compound around the transducer and the transducer itself, and the reflowed solder in the module caused it to short-circuit. The electronics module was also found to be internally short-circuited across the battery connection.

The CVR was powered directly from the essential 115v AC bus and was wired to record from the audio selector panels of the pilot, co-pilot, flight engineer and from the cockpit area microphone. The CVR was not wired for "hot mic" recording but all verbal communications from the abovementioned crew members via oxygen masks, hand held and boom microphones would have been recorded.

"HOT MIC" recording means that the microphones are connected to a recorder in a manner that ensures the recording of all cockpit sounds within the range of the microphones regardless of audio control panel selections.

Although the tape was not damaged , much of the information which was recorded on the area microphone channel only, was unintelligible. Only the last 1 minute and 14 seconds of the 30 minute recording cycle were reasonably clear. However, sufficient data was recovered to determine that the cockpit conversation prior to the sounding of the fire bell had been on personal and general topics only. "Joe" referred to in the following transcription was the senior flight engineer. Free translations of Afrikaans phrases are in brackets. Here again the best available interpretation has been put on words which are not clear.

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
28:31	Fire alarm bell (was stopped very quickly by the crew)	
28:35	Intercom chime	
28:36	Joe	What's going on now?
28:37	?	Huh?
28:40	Joe	Cargo?
28:42	Joe	It came on now afterwards
28:45		Strong click sound
28:45	?	And where is that?

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
28:46		Click sound
28:48	Joe(?)	Just to the right
28:49	?	Say again(?)
28:52	Joe	Main deck cargo
28:57	Joe	Then the other one came on as well, I've got two
29:01	Joe	Shall I (get/push) the (bottle/button) over there
29:02	?	Ja (Yes)
29:05	Capt	Lees vir ons die check list daar hoor (Read the check list there for us please)
		(Double click sound)
29:08	?	The breaker (presumably referring to the circuit breaker) fell out as well
29:09	?	Huh
		(Two click sounds)
29:11	?	We'll check the breaker panel as well
29:12	Capt	Ja (Yes)
		(Sounds of movement can be heard with clicks and clunks)
29:33	Capt	Fok dis die feit dat altwee aangekom het - dit steur mens (Fuck it is the fact that both came on - it disturbs one)
29:36	Intercom chime (while captain is speaking)	
29:38	?	Aag shit
29:40	!!!	(800 Hz TEST TONE signal commences)

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
29:41	Capt	Wat die donner gaan nou aan? (What the hell is going on now?) This is said in a surprised tone of voice.
29:44		Sudden loud sound
29:46		Large and rapid changes in amplitude of test tone start
29:51		End of test signal, very irregular near end
29:52		End of recording. There is about 1 second of old recording on this side of the tape.

The 800 Hz test tone is introduced on all four CVR channels. After about 6 seconds rapid changes in amplitude (warbling) commence. After another 5 seconds the signal ends. As noted above (in paragraph 1.1), these concluding sounds indicate that the audio input and test signal wiring were being affected by the fire.

The tape ran for exactly 29 minutes and 52 seconds. It was noted that neither the last HF communication with MRU at 23:14:00 nor the first VHF communication with MRU approach control at 23:48:51 was recorded on the CVR.

1.12 Wreckage and Impact Information

1.12.1 The search for the bodies and wreckage was commenced on November 30th 1987 after a decision was made to abandon the search for survivors. Numerous ships, aircraft and helicopters took part in the search. From December 2nd 1987 the search was concentrated on an accumulation of debris which was drifting in a westerly direction. Spotting was by aircraft crews who directed the ships to the floating wreckage. Helicopters were used to search the coral reefs for trapped wreckage. The search for floating wreckage continued in earnest until December 10th 1987.

The floating wreckage consisted mainly of articles of light cargo, cabin panelling, cabin furnishing and escape slides or rafts. It was soon noticed that many of the retrieved articles had been subjected to heat or smoke. Several cargo articles carried in the main deck cargo compartment were burned and some panels in the passenger compartment adjoining the main deck cargo compartment were covered with soot. The cabin to main deck cargo compartment door showed signs of heat damage. None of the retrieved articles positively identified as coming from the lower cargo holds had any signs of exposure to heat or smoke.

On 11 December 1987, 3 ships commenced the search for the underwater locating beacons (pingers) which were fitted to the CVR and to the DFDR. To accomplish this it was essential to set up a grid of navigational beacons. An oceanographic research vessel, which happened to be available at Mauritius, was contracted to do a sonar sea bed survey and to map the sea bed. This survey was conducted from December 12th to 21st 1987 during which time some light pieces of debris were seen on the sea bed by means of TV cameras and photographed.

The pinger search continued until January 2nd 1988 without success. Another vessel with special manoeuvring features was hired and then fitted with side scan sonar equipment to search for the wreckage field. Because of unfavourable weather conditions the search could only commence on January 25th. On January 28th the main wreckage field was identified at co-ordinates 19°10'5" S and 59°36'57" E at a depth of 4 400 m. The debris field position was then marked by the use of two underwater transponder beacons.

The wreckage pieces on the sea bed were found dispersed in two oblong areas with light wreckage some 2,4 kilometres to the North-west of the two areas which were displaced in the direction of the normal flight path.

The longitudinal axes of the two oblong areas were in a general direction of approximately 320° magnetic, which is the estimated direction of the ocean current in that region. This does not imply that the aircraft was not on a more or less correct flight path at the time of the initial impact. The flight path, if not disturbed, would have been in the direction of 250° magnetic.

The two oblong wreckage areas can be referred to as the North-eastern and South-western areas. The North-eastern area is approximately 900 m long and 450 m wide. The centres of the areas are approximately 600 m apart and their perimeters are separated by a zone of some 200 m. Some cargo items, mainly computers, and fragments of wreckage were observed in this area.

The North-eastern area contained debris from aft of No 4 doors and included the following: Horizontal and vertical stabilizers.

Some 70% of the aft fuselage structure.

The main deck cargo door.

Two sections of the main deck cargo floor.

No 4B galley.

Rear pressure bulkhead.

The auxiliary power unit with its compartment and the tail cone.

Numerous items of main deck cargo.

The South-western area contained the highest concentration of debris from forward of No 4 doors, which was extensively fragmented. Major items in this area included three engines, four landing gear assemblies and numerous items of fuselage and wing structures.

The debris in both areas had drifted while sinking. The dispersion of items was influenced by their individual sinking characteristics and the effect of the ocean current. High density items were found in the South-eastern area with a progressive spread of items with low sink rates in a downstream (North-westerly) direction.

After location of the wreckage a contractor was selected to provide the technology and equipment necessary to photograph pieces of significance and to retrieve selected pieces. The then state of the art made this a difficult and lengthy investigation, with a large experimental factor. Recovery of the recorders was considered first priority. Photography and recovery of the wreckage were conducted from a specially equipped ship, the STENA WORKHORSE, by means of a remotely operated vehicle (ROV). This took place under the control and supervision of the investigator-in-charge, and with the technical assistance and support of SAA on all aspects of the search, and of Boeing in the identification of items of wreckage.

The photographic and video equipment installed on the ROV also enabled visual inspection of the wreckage. It was therefore possible to identify and inspect many of the wreckage pieces on the sea bed and to decide on recovery priority. Some 3 940 colour photographs were taken and 806 hours of video tape recordings were made. Wreckage pieces of importance were given designated target references and numbered in sequence. Attempts were made to retrieve all items of cargo and all wreckage pieces showing evidence of heat, but unforeseen circumstances prevented these optimistic intentions. It was, however, possible to retrieve 25 targets, some of which proved very valuable for investigation purposes. Amongst these were the cockpit voice recorder, rearmost galley support structure, sections of main cargo deck fuselage and crown skin and a section of the rear pressure bulkhead.

* 1.12.2

* *ICAO Note.*— Paragraph 1.12.2 was not reproduced.

1.13 Medical and Pathological Information

Fifteen lots of human remains were found and presented for post-mortem examinations. One lot contained the fragmented remains of two different bodies. The lower respiratory passages of one of these two bodies contained soot. The contents of six lots were only described and not further reported on.

The reports on the medico-legal post-mortem examinations on 8 bodies indicated extensive injuries to the upper parts namely to heads, chests and ribs. The cause of death of six accident victims was given as multiple injuries and of two as multiple injuries plus carbon monoxide intoxication. The blood specimens of these two bodies were in an advanced state of decomposition. Analyses for carboxyhaemoglobin were done by gas chromatography. The carboxyhaemoglobin saturation was 60,5% and 67,2%. (see paragraphs 1.14.2 and 2.12 below). No cyanide was found in the blood from the victim that had 67,2% saturation. No mention was made of a cyanide test of the other blood specimen or of any other blood tests. The allocated seat numbers of the two victims with high carboxyhaemoglobin saturations were 30E and 40D. Seat 30E was located in the Business Class, at body station 1160, which was fairly far forward in the passenger cabin. The respiratory passages of all eight bodies examined, contained soot. Five of the victims could be identified. They had been allocated seats 30E, 37A, 37D, 40D and 42A.

Radiological examinations were conducted on 5 bodies. No signs of radio opaque foreign objects were found.

1.14 Fire

1.14.1 The first known indication of fire was an alarm signal on the flight deck (recorded on the CVR) that was identified by the flight crew as coming from the main deck cargo compartment smoke warning detectors. This occurred 28 minutes 31 seconds from the beginning of the CVR recording. Approximately twenty six seconds later the flight engineer stated that the "Other one came on as well, I've got two". At 29 minutes 5 seconds into the recording the main deck cargo fire check list was called for, and at 29 minutes 52 seconds the recording ended. This was 1 minute 21 seconds after the fire alarm bell was recorded.

At about 23:49 the pilot contacted Mauritius approach control and stated that the flight was in an emergency descent to FL 140 due to a smoke problem in the aeroplane. Two minutes later, in response to Mauritius' request for a position report, the pilot stated "Now we've lost a lot of electrics, we haven't got anything on the on the (sic) aircraft now". About nine minutes later, at 00:02:25 the pilot reported and confirmed "We are now sixty five miles". The flight was recleared to FL 50, which was acknowledged by the pilot. In the last series of communciations with Mauritius, the pilot requested runway 14 and in the last contact with Mauritius acknowledged an instruction to report approaching FL 50. There was no mention of smoke or fire by the crew during these last series of transmissions.

1.14.2 Examination of the aeroplane wreckage disclosed heat and smoke damage that was most prominent in the main deck cargo compartment, consistent with the alarm recorded on the CVR. Some heat and smoke damage was, however, found in the aft galley area, which is forward of the partition that separates the passenger cabin from the main deck cargo compartment. Additionally, lethal levels of carboxyhaemoglobin were found in the blood of two passengers from which specimens were obtained. See paragraph 1.13 above. These findings were challenged by counsel for Boeing before the Board, but as appears from the Analysis in this Report (paragraph 2.12 below), the Board is satisfied that they are correct. Soot deposits were present in the respiratory tracts of the eight bodies that could be examined. It was noted that the area of greatest concentration of structural damage due to heat was in the upper area of the fuselage in the right front portion of the main deck cargo compartment.

1.14.3 The main deck cargo compartment in the 747-244B Combi (Zone E) is a Class B compartment as defined by FAR 25.857(b). The compartment is divided into two smoke detection zones, each of which is equipped with a dual smoke detection system providing a warning to the flight crew. There is no evidence that the flight crew were aware of any indications of fire prior to the sounding in the cockpit of the main deck cargo warning alarm bell. None of the warning systems was recovered from the ocean.

The Boeing Flight Manual approved for the aeroplane does not prescribe emergency procedures for a main deck cargo fire but these procedures are contained in the Operations Manual and are included in the Operator's emergency check list carried in the cockpit.

The check list specifies that the flight crew should don their oxygen masks (and smoke goggles, if needed) and that a flight attendant must don an oxygen mask and portable oxygen cylinder and at the captain's direction enter the cargo compartment. The flight attendant must then close the partition door, unclip the fire extinguisher from its stowage, unclip the cargo net gate, remove the 3 m long applicator from its stowage and attach it to the extinguisher nozzle, find the source of the fire and apply the extinguishant. The areoplane must be landed at the nearest suitable aerodrome.

The flight crew is referred to the Upper and Main Deck Smoke Evacuation check list from the main deck cargo fire/smoke procedure "if a smoke condition exists in the passenger area". This procedure instructs the non-flying pilot to determine the status of the smoke in the cabin, and outlines a descent to 14 000 feet or the Minimum en-route Altitude (MEA) "if an immediate landing cannot be made and smoke condition is extremely severe". The procedure also calls for the crew to be on 100% oxygen, with smoke goggles on if necessary. The pilot not flying is to identify the cabin doors to be opened for smoke evacuation. The aeroplane is depressurized, is slowed to below 200 knots, and the doors to be opened placed in manual mode. The door/s is/are partially opened at the captain's direction. The captain stated to Mauritius approach control that the aeroplane was in a descent to FL 140 due to a smoke problem in the aeroplane, but he did not say whether the smoke had reached the flight deck. Cockpit smoke evacuation procedures are not used unless the smoke source is inside the cockpit.

1.14.4 None of the cockpit oxygen masks were recovered for examination, nor was any part of the oxygen system. Similarly, none of the fire fighting equipment for the main deck cargo compartment was found. It was noted that two of the cargo barrier net clips were unclipped at the release fittings. Evidence to indicate that fire fighting procedures had been commenced is provided by the splatter of barrier net material (i.e. from the cargo hold) on the Halon fire extinguisher from door 2R (i.e. from the passenger cabin).

There were in total eight 2.5 lb Halon 1211 fire extinguishers installed in the passenger and flight deck areas of the aeroplane. Three 3.63 lb water extinguishers completed the portable fire extinguisher complement that was available in the passenger cabin and cockpit. Of these, one Halon extinguisher that was installed at door 2R was recovered with the floating debris. The bottle was full, but this was the extinguisher on which there was some melted nylon present on the outside surface. All these fire extinguishers were checked and recertified during 1987.

1.14.5 Supplemental oxygen is provided by separate fixed systems for the flight crew and passengers, and portable oxygen bottles are positioned throughout the cabin and cockpit for use if needed. Individual oxygen masks are automatically released from the passenger service units when the cabin altitude is at or above 14 000 feet. The B-747 Operations Manual warns that passenger oxygen use should be discontinued "below 14 000 feet when smoke or an abnormal heat source is present. The use of passenger oxygen will not prevent passengers from inhaling smoke at any altitude".

1.14.6 Numerous articles of cargo carried in the main deck cargo compartment and also compartment structure, fittings, and components were damaged by fire. Many of the cargo articles and all the packing materials used were flammable. The cargo was largely comprised of electrical components and parts (mainly computers), hardware, paper articles, textiles and sports equipment. Inquiries revealed that several computers and some computer circuit boards were fitted with either nickel cadmium or lithium batteries. Visits to the places of business of 66 consignors revealed that packing materials were mainly polystyrene, polyurethane, polyethelene sheeting and paper. Light articles such as computers and parts were packed in cardboard cartons while heavy units such as machines were either in wood crates or wood boxes. The crates, boxes and cartons were stacked approximately 2 m high, on 6 pallets designated PL, RL and SL from front to rear on the left hand side of the main deck cargo compartment and PR, RR and SR on the right hand side. The base dimensions of the pallets were 3,175m x 2,235m for PL and SL and 3,175m x 2,438m for RL, PR, RR and SR. The longitudinal aisle width between two 2,235m wide pallets is 48,75cm (19,5 inches) and 9,062cm (3 5/8 inches) between two 2,438m wide ones. The left front (PL) and left rear (SL) stacks had been covered with poly-ethelene sheeting. The stacks had been secured to the pallet bases with nylon nets.

The pallets on which particular cargo consignments were placed could only be determined from the master air waybills as only these waybills had been recorded when the pallets were made up, but many of the master waybills were consolidations of house waybills from consignors. This means that a consignment on one master waybill was spread out on two or more pallets. For example, master air waybill No 4852 was a consolidation of 36 house waybills mentioning the articles despatched. The packages containing these articles were placed on pallets PR, SR and RL.

From the retrieved cargo items and from photographs taken of items on the sea bed it was determined that most of the cargo showing evidence of heat was on pallets PR (right front), RL (left centre) and SR (right rear). No heat exposed cargo items on pallets PL (left front), SL (left rear) and RR (right centre) were found.

The two pallets containing cargo consigned from Japan were PL and SL. Neither of these appears to have been involved in any way in the fire.

1.14.7 The Operator was not aware of any dangerous cargo in the aircraft and had ensured that cargo handling would be in accordance with procedures laid down by the International Air Transport Association (IATA). The Operator's manager in Taipei stated that he would have been informed of any dangerous cargo and that he had not received any such information. He further stated that security measures at Chiang Kai Shek Airport were above average. Security of cargo at Chiang Kai Shek Airport was investigated and found satisfactory. Taiwan's Commissioner for Customs had conducted random sampling of the cargo consignments from Taiwan before they were loaded on the aeroplane. A computer selected 10 house waybills and one master waybill out of 111 bills. It was found that the items in the consignments agreed with the respective documents. The Chief of the South African Defence Force confirmed that no weapons or explosive devices were carried in the aeroplane for the SA Defence Force . The Executive General Manager of Armscor confirmed that there was no consignment of cargo to or from Armscor on the aeroplane.

Lithium batteries and activated carbon are listed as dangerous goods in the Technical Instructions for Safe Transportation of Dangerous Goods by Air (Doc 9284 - AN/905) published by the International Civil Aviation Organisation (ICAO). Six consignments of electronic equipment contained small lithium battery cells fitted to circuit boards.

These cells were considered non-dangerous as Special Provisions A45 of Doc 9284 - AN/905 had apparently been met. A small quantity, 300 g, granulated activated carbon was carried in the lower cargo hold. According to Special Provision A51 of Doc 9284 - AN/905 granular activated carbon is considered non-dangerous if cooled for more that 8 days since manufacture. The manufacturer stated that the activated carbon in the consignment had been cooled for longer than 180 days after production.

1.15 Survival Aspects and Search and Rescue

On November 27th 1987 at 23:50 the approach controller at Plaisance Airport, who throughout acted with commendable efficiency, declared an emergency and an ALERFA was issued, followed by a DETRESFA at 00:40 on the 28th. At about this time two search and rescue co-ordinators activated the Search and Rescue Centre (SARC).

At 01:15 on November 28th 1987 an ALERFA - DETRESFA was sent to the civil aviation authorities and the Search and Rescue Centre (SARC) of the State of Registry. Plaisance ATC was asked if assistance was required and was informed that a Lockheed 382 aeroplane would be ready to depart from Jan Smuts Airport at 08:00 on November 28th 1987.

At 02:29 an Air Mauritius helicopter and a Mauritius Police helicopter departed for a search North of Mauritius. They were followed at 02:40 by a DHC-6 (Twin Otter) of Air Mauritius and a Transall of the French Air Force at 02:40. The search areas were extended to areas West, North-east and South-west of the island but nothing was found. At 12:47 the crew of a Beech 18 aeroplane, who took part in the search on their own initiative, saw wreckage pieces 136 nm North-east of Plaisance. At 15:20 the SARC issued a situation report giving the following information : "Position of accident site at 1904S and 5936E. One empty dinghy and some debris located including one escape chute, something resembling a kerosene tank and some luggage. Two ships proceeding to the accident site, estimated time of arrival 21:00. A search craft has dropped an emergency locator beacon to mark the accident site. The search will continue at first light (01:12) on November 29th. French C160, United States of America (USA) P3 Orion and Air Mauritius Aircraft will continue search for survivors as from dawn on 29th. Sea search is being carried out by a Mauritian navy vessel and other fishing vessels operating in the region".

On November 29th at 02:56 the wreckage pieces were relocated by the crew of a Transall aeroplane and the ships started with retrieval of bodies and floating wreckage. This was a slow process as floating objects were spread over a large area.

On November 30th at 07:30 it was decided, after anxious deliberation, to terminate the search for survivors and to concentrate on recovery of wreckage pieces. By this time mutilated human remains were retrieved but only 8 bodies were substantial enough for medico-legal post-mortem examinations. The nature of the injuries indicated that the impact forces were far too high for survival.

The following organisations immediately reacted positively to the search and rescue operations :

Mauritius Marine Authority
National Coastguard of Mauritius
Helicopter Section of Mauritius Police
Air Mauritius
French Air Force and Naval Base at Reunion
United States Navy at Diego Garcia
Perth Rescue Co-ordination Centre Australia
SARSAT Toulouse

The gratitude of all concerned for the unhesitating response of these authorities has been noted in the Foreword to this Report.

* 1.16 Tests and Research

* *ICAO Note.—* Section 1.16 was not reproduced.

* 1.17 Additional Information

1.18 Investigation Techniques

1.18.1 On Site Investigation

The remoteness and depth of the site at which the wreckage of the aircraft was believed to be lying necessitated the utilization of specialized techniques to locate and recover both floating and sunken wreckage. After completion of the search for survivors, the emphasis changed to the recovery of bodies and floating wreckage which by then had dispersed over a large area. Search aircraft were used to direct ships to specific areas. Much time had to be devoted to this operation. Not all floating wreckage could be retrieved. Although some floating wreckage ended up on the beaches of Mauritius and even South Africa, wreckage washed up on beaches on Malagasy could not be retrieved because of the political differences between that country and the Republic of South Africa.

First indications from the ATC tape were that there had been a fire related problem in the

* *ICAO Note.*— Section 1.17 was not reproduced.

aircraft which was confirmed by floating wreckage recovered from the aft section.

It was considered essential to recover the CVR, DFDR, and even the quick access recorder to obtain as much information on the cause of the fire and the subsequent flight path of the aircraft. The assistance of the United States Navy was requested. Nearly one week elapsed before the necessary agreement could be reached between the Governments of the USA and the RSA. It took yet another week to transport the necessary equipment from Miami (USA) to Mauritius by heavy lift aircraft. Thus more than 14 days of the guaranteed 30 day battery lives of the pingers, as fitted to the CVR and DFDR, were lost. During this time an RSA effort utilizing subcontractors was initiated and two RSA based tugs were despatched to act as search platforms. They took 10 days to reach Mauritius. In the meantime Dukane broomstick locators were used to search for the wreckage, but without success. A further search ship fitted with hull under water detectors was chartered.

As the area in which the wreckage was believed to be was relatively uncharted a German research ship was contracted to chart the sea bottom. The sea bed charted varied from 5 000 m below sea level to as little as 300 m.

A navigation system had to be deployed and supported on the islands of Mauritius, Roderigues and Cargados to ensure that adequate grid pattern searches were carried out.

The pinger search, as it was known, was a multinational effort and ended 33 days after the crash. More than 1 000 square nautical miles were searched without success. This large area was covered of necessity as it was not known whether the aircraft had broken up at altitude.

Three areas of probability were identified and covered by sidescan sonar search.

Because of the depth of the sea bed where the wreckage was located, contractors qualified and able to search for, locate, and recover the recorders and selected wreckage were not readily available. Various contractors worldwide were visited prior to a specification being drawn up and tenders called for. This included a "no cure no pay" clause which required the contractor to prove his capability to carry out the task before any payment was made. The company Eastport International of the USA was contracted by the Department of Transport, and Operation Resolve, as it became known, was initiated. This called for the manufacture of a 22 000 ft umbilical fibre optic cable to control the remotely operated vehicle (ROV), known as the Gemini.

Problems were experienced with the ship to ROV navigation system, as well as with ROV and deployed sea bed transponders. No real time navigation was possible because of acoustic interference. ROV thrusters had to be switched off each time a fix had to be obtained. Use of INS in future ROV's could overcome this. Ship navigation was by means of GPS which had a limited window in this portion of the Indian Ocean (about 4 hours in 24 hours).

Photomapping and recovery of the CVR were successful. However, with recovery of selected wreckage (it was impossible to recover all wreckage), two significant items were lost at 4 000 ft and 400 ft below the surface respectively. These were the horizontal stabilizers and a section of the main deck cargo floor. Smaller items were placed in a basket which could be closed prior to recovery to prevent loss through drifting. Bigger items were recovered by means of a lift line on a drum on the sea bed.

Ballistic tests carried out in water tanks indicated that the drift-down characteristics of the CVR and the DFDR were different with the DFDR being less stable and less predictable on location. The CVR was in fact located within the predicted area.

Although the minimum contract period for Operation Resolve was 20 days, it soon became apparent that a minimum of 40 days was more realistic. In fact Operation Resolve lasted 101 days. Notwithstanding the high cost, Operation Resolve was undoubtedly a highly successful undertaking.

1.18.2 Cockpit Voice Recorder and ATC tape analysis

After recovery, the cockpit voice recorder (CVR) was transferred under water, to a transport container. The sea water in the container was then replaced with deionised water and ice to maintain the temperature below 12°C, during transportation to the Operator's laboratory.

In the laboratory the temperature was allowed to stabilize at room temperature, approximately 21°C. The CVR was opened. There was minimal internal damage, and the tape was transferred, without difficulty, to a reel. Cleaning was then accomplished by reeling it from reel to reel in deionised water, with frequent salinity checks. The tape was then dried in a vacuum chamber, with dry nitrogen purging at 10 minute intervals. This process was continued for 24 hours.

The tape was then carried by hand, circumventing all magnetic security checks to the National Transportation Safety Board flight recorder laboratory in Washington D.C. There the tape was copied. The first generation master copy was made from reel to reel.

The CVR tape voice analysis was carried out in the Republic of South Africa. The only recorded data was on the cockpit area microphone channel (CAM) and as most of the conversation, before the master fire warning bell sounded, was between the 2 flight engineers, the quality of the recording was exceptionally poor.

The system of data recovery employed was unique in that the data was digitized and then computer analyzed. Approximately 60% of the data were retrieved using this method. This figure was remarkable considering that less than 5% was recovered by conventional methods.

A first generation copy of the CVR tape was analyzed by the National Research Council (NRC) in Ottawa, Canada, in an endeavour, using techniques developed by the NRC, to identify an explosion signature. The results of this highly complex and time consuming technique were conclusively negative.

The Air Traffic control (ATC) tape recording was also computer analysed in an attempt to retrieve the data from the very garbled inadvertent transmissions made from the aircraft. This was less successful than the CVR tape analysis.

The manner in which the 3 940 still photographs, taken on the sea bed, were utilized is worthy of note. The photographs were mounted on stands in the dive sequences. From the photographs, the operator's experienced maintenance personnel, together with representatives of the manufacturers, were able to identify most of the components, in spite of the degree of fragmentation that had occurred. The video tapes, after being suitably catalogued, were analyzed in a like manner.

In preparation for the possible recovery of both the flight recorders, a team of investigators visited no less than 5 establishments in the USA and 2 in the United Kingdom, to obtain first hand knowledge of problems likely to be encountered with the recording medium after so long an immersion in sea water at such a great depth. The successful recovery and tape handling methods were devised from the information received.

2. ANALYSIS

2.1 When the aircraft disappeared there was scant evidence of what had occurred and of where it was. Step by step, by painstaking and at times very costly efforts, important evidence has been recovered. That evidence has come from, inter alia, the findings at the post mortem examinations performed on the few bodies which, by an extraordinary chance, were recovered from the sea; the location by sonar side-scan devices, after prolonged, expensive and fruitless searching, for the wreckage in the Indian Ocean 134 nautical miles North-east of Plaisance Tower, lying at depths of the order of 15 000 feet (about 4,5 kilometers); the identification, in Operation Resolve, of two distinct fields of wreckage; the expert analyses and interpretation of the ATC tape, portions of which were unintelligible; the remarkable technological achievement of locating and recovering the CVR from the ocean floor and the expert analyses and interpretation of garbled but significant items of speech and noise recorded thereon; the location and recovery of important elements of wreckage from the ocean floor; the production and analysis of some 3 900 photographs and over 800 hours of video studies of selected items of wreckage at these great depths; the identification and sources of the cargo packed in the respective pallets on board the Helderberg at the time of the accident; a mass of expert findings on numerous other aspects of the crash, following metallurgical, chemical, electronic and other tests of pieces of wreckage and items of cargo; the flight characteristics of the Boeing 747 with heat damaged portions of the structure and controls; the significance of the wreckage pattern; the evidence of experts on aircraft fires and explosions; and volumes of documentary data on Combi aircraft, spontaneous fires and other matters relevant to this Inquiry.

2.2 From evidence pieced together it is clear that a fire commenced in the front pallet on the right hand side (pallet N° PR) in the main upper deck cargo hold. The fire developed rapidly and could not be controlled. It generated smoke, carbon monoxide and carbon dioxide, some of which penetrated to the passenger cabin and possibly to the flight deck.

Mr , the FAA expert explained that there were too many unknown variables to determine whether smoke could in fact have reached the cockpit.

He said : "... it depends on the airflow and whether the airflow systems are working or not, as to what is going to happen, whether the smoke is going to propogate into the cockpit or not, or how long it would take, and I couldn't tell you whether it would or it wouldn't, without knowing all the conditions that were going on inside that aircraft at that particular time".

Another FAA expert, Mr , agreed with this view on the complexities of analyzing the air movements in an aeroplane, particularly when that analysis must take into consideration a thermal driver, such as a fire. If, as is believed, the crew were following the smoke evacuation check list, the requirement for the recirculating fans to be on could have significantly increased the flow of the products of combustion into the passenger cabin. The fire also caused heat damage in varying degree to the aircraft's skin and the supporting (longitudinal) stringers, mainly between stringers R4 and R16; to (circumferential) frames, mainly between body stations 1640 and 1960; to the empennage flying control cable pulley clusters above the No 4 galley and as far back as body station 2080 (the controls involved here were the elevators, the rudder, the rudder trim and the manual operation of the horizontal stabilizer); to part of the elevator cables; to the crown of the cargo hold; and to the electric wiring running in the raceways on either side thereof, including the wires supplying current to the CVR and DFDR at the rear end of the aircraft. Further, the fire caused a number of plastic supports for the insulation blankets to melt, and damaged some of the blankets themselves.

The effects of the fire eventually led to the aircraft crashing into the sea, with severe impact damage and disintegration of the aircraft itself, and of items of cargo and baggage.

2.3 The two main aspects upon which the evidence does not justify precise findings are the ignition source of the fire and the causal chain between it and the aircraft's crashing into the sea. Nevertheless, the evidence has provided positive guidelines on both these aspects.

2.4 On the question of the ignition source, the possibility of an explosion is considered to be remote, for the following reasons :-

(a) The CVR tape was tested in Canada by the National Research Council for the presence of an explosion "signature" indicative of a disturbance which would be registered by an explosion of as little as 300 gm of explosive. The findings were negative. Forensic tests on many pieces of floating wreckage were also negative (see para 1.16.3 above).

(b) An explosion of any consequence would have resulted in depressurization, but there was no mention of any such occurrence on the ATC tape of the communications between the flight deck and Plaisance Tower.

(c) The CVR tape also contains no mention of any explosion or depressurization.

(d) According to the CVR, the emergency which developed in the aircraft was not the occurrence of an explosion, but the activation of the fire alarm's signal on the flight deck by smoke sensors in the cargo hold.

(e) For what that may be worth, there was no claim by any organisation of a terrorist attack on the Helderberg.

(f) Mr , an expert on fires and explosions, examined the wreckage and photographs for indications of "an explosion in terms of high explosives", i.e. one that creates a shock wave greater than the speed of sound. He found no evidence of any such explosion.

(g) Radiological investigation of the bodies recovered from the sea revealed no radio-opaque objects.

2.5 Sabotage by means of an incendiary device also appears to be improbable. Here again, no claim by any organisation was made. Obviously there was no pressure-activated device, for the aircraft had been at its final cruising altitude for some six hours when the fire developed. The indications are also against a timing device. The aircraft was one and a half hours late in take-off through an unexpected delay that developed after it had been loaded. If a timing device had been used it would have been calculated to explode approximately an hour after the aircraft had already landed in Mauritius.

2.6 There was nothing in the cargo contents in pallet PR, as declared, that could be described as dangerous goods. Some of the computers consigned in pallet PR and other pallets were fitted with nickel-cadmium or lithium batteries, but in the circumstances those items were not likely to have caused any ignition or explosion. See paragraph 1.16.1 above. Moreover a security check at Taipei of a representative percentage of the cargo on board the Helderberg showed that the cargo manifests tallied with the cargo itself. Subsequent investigation of the consignors of the cargo in pallet PR revealed nothing suspicious. Nevertheless, the possibility of a misdeclaration or a false declaration in the consignment notes or cargo manifests cannot be ruled out entirely.

2.7 Practical experience of and research into cargo hold fires, as communicated to the Board, demonstrate that such fires can originate from any of a wide variety of causes. Ignition is certainly not limited to items such as matches ignited by friction, fireworks, cigarette lighter fluid, nitric acid, peroxides, or any of the many other chemicals which when mixed together can burst into flame or generate temperatures high enough to cause fire in other materials in the vicinity. As Mr the FAA expert on fires, put it when consulted by the Board: "... (A) fire initiated from just about any source spreading through packing material and cardboard boxes can lead to catastrophic occurrences. ... (T)here are numerous ways of igniting various materials". Mr expressed the opinion that the damage to the aircraft was entirely consistent with a fire in typical cargo packing materials, and that cardboard and plastic packing materials could have generated enough heat to produce the results that occurred in this particular instance. He explained that a fire in such packing materials can build up rapidly and within three to five minutes from the time of ignition develop into a "flash fire", i.e. a fire in which the material has given off combustible gas which ignites at the ceiling level, with flames progressing rapidly at the ceiling from one end of the compartment to the other, and consuming much of the oxygen in that compartment. With such a fire the temperatures at the ceilings generally range upwards to 2000°F (about 1093°C) and last for a period of anything from thirty seconds to a few minutes, depending on how quickly and violently this occurs, and on the amount of material in the compartment. Sometimes the fire dies down from lack of oxygen and reaches an equilibrium point depending on how much air is being induced back into the compartment. The fire can stay in a steady state of smouldering for as long as two hours, or if enough oxygen is induced back into the compartment as part of the air, the fire can go back into a flaming mode. Exactly how a fire would burn in a compartment therefore depends on a number of variables. The generation of smoke in a "flash fire" or even a "flash over" where a number of other materials are ignited is rapid and dense. There have been instances in actual fires in aircraft where visibility was severely limited by smoke. In a test of these conditions run by the FAA, the obscuration, i.e. the amount of light visible over a distance exceeding one foot, went to zero almost immediately upon the flash fire in the compartment and stayed there for a total of two hours of the test. The only thing that burnt were the packing materials. That was what was making the smoke. Also the amount of material consumed at the end of the two hours was relatively little and most of it was in the area in which the fire started.

2.8 Mr , the fire and explosions expert, who was called to testify by The Boeing Company, discounted discarded smoking materials as a possible cause of the fire, and also electrical arcing from the raceways in the crown. In his opinion the fire started as a result of something within the cargo in pallet PR.

Having regard, inter alia, to the signs of fire damage in the cargo hold, to the restricted oxygen supply within the pallet, and to the amount of oxygen that would have been necessary to achieve the energy output for that fire, Mr considered that the source was not a diffusive fire (i.e. one in which combustion feeds on an outside supply of oxygen), but a promoted fire (i.e. one in which there is an intrinsic supply of oxygen within the material involved in the combustion).

In the opinions and experience of the FAA and of Mr , the fire could have developed very rapidly into a "flash fire" even before the smoke sensors activated the fire alarm system on the flight deck, or at least within a minute of that alarm sounding.

In the Board's view there is insufficient evidence to determine the precise source of ignition. Nevertheless certain inferences on the fire and its effects can safely be drawn, viz :

(a) Whatever the source of ignition, the cardboard and plastic packing materials in pallet PR were undoubtedly involved in the fire, which caused the damage described in the evidence.

(b) The burning of those materials produced the smoke problem mentioned on the ATC tape, and also carbon monoxide and carbon dioxide, which, as noted earlier, penetrated to the passenger cabin and possibly to the flight deck.

NOTE: On the presence of carbon monoxide see paragraphs 1.13 and 1.14.2 above and paragraph 2.12 below.

(c) The fire could have developed rapidly, so rapidly indeed that by the time a crew member or members arrived in the cargo hold, visibility could have been severely restricted by the smoke, and by then the lights in the cargo hold could have gone out through damage to the wires in the crown, or were of little value because of the smoke.

(d) There was no torching, i.e. the fire did not burn outside the fuselage.

(e) The heat given off by the fire while flashing, and reflashing, and the residual heat, would have prevented the crew from getting close enough to it to operate a fire extinguisher effectively.

2.10 The next aspect to be examined is the causal chain between the fire and the aircraft's crashing into the sea.

Certain inferences can be stated with certainty, viz :

(a) The cause of the crash was the fire.

(b) The fire got out of control and either remained so or was only extinguished after an irretrievable position had developed.

(c) The smoke problem led the crew to decide on an emergency descent to FL 140.

(d) "Something catastrophic" (as it was put in the testimony of the Director of Flight Operations of SA Airways) occurred between the last communication from the flight deck at 00:04:02, when the aircraft acknowledged "Kay" in respect of the Tower's instruction to report approaching FL 50, and 00:07:00 when the crash occurred as indicated on the two watches found in the wreckage.

2.11 On all the evidence, the total range of possibilities, which were examined at great length before the Board, is as follows :

1. The crew were overtaken by toxic levels of carbon monoxide and carbon dioxide, and ceased to control the aircraft effectively or at all, or they became disorientated or unable to see the instruments because of smoke.

2. Crew distraction.

3. The aircraft broke up through weakening of the structure by fire damage.

4. The aircraft became uncontrollable through expansion beyond the limits of tolerance, or a fracture of the elevator control cables, and/or through damage to the empennage flying control cable pulley clusters.

5. The aircraft became uncontrollable through deformation of the fuselage by heat from the fire.

2.12 On the first point, it was suggested by Boeing's counsel before the Board that the medical evidence, of fatal levels of carbon monoxide in the blood samples taken from two of the bodies, was unreliable. The evidence of carbon monoxide in the blood of these two persons, however, becomes overwhelmingly probable when account is taken of the further facts that the fire penetrated via the crown of the cargo hold to the passenger cabin, that the crew reported a smoke problem, and that soot was found in the respiratory tracts of the passengers upon whose bodies post-mortem examinations were performed.

The scientific evidence presented on the laboratory investigations in regard to carboxyhaemoglobin levels thus becomes particularly cogent.

Besides, the analyses for carboxyhaemoglobin were carried out by the use of gas chromatography, which largely obviates false readings due to decomposition haemoglobin pigments. Medical evidence was led that the blood samples were obtained from closed thoracic cavities and had not been exposed to outside air or water.

The high levels of carboxyhaemoglobin found (60,5% and 67,2%), together with the post-mortem observations, indicate that there were fairly high levels of smoke, soot and carbon monoxide in the passenger cabin.

The allocated seat numbers of the passengers with high carboxyhaemoglobin saturations were 30E (business class, fairly far forward in the passenger cabin), and 40D (economy class). Other identified passengers in allocated seat numbers 37A, 37D and 42A (all in economy class) had soot in their respiratory systems, and, presupposing that they were in those seats when the fire occurred, the indications are that they too were exposed to carbon monoxide gas. On the probabilities, most if not all of the passengers would have moved as far forward as possible after the smoke had penetrated the passenger cabin.

It is possible that smoke, soot, carbon monoxide and carbon dioxide penetrated to the flight deck. Dr the expert on electronic tape recordings, expressed the opinion that the captain's voice on the ATC tape during the emergency indicated that he was not wearing an oxygen mask. It was, however, not a dogmatic opinion, and the Board is satisfied that the almost certain reaction of the crew, based on the evidence of the check list, their training and their responses to the critical situation confronting them, was to don their oxygen masks and keep them on at least until FL 140 was reached, if not until the end. There was an adequate supply of oxygen available to the flight deck crew, the duration of which for 3 crew members on "Emergency" selection was 42 minutes. It is believed that the inadvertent transmissions made on the approach frequency resulted from the captain repeatedly having to select between VHF1 and interphone, during a period of extreme tension in the cockpit. These inadvertent transmissions, the last of which was made some 4 minutes before the aircraft crashed, strongly suggest that the oxygen masks were worn by the crew right up to the end. If the flight deck crew were using oxygen masks immediately after the fire alarm sounded, as required by the check list, they would have been breathing one hundred per cent oxygen, and would have been largely protected from carbon monoxide intoxication and smoke inhalation. This assumes that the oxygen masks were fitted properly to the faces of the crew members concerned. The possibility cannot be ignored that, because of his skin ailment, the captain might from time to time have found the pressure of the mask on his face uncomfortable and have moved it to scratch the skin under it. In that event, he would from time to time have been exposed to the risk of inhaling carbon monoxide and carbon dioxide.

Carbon monoxide and carbon dioxide are toxic gases which can cause incapacitation. Carbon dioxide is evolved in large amounts in nearly all fires. Inhalation of air containing thirty per cent by volume of carbon dioxide induces anaesthesia in a few minutes.

Owing to the stability of carboxyhaemoglobin which continues to accumulate as the blood absorbs the gas from the lung alveoli, even very small proportions of the gas (not immediately dangerous), may eventually prove fatal. Thus one per cent by volume in the air can cause unconsciousness in fifteen to twenty minutes. It has been established that carboxyhaemoglobin levels as low as five per cent, particularly at high altitudes, can cause severe intellectual impairment. From the aforegoing it can be deduced that :

(a) There is a real possibility that some, if not all, of the passengers and cabin crew were unconscious or dead from carbon monoxide and carbon dioxide intoxication before the impact.

(b) If (as is unlikely), the flight deck crew were not using oxygen masks, it is possible that they too became incapacitated by carbon monoxide and carbon dioxide gases and smoke.

(c) If the flight deck crew reverted to normal oxygen on reaching FL 140, when the cabin oxygen was switched off, they would then have been inhaling a mixture of 40% oxygen and 60% cabin air, and could have been subjected to the effects of carbon monoxide and carbon dioxide, with a consequent possibility of ensuing impairment of intellectual and physical capacity.

2.13 On the question of the possible break-up of the aircraft in the air, there are arguments on both sides, but nothing conclusive.

The main arguments against a break-up in the air are that :

(a) calculations indicate that even if the damaged area of skin and underlying stringers and frames were to have broken away, there would not have been *any structural failure of the airframe within* the normal operating parameters of 1,3 to 0,7 g;

(b) there have been cases where, relative to this accident, *proportionately larger areas of skin,* stringers and frames have been lost from areas that are more critical to the aircraft's structural survival, and where no catastrophe ensued;

(c) the pattern of the wreckage is not consistent with structural failure unless such occurred at a very low altitude;

(d) the manufacturer of the engines is of the view that they were attached to the airframe at impact (see Appendix C Volume 2), although the fact that the engines were not "shed" in the air is not necessarily inconsistent with a prior break-up of the rear portion of the aircraft.

Some of the arguments in favour of break-up in the air are that :

(a) there is clear evidence of two separate fields of wreckage about 200 metres apart;

(b) there is evidence that the engine fans were not windmilling and had ceased or almost ceased to rotate before impact with the sea, which would indicate that the aircraft was not flying but falling or tumbling or engaged in some other unusual manoeuvre;

(c) there can be no assurance that the aircraft remained within the parameters of 1,3 to 0,7 g.

There was a wrinkling of the skin in the aft fuselage and empennage, suggestive of structural failure, which could be indicative either of in-flight break-up or impact damage.

In the Board's view it would not be helpful to pursue these and other arguments pro and con in any detail, because no sure findings can be made thereon, not even on the probabilities.

2.14 This view also applies to the question of whether there was interference with the empennage flying control cable pulley clusters or elevator control cables or the aerodynamic integrity of the aircraft. There is cogent evidence from the manufacturers of the Pratt & Whitney engines, with which the aircraft was fitted, based on the appearances of the engine fans as shown in the underwater photographs, that the aircraft must have hit the water with the wings perpendicular to the surface of the sea. That could mean either that the aircraft was out of control (but there is still no indication of precisely how that could have been caused), or that the aircraft "bounced" after its initial impact with the water and then proceeded to tumble.

2.15 It is necessary to analyse the actions of the crew, both those on the flight deck and those in the cabin, subsequent to the sounding of the fire alarm on the flight deck.

2.16 Before proceeding with that analysis, however, it is convenient at this stage to deal with an aspect of the flight prior to the sounding of the fire alarm. The history of the flight until the fire warning sounded appears, on all the evidence, to have been entirely normal, save for the omission to comply with standing instructions of the Operator relative to regular communication between the aircraft and ZUR, the high frequency radio transmitting station based at the Operator's headquarters at Johannesburg (see paragraph 1.9 above). The purpose of the standing instructions was that contact should be maintained between the Operator's home base and its aircraft flying in various parts of the world. The evidence reveals that those responsible for establishing such contact with the aircraft from time to time failed to carry out their instructions. Moreover, the tape recordings of the activities of the ZUR station over the relevant period were either mislaid or inadvertently wiped out. The circumstances were investigated in full by the Board, which is satisfied that there was no connection between the failure to comply with the instructions and the accident to the Helderberg. The kind of communication that normally takes place between ZUR and an aircraft flying on any of the Operator's routes would have had no bearing on the circumstances which befell the Helderberg. On the other hand, because of the fire on board the aircraft, the crew of the Helderberg would have been preoccupied with communications to and from Plaisance Tower. That was the source from which assistance would be expected, whereas ZUR could have done nothing in the circumstances. Insistence on communications with ZUR at that time would have been an interference with the handling of the aircraft and the reports of its progress to Plaisance Tower.

2.17 We return now to the actions of the crew subsequent to the sounding of the fire alarm on the flight deck.

According to the ATC tape, the first transmission from the aircraft to Mauritius Approach Control on VHF RTF was at 23:48:51. It is apparent that the fire warning bell and light signal preceded this transmission, as also the eighty seconds of cockpit voice recorder (CVR) recordings which contained such of the information regarding the fire situation as was available at that time. Because of the interruption of the electrical power supply to the CVR no further data was retrievable from this source.

It is not possible to establish positively how long after the fire warning bell had sounded the first call was made to Mauritius Approach Control. This period could have been anything between three and five minutes. If the fire was already burning as a "flash fire" when the alarm sounded, the development of the smoke and its penetration into the passenger cabin could have occurred very rapidly.

2.18 The most acceptable explanation of the intercom chime which is heard on the CVR four seconds after the master fire warning bell had sounded is that a cabin crew member became aware of the problem in the main deck cargo area behind the forward non-structural cargo bulkhead. In its transmission to Mauritius the aircraft stated that it was already established in an emergency descent to flight level (FL) 140. Some thirty four seconds after the bell had sounded, the captain requested the flight engineer to read the appropriate check list. Although he did not specify which check list should be used, it is overwhelmingly probable that it was the Main Deck Cargo Fire/Smoke : Mixed Passenger and Cargo check list.

2.19 The first action on this check list requires all cockpit crew to don oxygen masks and select one hundred percent oxygen on the regulators. The cockpit crew should have remained on oxygen until the fire was extinguished and any smoke had been evacuated. If there was smoke present on the flight deck, the crew should have donned smoke goggles. If there was no smoke apparent on the flight deck it is possible that the cockpit crew, consisting of the captain, co-pilot and flight engineer, removed their oxygen masks after reaching FL 140 (which would have been contrary to their training), or selected the "Normal" position on their oxygen regulators.

Under normal circumstances it would be probable that the extra flight crew members, i.e. the third pilot and the second flight engineer, would have been resting in the special crew rest area. However, the evidence of Captain , who became familiar with the voices of some of the crew, indicates that the senior flight engineer (Joe) was in the jump seat behind the captain, and that the other flight engineer was in the flight engineer's seat on the starboard side of the cockpit. When the alarm sounded, it is probable that the extra pilot would have been sent back together with the second flight engineer, with Joe and the co-pilot remaining on the flight deck with the captain. It would have been more likely that the captain elected to send a flight engineer and/or pilot aft rather than leaving the situation to the evaluation of a member of the cabin crew.

2.20 Only sixty five seconds after the fire bell had sounded, the cabin intercom chime sounded again. It is considered that this was a further attempt by a cabin attendant to contact the flight deck. On the probabilities it would not have been the third pilot or the second flight engineer sounding the intercom chime, because they would not have had time to go initially to the cockpit to receive instructions from the captain, then proceed to the aft bulkhead adjacent to the main cargo area, then enter the cargo hold in order to evaluate the situation, and then only report to the captain on the intercom.

2.21 The CVR record does not contain any further reference to the check list. From the fragmentary evidence available it is clear that electrical supply problems were occupying the attention of the flight deck crew. It has been estimated by the Operator that a possible total of eighty circuit breakers, of which fifty eight were located in the cockpit, could have been "tripped" as a result of the fire damage to electrical circuits in the main deck cargo area. This is borne out by the VHF RTF conversations with Mauritius Air Traffic Control, during the course of which the comment was made from the flight deck "We have lost a lot of electrics, we haven't got anything on the ... aircraft now". This transmission at 23:51:08 followed the aircraft's affirmative response at 23:50:00 to the question by the Air Traffic Controller on whether or not they wanted a full emergency declared.

While the captain did not send a "Mayday" call, there is no doubt that he considered the situation to be extremely grave. There is a natural reluctance on the part of professional pilots to declare a "Mayday" except as a last resort.

2.22 At 23:52:40 an estimated time of arrival (ETA) at Mauritius was given as 00:30, i.e. some thirty eight minutes ahead. This was a fairly accurate prediction. Some ten minutes later, however, at 00:02:43 the aircraft gave a distance out from Mauritius of sixty five nautical miles. This figure could not have been accurate or derived from a DME as the aircraft at that time would have been one hundred and sixty nautical miles from Mauritius and possibly below the DME radio horizon. The most likely explanation would be that the sixty five mile figure was the distance to run indicated by the inertial navigation system (INS), which could have been operating off its own internal battery power, in the absence of the main bus electrical power, had this been lost. In the opinion of both the Manufacturer and the Operator, the circumstances were not such as to have caused the loss of the essential AC and DC power on the aircraft.

Sixty five nautical miles was actually the distance to the next way-point, Xagal.

The fact that the aircraft as yet had no DME reading, but was in VHF contact with Mauritius, could be explained either by loss of power to the DME or by the difference in altitude of the antenna for the two different facilities. The VHF RTF antennae were located some two thousand feet above sea level, while the DME aerial was sited virtually at sea level.

2.23 At 00:02:50 Mauritius cleared the aircraft to FL 50; this instruction was acknowledged. The Board believes that the aircraft would have started a descent immediately from FL 140, had it been at that altitude. This was estimated to be some three minutes before impact with the water. A descent under control to FL 50 in three minutes would by itself have required a rate of descent of some three thousand feet per minute, a fairly high rate under normal circumstances. The actual descent from FL 140 to the water in three minutes would have been much more rapid.

2.24 After the Mauritius weather was copied at 00:03:00, some four minutes before impact with the water, there was according to the ATC tape a noticeable reduction in the tension on the flight deck. The impression is that the crew felt that the situation was now under control and that a safe landing at Mauritius was possible. This impression might appear to be supported by the last few contacts with the aircraft which were almost normal, concerning the runway to be used and reclearance down to FL 50. The last transmission from the captain was a relatively relaxed "Kay" in response to the ATC indication to report approaching FL 50. Some three minutes later the aircraft crashed into the sea one hundred and thirty four nautical miles North-east of Mauritius. Notwithstanding these inferences of a greatly relieved crew, the basic anxiety generated by the situation must still have been felt. A possible sequence of events in such a context would be an over-rapid descent developing while the crew were concentrating on their problem, with the downward inertia forces overcoming any attempts to pull out and the aircraft crashing into the sea in a tail-down attitude, "bouncing" and tumbling and even breaking up into two main portions. Such a scenario could account for the finding of the manufacturers of the engines that the wings sliced into the water at an angle of 90°. That would have been in a secondary or even subsequent impact with the sea.

Because of the presence of cloudy conditions at FL 50, the captain rightly decided to use runway 14 at Plaisance Airport, which would have involved alignment with the ILS localizer approximately on the reciprocal of his approach to the Airport, rather than trying to save time by coming straight in on runway 32. The indications are that at that time the captain considered the aircraft to be under control. Even if at that stage the captain was under some degree of euphoria through carbon monoxide intoxication, his responses were logical and consistent. That supports the inference that he believed that the aircraft could be landed at Plaisance. It would follow from this that the situation in the aircraft must have deteriorated rapidly after the captain's last acknowledgement at 00:04:02. This is the conclusion of the two senior and experienced 747 pilots who testified before the Board, and it is to some extent confirmed by the absence of any further message from the aircraft. If the aircraft had broken up, there would have been little or no opportunity of transmitting an explanation of what was happening. The same applies if the crew had, without realising what was happening to them, been overcome by carbon monoxide and carbon dioxide intoxication. However, if the aircraft had been difficult to control, it is possible that a message would have been transmitted by the pilot who was not handling the aircraft. As earlier indicated, the reasons for the rapid loss of control can only be speculated upon.

In the aforegoing analysis of the actions of the crew, there is no indication of any culpable failure of judgment, or competence or appropriate response.

2.25 The inability of the Board, for want of adequate evidence, to arrive at a precise finding on what must have occurred after the fire broke out, does not mean that this Inquiry has been sterile. On the contrary, sufficient evidence has been recovered to enable the Board to determine that the fire broke out in the forward pallet on the right side, the circumstances being such that a similar fire could occur again in another aircraft; that the fire got out of control, and generated consequences, either by way of damage to the aircraft, or by way of loss of control of the aircraft, or by way of incapacity (which term includes distraction) of the crew, which caused the aircraft to crash into the sea. On these firm bases, the Board is able to make recommendations of a practical nature which are aimed at ensuring that such a situation will not happen again.

3. The USA Federal Aviation Administration's Response to the Helderberg Accident and the Board's Approach

3.1 The Background

3.1.1 The Board's attention has been directed to documentation emanating from IFALPA's Dangerous Goods Committee in June 1987, and to certain other memoranda from pilots' organizations in which it was contended that the use of Class B cargo compartments could be hazardous. Those contentions were not generally accepted, but it is no part of this Board's functions to comment on those issues in the light of knowledge and experience at that time.

In over 20 years of operations by Combi aircraft the Helderberg accident is the first in-flight fire which resulted in the loss of the aircraft. As a direct result of the accident, the FAA undertook an in-depth review of the adequacy of existing regulations, policies and procedures pertaining to the certification of main deck Class B cargo compartments with volumes exceeding 200 cu ft. Class B cargo compartments have been in use in transport aircraft for approximately 40 years. Over the years, however, the size of the compartments and the size of the cargo packages have increased substantially. The Helderberg accident has focussed attention on the fact that, although the size of the compartments and of the cargo packages have been increased, the criteria for certification of Class B cargo compartments have remained virtually the same and are inadequate. The Helderberg accident has established further that even compliance with existing certification criteria will not always prevent the development of an uncontrolled cargo fire which could result in system and/or structural damage and/or crew incapacitation, which in turn could lead to loss of the aircraft.

3.1.2. The certification criteria for Class B cargo compartments are based upon the assumptions of timely fire detection, fire location identification and manual fire suppression and extinguishment by a single crew member. For type certification, the FAA criteria consider only the required minimum flight crew, i.e. two pilots and a flight engineer. Therefore, the flight engineer was the crew member expected to extinguish the fire (although in practice use could be made of a cabin crew member). Those criteria clearly are no longer adequate since the assumptions have been proved by the Helderberg accident to be invalid. In Class C cargo compartments, by contrast, cargo is not accessible by a crew member. A Class C cargo compartment is self-contained and is equipped with cargo liners for containment of any fire, control of ventilation and drafts and fire detection and suppression systems to control and extinguish the fire. It is significant that there is no known loss of aircraft due to fire in a Class C cargo compartment.

3.1.3. While the Helderberg accident is the only loss of a Combi aircraft due to a fire in a main deck Class B cargo compartment, it is beyond question that there can be others unless effective steps are taken by the appropriate licensing authorities to remedy the position, e.g. by prohibiting the transportation of cargo in a Class B cargo compartment.

3.2 The Inadequacies of Class B Cargo Compartments in Combi Aircraft

3.2.1 The existing certification standards with respect to Class B cargo compartments specify that a fire must be detected rapidly and that, following detection, a crew member must be able, within five minutes, to leave his or her station, don protective equipment, enter the cargo compartment, locate the fire extinguisher, attach an extension nozzle (applicator or wand) to it, locate the origin of the fire and extinguish it.

The type certification standard in effect for the B-747-244 Combi aircraft required that smoke detection be obtained within five minutes of fire initiation. During one of the certification tests, detection was received within 27 seconds. The flight engineer was able to configure the aircraft in accordance with the emergency procedure, then walk to the cargo compartment access door, don his protective breathing equipment, enter the compartment, open thé cargo net access, pick up the portable fire extinguisher, connect the extension nozzle, and walk to the middle of the compartment in three minutes, thirty seconds after the initiation of the fire simulation in the compartment. In practice, however, conditions in the cargo hold could be more difficult because of factors, such as poor visibility in smoke, bulky and high pallets, delay in finding the source of the fire, and the aircraft being in a steep nose-down attitude.

Prior to the Helderberg accident, inadequate data was available to support the effectiveness of the sequence of fire detection, suppression and exinguishment techniques within the prescribed time in the face of an actual in-flight fire in a main deck Class B cargo compartment. The effectiveness of these fire suppression techniques relies essentially on rapid detection and extinguishment of the fire by a crew member. The inadequacy of the detection, suppression and extinguishment systems relied on when this accident occurred is demonstrated in the evidence, and in what the Board observed during its inspection of a simulated fire-fighting attempt.

3.2.2 Both the detection and suppression techniques relied upon can no longer be accepted as adequate. The smoke detectors in a Class B cargo compartment are located in the crown of the compartment, i.e., on the ceiling, and are ineffective to detect smoke which exits a pallet of cargo at the floor level until sufficient heat has been generated to force the smoke to the crown of the compartment where the smoke detectors will then activate the warning bell in the cockpit. It is true that in the limited testing which was conducted in the B-747 Combi, and which is referred to in section 1.17.6 ', a significant portion of the cold smoke rose towards the ceiling. That result must, however, depend on the conditions in the cargo compartment at the time. Thus, only after sufficient smoke has exited a pallet and the thermal energy of that smoke has exceeded the force of the downward air current within the compartment would the smoke rise to the smoke detectors. By this time, that is before the alarm bell has been activated by smoke detectors, the material in the pallet could be pre-heated to a point where a fire has developed and grown rapidly. The members of the Board have witnessed a demonstration of the fire suppression and extinguishment techniques in a Class B cargo compartment, from which it is readily apparent that, even under ideal circumstances, the ability of a crew member to locate and fight a fire in the compartment successfully is severely limited. At worst, the task could be impossible. After entering the compartment, donning the protective equipment and preparing the extinguisher and wand, a crew member is required first to find the source of the fire. The ability to do so is rendered extremely difficult if sufficient smoke already has been generated to reduce the visibility within the compartment, and/or if there is no or reduced illumination, and/or extreme heat, and/or difficulty in passing between pallets or in passing pallets on the outboard side, and/or if the fire origin is located in the internal portion of a cargo pallet. These difficulties would be increased if the aircraft were to be making an emergency descent at an angle of the order of 10° (as occurred in the case of the Helderberg). The crew member entering the cargo hold would then have to move "uphill". Additionally, the fire extinguishing agent available to fight the fire lasts for only twelve seconds and if the extinguisher is used to its limit without extinguishing the fire, the crew member is left with no other specific means to suppress the fire and ensure the safety of the flight. In this connection a fire extinguisher normally stowed adjacent to the No 2 right hand door in the passenger cabin was recovered from the sea. It had not been discharged and there were molten drops of nylon adhering to it which could only have come from material in the cargo hold. The probable inference is that it had been taken to the cargo compartment (which would have been standard procedure) but had not been used because the crew member concerned had been overcome, or because catastrophe had occurred before it could be used.

It is significant that, in tests conducted by SA Airways on March 1st, 1988, at the request of the Board, with a Combi aircraft stationary on the ground, and no passengers or obstacles, a fully trained cabin attendant took 5 minutes 15 seconds to follow the prescribed routine and to be ready to locate the fire and commence fire-fighting. Even though the pallets were located within the prescribed envelope, on several occasions the cabin attendant's portable oxygen cylinder snagged in cargo netting used to restrain the cargo on the pallets.

3.3 The National Transportation Safety Board Safety Recommendation

3.3.1 As a result of the information available from the preliminary investigation of the Helderberg accident, the National Transportation Safety Board (NTSB), on May 16th 1988, issued Safety Recommendation A-88-61 through 63 recommending that the FAA :

1. Require that all cargo carried in Class B cargo compartments of United States registered aircraft be carried in fire resistant containers until fire detection and suppression methods for Class B cargo compartment fires are further evaluated and revised as necessary.

2. Conduct research to establish the fire detection and suppression methods necessary to protect transport aircraft from catastrophic fires in Class B cargo compartments.

3. Establish fire resistant requirements for the ceiling and sidewall liners in Class B cargo compartments that equal or exceed the requirements for Class C and Class D cargo

compartments as set forth in the applicable FARs.

The NTSB Safety Recommendation of May 16, 1988 is appended to this Report as Appendix E Volume 2

3.4 <u>The Evaluation of Certification Criteria and Findings of the FAA Review Team</u>

3.4.1 The results of the FAA's review of existing regulations, policies and procedures for certification of main deck Class B cargo compartments are contained in a report entitled "Evaluation of Transport Airplane Main Deck Cargo Compartment Fire Protection Certification Procedures". A copy of this report, dated June 1 1988, is appended hereto as Appendix F Volume 2

. The FAA Review Team met with representatives of The Boeing Company, McDonnell Douglas Corporation, Alaska Airlines, Federal Express and the Los Angeles Fire Department.

The report concluded that aircraft equipped with main deck Class B cargo compartments complying with existing regulations "do not provide an acceptable level of safety in terms of smoke and fire protection".

3.4.2 The significant findings and conclusions of the FAA Review Team have already been summarized above in paragraph 1.16.2 , For convenience they are set out here, viz :-

" 3.4.2.1 Existing rules, policies and procedures being applied to the certification of Class B cargo or baggage compartments in terms of smoke and fire protection are inadequate.

3.4.2.2 The use of pallets to carry cargo in Class B compartments is no longer acceptable.

3.4.2.3 While entry into the cargo compartment is available, not all cargo is accessible.

3.4.2.4 It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

a) The reliance on crew members to fight a cargo fire must be discontinued.

b) The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

c) The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

3.4.2.5. Most existing transport airplane smoke or fire detection systems ... are incapable of giving timely warning."

These findings and conclusions were extensively criticised, mainly by members of the air transportation industry. The Board of Inquiry has given full consideration to these criticisms, but, upon the basis of the results of the investigation of the Helderberg accident and the evidence received during the Public Inquiry, the Board unanimously agrees with the foregoing findings and conclusions of the FAA Review Team.

3.5 The FAA Notice of Proposed Rule Making

3.5.1 Following the issuance of the report of the FAA Review Team on June 1, 1988, concluding that, notwithstanding compliance with existing regulations, aircraft with main deck Class B cargo compartments - Combi aircraft - "do not provide an acceptable level of safety in terms of smoke and fire protection", the FAA issued a Notice of Proposed Rule Making (NPRM) on July 8, 1988, which proposed a new Airworthiness Directive (AD) to require design changes in existing aircraft either to modify Class B cargo compartments to the Class C configuration or to require the use of flame penetration-resistant cargo containers in Class B cargo compartments. A copy of the NPRM is appended to this Report as Appendix G, Volume 2

3.5.2 The NPRM and proposed AD were the direct outgrowth of the Helderberg accident and subsequent review by the FAA of existing certification standards for Class B cargo compartments. The AD, as initially proposed, would have required affected operators :

" To minimize the hazard associated with a main deck Class B cargo compartment fire, ... (by accomplishing) the following :

A Within 180 days after the effective date of this AD, or prior to carrying cargo in a main deck Class B cargo compartment, whichever occurs later, accomplish either of the following :

1. Modify all main deck Class B cargo compartments of volume exceeding 200 cu. ft. to comply with the design standards specified in the FAR 25.857(c) for a Class C compartment. In addition, the ceiling and sidewall liner panels must meet ..." the current FAR requirements.

" 2. Modify all main deck Class B cargo compartments to require that ..." a placard be installed in conspicuous locations that cargo carried in the compartment must be loaded in an approved flame penetration-resistant container meeting the requirements of currently effective FARs.

The FAA recognized in the NPRM that alternative means of compliance, or adjustment of the 180-day period, which provided an acceptable level of safety, might be used when approved by the FAA. The NPRM invited comments from interested parties by not later than November 7th 1988.

3.5.3 Extensive comments were received by the FAA from various industry interests in response to the NPRM.

Concerns expressed by operators generally were based on the contention that Class B cargo holds had not yet been shown to be unsafe. There were also representations relating to the very high capital cost of retrofitting of Class C cargo compartments in place of Class B, the increased operating costs and consequent jeopardy to certain highly economic and useful cargo operations with Combi aircraft, and the very short time allowed for the introduction of the proposed remedial measures. The operators also expressed the view, generally, that existing fire detection, suppression and extinguishment procedures, with some improvements, would be adequate to prevent a recurrence of a Helderberg type accident. Pilot associations, generally, urged a complete ban on Class B cargo compartments in Combi aircraft.

3.6 <u>The Final Airworthiness Directive issued by the FAA</u>

3.6.1 The FAA issued a final AD on August 10, 1989, to be effective September 25, 1989. The FAA recently revised the effective date of the AD to May 3, 1990. The AD requires certain operational and equipment changes and design modifications to maximize fire detection and control. The preamble to the AD recites that it is prompted by the loss of the Helderberg which apparently developed a major fire in the main deck cargo compartment. The FAA determined that this condition, "if not corrected, could result in an uncontrolled cargo fire that could cause system and structural damage leading to the loss of the airplane".

3.6.2 In issuing the AD, the FAA again emphasized that under existing regulations aircraft equipped with main deck Class B cargo compartments "do not provide an acceptable level of safety in terms of smoke and fire protection" for the reasons that :

" 1. The existing rules, policies, and procedures being applied to the certification of Class B Cargo or baggage compartments in terms of smoke and fire protection, are inadequate.

2. While entry into the cargo compartment is available, not all cargo is accessible.

3. It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

4. The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

5. The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

6. Most existing transport airline smoke and fire detections systems ... are incapable of giving timely warning.

7. Current designs do not provide adequate means to monitor conditions in the cargo compartment after fire warning and fire-fighting procedures have been implemented.

8. Cargo compartment lining does not provide adequate fire containment.

9. Current designs do not provide a means to shut off ventilation air into the cargo compartment to limit oxygen to the fire."

3.6.3 After further consideration of the AD proposed in the NPRM, in the light of the extensive comments received from industry interests, the FAA has determined that the following design changes and procedures are appropriate to achieve major fire safety improvements for Class B cargo compartments:

" 1. Provide a smoke or fire detection system that meets FAR 25.858 (Amdt. 25-54), FAR 25.1309, and also provide an aural and visual warning to the station assigned to individuals trained to fight cargo fires.

2. Require a compartment fire extinguishing system that provides an extinguishant concentration to knock down a fire and suppress it, allowing time for a trained individual to find and extinguish a fire, or to verify that the fire is extinguished; and provide a means of shut off ventilation system air inflow to the compartment from the flight deck.

3. Require individuals trained to fight cargo fires.

4. Provide a cargo compartment liner that meets FAR 25.855 (Amdt. 25-60).

5. Provide two-way communication means between the flight deck, the station assigned to the trained individual, and the interior of the cargo compartment.

6. Provide improved illumination within the cargo compartment.

7. Require cargo loading envelopes and limitations to provide access to all the cargo for fighting a fire.

8. Provide a cargo compartment temperature indication system to the flight deck and designated station."

3.6.4 In addition to the foregoing design changes and procedures, the FAA has determined that the following features are necessary to ensure that an acceptable level of safety is attained :

" 1. Additional portable fire extinguishers appropriately located for use in the compartment and a means to effectively discharge portable fire extinguishers into each container or into each pallet that is covered. This will provide sufficient extinguishing agent and will ensure a means to properly use that agent in containers or covered pallets.

2. Protective garments and protective breathing equipment for individuals fighting a cargo fire. This will provide protection for the

individual assigned to control a cargo compartment fire.

3. Fire thermal protective covers for cockpit voice and flight data recorders, windows, safety devices, wiring, flight controls (unless it can be shown that a fire could not result in jamming or loss of affected control systems), and other equipment necessary for safe flight and landing that is located within the compartment. This is necessary to ensure that items which are not critical for continued safe flight, but are essential for the overall safe operation of the airplane, are not damaged in the event of a cargo compartment fire."

3.6.5 The final AD adopted by the FAA was revised from the NPRM proposed AD to include the accomplishment of the design changes and procedures set forth above as an alternative means of compliance. The FAA has determined that if the foregoing design changes and procedures are incorporated, "they will adequately address the unsafe condition."

3.6.6 The position of the FAA on the revised approach to this acknowledged "unsafe condition" is stated as follows :

> " It is not the FAA's intent to deny the use of pallets in 'Combi' aircraft. The issue is the fire control and containment capability with cargo loaded on pallets. With the present practice, in which the cargo is loaded on pallets, a deep-seated fire could develop and result in the compartment being filled with dense smoke. By revising the final rule, as described above, the FAA has addressed these concerns by requiring a means to discharge portable extinguishers into covered pallets, improved access, lighting, and protective equipment for the individual fighting the fire."

3.6.7 The final AD, effective May 3, 1990, a copy of which is appended to this Report as Appendix H Volume 2 , provides for alternative means of compliance "to minimize the hazard associated with a main deck Class B cargo compartment fire". The alternative means of compliance, in summary, are :

3.6.7.1 PARAGRAPH A. Within one year after the effective date of the AD (May 3, 1990) or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, incorporate the manual revisions, procedures, systems and equipment set forth in paragraph A of the AD. See Appendix H Volume 2

3.6.7.2 PARAGRAPH B. Alternatively, within three years after the effective date of the AD (May 3, 1990), or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, either modify the Class B cargo compartment to comply with the requirements for a Class C cargo compartment (paragraph B.1) or modify all main deck Class B cargo compartments to require that a placard be installed in the compartment, that cargo carried in the cargo compartment "must be loaded in an approved flame penetration-resistant container ... with ceiling and sidewall liners and floor panels" meeting the requirements of applicable FARs (paragraph B.2) or in addition to the requirements of paragraph A, modify Class B cargo compartments and associated systems to include the systems, means and equipment as set forth in paragraph B.3 of the AD. See Appendix H Volume 2

3.6.7.3 The AD provides that if the requirements of either paragraph B.1 <u>or</u> B.2 are accomplished within 1 year after the effective date of the AD (May 3, 1990), compliance with paragraph A of the AD is unnecessary. The AD thus gives the industry the option of converting existing main deck Class B cargo compartments to Class C standards <u>or</u> restricting the carriage of cargo in main deck Class B cargo compartments to approved flame penetration-resistant containers with ceiling and sidewall liners and floor panels meeting the requirements of applicable FARs. Alternatively, if Class B cargo compartments are not upgraded to Class C standards or restricted to cargo carried in approved containers, substantial improvements in fire detection, suppression, design and procedures for extinguishment and protection must be adopted.

3.6.8 It is obvious that the FAA has given serious and in-depth consideration to the acknowledged unsafe condition posed by a fire in a main deck Class B cargo compartment. There can be no qualification of the FAA determination that an unsafe condition presently exists with regard to Class B cargo compartments. The original NPRM was designed to address this unsafe condition by eliminating main deck Class B cargo compartments or restricting their use to flame penetration-resistant containers, with appropriate ceiling and sidewall liners and floor panels. The final AD modifies the original proposed AD by giving the aircraft operator the option of retaining main deck Class B cargo compartments by improving existing fire detection, suppression, extinguishment and protection facilities and procedures.

3.6.9 It is the unanimous view of this Board, however, upon the basis of the evidence presented during the course of the Public Inquiry as to the circumstances surrounding the loss of the Helderberg, that there is no acceptable compromise for the acknowledged unsafe condition of main deck Class B cargo compartments. Passenger and cargo should not be mixed on the same deck level of the aircraft in an adjacent compartment and in the same atmosphere under any circumstances. The licensing authorities throughout the world are urged to re-examine and re-assess whether there is any acceptable compromise to the outright prohibition of main deck Class B cargo compartments in passenger aircraft. The Board is of the view that in the light of present experience and knowledge the prohibition should remain if the acknowledged "unsafe condition" of Combi aircraft is to be eliminated.

3.6.10 The Helderberg accident has demonstrated that the procedures and regulations that heretofore were considered adequate can no longer be accepted. The circumstances of the Helderberg accident also have demonstrated that there is no acceptable compromise to the outright prohibition by the appropriate licensing authorities of the carriage of cargo and passengers on the same cabin floor level of Combi aircraft.

4. FINDINGS AND CONCLUSIONS

4.1 At the time of take-off from Chiang Kai Shek Airport, Taipei, the aircraft was serviceable, with no reported carried forward defects. It was correctly loaded and carried sufficient fuel.

4.2 The aircraft had current Certificates of Airworthiness and Fitness for Flight.

4.3 The cockpit and cabin crews were all properly licensed, experienced on the route and qualified to carry out the flight and had had an adequate rest period.

4.4 The aircraft was configured as a seven-pallet Combi with six pallets in place.

4.5 The flight proceeded normally until some nine hours after the aircraft had left Chiang Kai Shek Airport in Taipei, when an intense fire developed in the right-hand forward pallet (PR).

4.6 The substances involved in the combustion included plastic and cardboard packing materials, but the actual source of ignition cannot be determined.

4.7 It is virtually certain that there was no sabotage. There was no explosion in the aircraft, and the presence of a pressure or time activated incendiary device was extremely unlikely.

4.8 The fire generated considerable smoke, carbon monoxide and carbon dioxide, which penetrated to the passenger cabin and possibly to the cockpit.

4.9 The fire caused extensive heat damage to the fuselage structure, the insulation blankets and electric wiring in the main cargo deck area, including the wires serving the power supply to the cockpit voice recorder.

4.10 At the time of the accident, the aircraft, a Boeing 747-244B Combi, complied with the certification requirements of a Class B main deck cargo compartment, save that adequate flight tests do not appear to have been conducted in terms of FAR 25.855(e)(2) to show compliance with the requirements of FAR 25.857(b)(2) for Class B cargo compartments concerning the entry of hazardous quantities of smoke into compartments occupied by passengers. In the light of further experience since these requirements were formulated they can no longer be regarded as adequate from a safety point of view. The FAA has pointed out that "the configuration was shown during flight tests to exclude hazardous quantities of smoke from the occupied compartments using criteria for testing which had been developed from years of transport experience". In the Board's view, however, the effects of thermal expansion were not adequately demonstrated in the tests.

4.11 The fire/smoke detection systems in the Boeing 747-244B Combi main deck cargo compartment were inadequate. Although the evidence indicates that the fire/smoke detection systems functioned, the extent to which the fire developed and the fact that smoke penetrated the passenger cabin suggest that the fire was not discovered early enough to prevent these consequences.

4.12 The fire fighting facilities provided for the main deck cargo compartment were inadequate.

4.13 The aircraft crashed into the sea some three minutes after the last transmission from the captain, acknowledging clearance for a further descent to flight level 50.

4.14 The aircraft was not under control when it crashed into the sea.

4.15 The only possible causes for the loss of control were one or more of the following :

(a) pilot incapacity from carbon monoxide and carbon dioxide poisoning, and/or smoke inhalation, or disorientation *consequent on reduced cockpit* visibility in smoke, or pilot distraction;

(b) damage to the structure and/or to the control systems of the aircraft *directly or indirectly* caused by the fire.

4.16 Irrespective of which of these causes might have been operative in the crash itself, there is a strong possibility that the quantity of carbon monoxide and carbon dioxide released by the fire caused loss of consciousness in or the death of some, if not all, of the occupants before the aircraft crashed into the sea.

4.17 There was no connection between the accident and the omission of Station ZUR to communicate with the Helderberg at the pre-arranged time. Nor is there any significance in the fact that the ZUR tape covering that time was mislaid or wiped out by later use.

4.18 The Board agrees with and supports the findings and conclusions of the FAA Review Team in its Report of June 1st 1988 (Appendix F Volume 2).

4.19 Despite intensive investigation the Board was unable to find or conclude that fireworks or any other illegal cargo were carried in the aircraft.

5. CAUSAL FACTORS AND RESPONSIBILITY

5.1 The accident followed an uncontrolled fire in the forward right pallet on the main deck cargo compartment. The aircraft crashed into the sea at high speed following a loss of control consequent on the fire.

5.2 In terms of Section 12(1) of the Aviation Act, No 74 of 1962, as amended, the Board is required to determine not only the cause of, but also responsibility for, the accident (compare paragraph 3.1 of Annex 13). There is, however, no basis in the evidence from which the Board would be justified in assigning responsibility for the accident to any person or body, and, therefore, the Board is unable to do so.

6. RECOMMENDATIONS

6.1 The Combi type of configuration, with passengers and cargo on the same deck and provision for fire fighting on the cargo deck based on, inter alia, crew access to the seat of the fire and hand fire extinguishers to fight the fire, should be prohibited as creating an unacceptable risk to life and property, at least until such time as adequate provision is made to overcome the present shortcomings in fire detection, fire fighting equipment and fire fighting procedures.

6.2 For as long as Combi operations are permitted, effective fire detection and fire fighting systems, as laid down in the FAA AD No 89-18-12 R1 of August 10th 1989 (Appendix H Volume 2), should be strictly enforced. The recommendations in paragraph 6.1 and in this paragraph are designed to eliminate any risk to life and property emanating from a main deck cargo fire, whatever the source, *whereas the purpose of the FAA AD, though a step* in the same direction, is, as stated therein, "To minimize the hazard associated with a main deck Class B cargo compartment fire...".

6.3 Since it has by no means been established that the aircraft was carrying dangerous goods, it is not for the Board to comment on the various ICAO and IATA documents on the subject. See for example Annex 18, ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air - Doc. 9284 - AN/905; ICAO Dangerous Goods Training Programmes - Doc. 9375 - AN/913 Books 1 - 6; and IATA Dangerous Goods Regulations; and see also RSA Regulations for the Carriage in Aircraft of Dangerous Goods, 1986. Nevertheless, in the Board's view continuing vigilance and research are required to eliminate all possible sources of packaging and cargo ignition, whether from dangerous goods or otherwise. *Moreover, if Combi operations are to be permitted to* continue, consideration should be given to revising the categories of dangerous goods to distinguish between those made up into pallets and those loaded in approved flame penetration-resistant containers.

6.4 Cockpit Voice Recorders

(a) should retain flight deck communications and sounds for the last hour, and not be limited to 30 minutes only;

(b) should be fitted with a "hot mic" system, i.e. a system in which the microphones are connected to a recorder in a manner that ensures the recording of all cockpit sounds within the range of the microphones regardless of audio control panel selections;

(c) should be equipped with additional area microphones at the flight engineer's and supernumerary crew's station.

6.5 At least one pilot and the flight engineer should at all times use head-sets and boom microphones.

6.6 Both CVRs and DFDRs

(a) should be fire-protected in the aircraft, as should the wiring to the units;

(b) should where practicable have a back-up system of battery power in the event of failure of the primary power source;

(c) should be fitted with a pinger system in which a first pinger operates for 30 days and a second 30-day pinger only commences operating after the first pinger ceases to function;

NOTE: The suggestion that, on long transocean flights, the CVR and DFDR should be floatable, overlooks the fact that in a short time the recorders may drift away over long distances from the site of the aircraft wreckage.

6.7 The Boeing 747 emergency check lists for "Upper and Main Deck Smoke Evacuation - Mixed Passengers and Cargo" and for "Main Deck Cargo Fire/Smoke - Mixed Passengers and Cargo" respectively require to be integrated. No provision appears to be made for the situation in which there *is an uncontrolled fire in the main* deck cargo hold and a smoke problem in the passenger cabin and/or cockpit. The matter to be cleared up is whether the crew should follow the smoke evacuation check list if the fire is still burning.

6.8 *Means should be established by ICAO by which assistance* in respect of underwater location searches for DFDRs and CVRs can be accelerated. The existence of standard procedures and agreements in respect of necessary actions and the funding thereof could be of great benefit and should be encouraged.

ICAO Note.— The foreword, parts of the synopsis, 1.5, 1.12.2, 1.16, 1.17 and the appendices were not reproduced. Names of personnel were deleted.

ICAO Ref.: 298/87

No. 5

Boeing 707-3B5C, HL-7406, accident in the Andaman Sea between Urdis and Tavoy, Burma, on 29 November 1987. Report released by the Department of Civil Aviation, Ministry of Transport and Communications, Burma.

1. Factual Information.

1.1. History of the flight.

Korean Airlines Boeing 707-3B5C Registration No. HL-7406 flight number KE 858. Journey Baghdad to Seoul via intermediate stops at Abu-Dhabi and Bangkok. Departure Baghdad 2042 UTC on 28th November 1987, with 99 passengers and 12 crew, arrived Abu-Dhabi at 2240 UTC on the same day. On board were Mr. Hachiya Shinichi and Miss Hachiya Mayumi who left the aircraft along with other disembarking passengers at Abu-Dhabi . These two passengers were seated in seat Nos.B and C of seat row 7 in the economy class, forward passenger cabin. KE 858 departed Abu-Dhabi at 0001 UTC on the 29th November 1987 bound for Bangkok with 104 passengers and 11 crew. The KE 858 flight plan route was along airways R-219E,R-468 and R-68 via reporting points which included Muscat, Bombay and Vishakapatnam.Upon entry into Rangoon FIR over TOLIS at 0431 UTC at flight level 370 KE 858 reported position to Rangoon ACC on 10066 KHZ, giving its next position estimate at URDIS to be 0459 UTC.

At 0500 UTC the controller at Rangoon ACC noting that KE 858 did not report position as expected, initiated a call on 127.1 MHZ to which KE 858 replied that it estimated URDIS at 0501 UTC and at the same time giving the spot wind of 140°/15-20 Kts and temperature at flight level 370 to be minus 46° centigrade and it's estimate time for TAVOY to be 0522 UTC. This was the last message received from KE 858.

Due failure to report by KE 858 over TAVOY at the expected time, Rangoon ACC communicated with Bangkok ACC to find out if the KE 858 were in contact with them on any other frequency; the answer was negative.Rangoon,then,requested and obtained from Abu-Dhabi the flight plan details of the aircraft.

Having determined that the aircraft failed to arrive either at it's destination or flight planned alternate, Rangoon ACC alerted Bangkok, Kuala Lumpur and Singapore of the KE 858 situation and continued action appropriate to the phase of emergency.

Search and Rescue operations were initiated immediately when the calculated aircraft's endurance was exhausted and no report of its arrival was received from other stations.

Search and Rescue aircraft and vessels were deployed to search along the route from it's last reported position all the way to the RGN/BKK FIR border and in all areas of probability ; Notices to Mariners were issued in respect of the missing aircraft and all fishing vessels and other local craft within reach were alerted to be on the look out. Although the main wreckage was not found,partly damaged and partially submerged life raft floating in the Andaman Sea approximately 74 miles North West of TAVOY was picked up by a local schooner enroute Mergui to Rangoon on the 13th December,1987.This life raft was handed over to Korean Authorities for investigation and was later identified to be the 25-man life raft installed in the No.2 stowage compartment in the forward passenger cabin of HL- 7406.There were no survivors.

According to the eyewitnesses who were fishing in the sea North West of Tavoy, they had seen a bright flash in the sky followed by a trail of smoke falling into the sea and black smoke rising from the spot some distance far away to the South East from his position at about the time of KE 858 disappearance.

1.2 Injuries to persons.-

Total persons on board 115.

Injuries	Crew	Passengers	Others
Fatal	11	104	-
Serious	-	-	-
Minor / None	-	-	

1.3 Damage to aircraft.

The aircraft was assumed to be destroyed.Apart from one unused life raft and part of a folding meal table from the passenger seat back which were retrieved from the Andaman Sea,the main wreckage of aircraft was not found.

1.4 Other damage.

None.

1.5 Personnel Information.

There were (3) flight crew, (8) cabin crew and (104) passengers on board the aircraft. Out of (104) passengers, (9) were Korean Airlines Dead Heading crew.

Duty flight crew status.

Name	Captain	First Officer	Flt, Engineer
Pilot and Flight Engineer Licence No. (Issue date)	ART No. 287 (14.5.74)	ART No. 667 (8.4.87)	No. 262 (8.10.81)
Age of Flight Crew	58	36	32
Type rating	B-707 (11.10.79) F-27 (28.3.74)	B-707 (20.7.87)	B-707 (8.7.82)
Medical Certificate	No. 15012 (Valid until 31.3.88)	No. 14670 (Valid until 30.6.88)	No. 14183 (Valid until 31.1.88)
Last proficiency check date	18.6.87	13.11.87	25.6.87
Total flying Hrs. Flying Hrs, B-707	11,161:05 5,416:33	3,882:47 134:14	3,083:12 2,765:21
Flying hours last 30 days before the accident.	143:42	78:48	118:44

The flight crew were properly certificated and qualified for the flight.

.6 Aircraft information.

Korean Airlines Flight No. KE 858 aircraft particulars:-

Aircraft type	-Boeing 707 3B5C
Registration	-HL-7406.
Aircraft Serial No.	-20522.
Date of manufacture	-21.6.1971

Date of first flight by KAL	-4.8.1971
Certificate of Airworthiness	-No.8706,valid until 11.2.1988
Date of C of A last renewal	- 12.2.1987
Total airframe hours	- 36,047:49
Total number of landings	- 19,941
Engine type	- Four P & WA JT 3D - 3B

Aircraft maintenance history.

Four Pratt and Whitney JT3D - 3B engines.

No	S/N	Date installed	TBO(EHM)	Total time	Total cycles	Date of last+EHM	TSO (TSEHM)
1	P644017	13-7-83	10,000	51,553	27,0375	18-2-87	430
2	P644022	28-7-87	10,000	52,280	15,352	27-7-87	365
3	P668029	3-10-87	10,000	42,105	15,684	7-4-87	657
4	P645227	13-1-87	10,000	47,849	21,777	17-3-87	5754

The aircraft was maintained in accordance with the maintenance schedule approved by Korean Civil Aviation Bureau(KCAB).

The last routine maintenance is as follows :-

Last "A"	- 26 Nov. 1987.
Last "C"	- 26 Nov. 1987.
Last SSI	- 2 April 1986
Last "D"check (Overhaul)	- 21 Dec 1984
Last maintenance release issued	- 29 Nov 1987
Hours since Last "C" check	-977 :49.
Hours since Last "D" check	-5754:49

Previous accident involving structural damage :

This aircraft had made two nose up landings before this accident:-

1st. Nose up landing :13 Sep. 1977.

2nd. Nose up landing : 2 Sep. 1987.

After these nose up landings, repairs and NDT inspections were carried out by KAL in accordance with the overhaul manual and the engineering order approved by the Boeing Co. and inspected by KCAB.

1.7. Meteorological Information.

The prevailing weather conditions at flight level 370 on 29th November, 1987, over Andaman Sea was reported as: Cirrus cloud of 1-2/8, wind 120/20 Kts, temperature-44° C and visibility was good. A seasonal depression was moving East to West at the time of accident but was assessed as not hazardous to the flight safety of KE 858.

1.8. Aids to Navigation.

VOR/DME and NDB at Rangoon was operating normal. No radar facilities at Rangoon. Navigational Aids at TAVOY was not on the air at the time of accident as it operates on request.

1.9. Communications.

There were no communications difficulties between Rangoon Area Control Centre and KE 858. Radio Contact between Rangoon ACC and KE 858 was well established on enroute HF frequency of 10066 KHZ over reporting point TOLIS and again over URDIS on VHF 127.1 MHZ.

1.10. Aerodrome and Ground Facilities.

Not relevant to accident.

1.11. Flight Recorders.

A Flight Data recorder serial No.3818 (FA 542) and a Cockpit Voice Recorder serial No.327 (AV 557B) were installed in the aircraft HL-7046 but they were not recovered from the sea.

1.12. Wreckage and impact Information.

Two crew members, from a fishing boat of 54 feet by 14 feet, who happened to be at a position around lattitude 15° 01′ North-Longitude 96° 54′ East at the time of the accident, had reported to have witnessed a bright flash in the sky followed by a smoke trail falling into the sea and black smoke rising from this splash spot some distance far away from them and approximately in the South East direction. The approximate position of splash spot was determined to be lattitude 14° 33′ North and Longitude 97° 23′ East. A 25 men capacity life raft, in a partly damaged and partially submerged condition, was retrieved from the Andaman Sea (14) days after the accident at approximate position of

Lattitude 14° 51' North and Longitude 97 16' East. Damage to the life raft was assessed by the Korean Authorities to have been caused by an explosive blast.

1.13. Medical and pathological information.

It is assumed that there were no survivors, as no bodies were recovered from the Andaman Sea.

1.14. Fire.

The eye withnesses, who were fishing in the sea about 96 miles North West Tavoy at the time of accident, had reported to have seen a bright flash in the sky followed by a trail of smoke falling into the sea and black smoke rising from the splash spot approximately in the South East direction far away from their position. Witnesses being simple fishermen with no knowledge of aviation did not realise the gravity of the situation and being in a small country craft not equipped with two-way radio, they were neither able to report nor query from shore of what they had seen. This information was brought to the attention of the local authorities of their home port only after their return to shore two weeks later.

1.15. Survival aspects.

Inspite of intensive search, neither survivors nor bodies were found. It was a non-survivable accident. It was possible that the servere blast, explosive decompression of the cabin and fire could have caused instant death to the passengers and the crew. The aircraft was equipped with an emergency locator beacon(ELB), type Rescue-99 but no signals were received from it.

2. Analysis

2.1. KE 858 estimated time over reporting point URDIS in Burma FIR was late by two minutes. This could be due to prevailing wind conditions of 140° /20 Kts encountered at FL 370 over the Andaman Sea.

2.2. The Accident Investigation Commission, based on the available information, determined the probable splash point was at lattitude 14°33' North and longitude 97°23' East in the Andaman Sea about 60 nautical miles North West of TAVOY.

2.3. Korean Authorities, suspecting sabotage after the aircraft became missing, started checking on passengers who disembarked at Abu-Dhabi and traced the suspects Mr.Hachiya Shinichi and Miss Hachiya Mayumi to Bahrain where they were apprehended while going through exit formalities at the airport. It was reported that they were found to be holding false Japanese Bassports. While being held for interrogation, both committed suicide by taking poison capsules hidden in the cigarettes and Mr.Hachiya Shinichi died.Miss Hachiya Mayumi who survived the attempt was extradited to Korea.

It was reported that in her testimony to the Korean Authorities, Miss Hachiya Mayumi recounted their action which led to the cause of destruction of Korean Airlines Boeing 707 aircraft registration No.HL-7406 of flight No. KE 858. During the period while they were awaiting embarkation at Baghdad Airport,composition C 4 type explosive hidden in a battery operated portable transistor radio which was used as a timing device was activated to go off (9) hours later. Together with this transistor radio, a liquor bottle containing liquid explosive (type PLX) was taken on board and placed in the overhead baggage rack above seat row No. 7 in the forward cabin section of the economy class compartment where they were seated. These timed explosives were left in that place when they disembarked at Abu-Dhabi.

It was reported that Mr. Hachiya Shinichi and Miss Hachiya Mayumi were found to be Mr. Kim Sung -il and Miss Kim Hyon-hui of Korean origin.

2.4. According to laboratory report released by the Korean Authorities, explosive power of C 4 composition was 1.34 time that of T.N.T.

2.5. The Commission determines that the probable cause of the accident was that the aircraft was destroyed by the explosion of time bomb planted in the passenger cabin, and due to severe blast of the bomb followed by explosive decompression of pressurised cabin and fire could have caused instant death to the passengers and the crew.

3. Conclusions

3.1. Findings

1. The aircraft was properly certificated and maintained in accordance with Civil Aviation Law and Korean Civil Aviation Bureau(KCAB) requirements.
2. The flight crew were properly certificated and qualified for the flight.
3. Loading and centre of gravity were in accordance with the company procedures and within the prescribed limits.
4. Adequate numbers of survival equipment were installed.
5. The radio and liquorbottle containing the hidden explosives were left in the overhead rack at number 7 seat row by two saboteurs disguised as passengers who disembarked at Abu-Dhabi airport.
6. Inflight explosion of time bomb (C 4 composition and PLX liquid explosives) detonated by the battery radio.
7. Laboratory test explosion of C 4 composition explosives by the Korean Authorities confirmed that explosive power of C 4 composition is 1.34 times that of T.N.T and capable of bursting the aircraft structure..
8. Prevailling weather at the time of accident was not a contributory factor.
9. No radio communication problem with KE 858 and Rangoon ACC. TAVOY VOR was not on the air at that time.
10. Aircraft was destroyed by the bomb explosion.
11. All crew and passengers on board KE 858, totalling 115 perished on 29-11-87 due to bomb explosion.
12. Security check on embarking passengers at KE 858 first departure airport needs to be more stringent.

3.2. Probable Cause

The cause of accident was in flight explosion of time bomb planted in the aircraft by the two saboteurs disguised as passengers.

4. Recommendations

To prevent the recurrence of such a tragic accident, authorities concerned responsible for the enforcement of aviation security should take stringent measures in checking embarking passengers.

ICAO Note.— Names of personnel were deleted. The attachments were not reproduced.

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