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FINAL REPORT

HCL 34/97 Incident			
Aircraft:	Boeing 737-500	Registrated:	EI-CDT
Number and type of Engines	2 CFM 56-3B1	Type of flight:	Scheduled public transport, IFR
Crew:	2/4 - no injuries	Passengers	60 - no injuries
Location:	Copenhagen Airport, Kastrup	Date and time:	20.07. 1997 at 1449 hrs

History of the flight

EI-CDT was on a flight from Dublin (EIDW) to Copenhagen (EKCH). The flight had been uneventful until EI-CDT was on finals for EKCH runway 22L under visual meteorological conditions (VMC).

In connection with the completion of the landing checklist the commander selected Speed Brakes to armed. The SPEED BRAKE ARM light lit up for a moment, and then the SPEED BRAKE DO NOT ARM light came on. Immediately afterwards the crew noticed that the three green LANDING GEAR INDICATOR LIGHTS, which indicate that the gear is down and locked, were not lit, and there was no light in the three red LANDING GEAR INDICATOR LIGHTS which show that the gear is "unsafe" either.

The commander then decided to perform a go-around. During go-around FLAPS 15° were selected, but when the gear selector was to be moved to the UP position, it was not possible to move the selector from the DOWN position.

At this time the crew noticed that several other indicators and instruments were not indicating correctly. For instance there was no N1, Fuel Flow or Standby Horizon. There was a warning for speed limit, light in SPEED TRIM FAIL, MACH TRIM FAIL, AUTO SLAT FAIL and bell and cabin address system were not working.

As there was no single checklist that covered all the faults noticed by the crew, they elected to complete the Gear Does Not Retract After Take Off checklist. This did not remedy the faults. The crew was in contact with Air Traffic Control several times concerning the technical problems, and Air Traffic Control could inform them that the landing gear had been down when EI-CDT performed the go-around.

During the go-around and subsequent flight the crew recognized that they had full control over the aircraft. The crew were of the opinion that the actual fault was

probably a computer problem. The crew informed the cabin crew and asked them to inform the passengers of the situation.

The commander then declared EMERGENCY to Air Traffic Control who cleared EI-CDT for an ILS approach to runway 22L.

During this approach the crew tried disconnecting the generators one at a time to see whether the problem was due to an "el-power transfer" problem. This did not make any immediate difference, but shortly afterwards all indications were suddenly normal. The crew made a normal landing on runway 22L and began taxiing towards the parking area via taxiway T2. The commander began addressing the passengers via the cabin address system but just after he had started his address the sound was cut off and the same indication problems as before arose.

When the aircraft had passed runway 12/30 the crew sensed smoke in the cockpit and a cabin crew member came to the cockpit and said that there was smoke in the cabin. Consequently the commander decided to evacuate the aircraft and stopped on the taxiway. All 66 persons on board left the aircraft by way of its four slides without further incident.

During and after the evacuation there were no visible signs of fire or heat development. The aircraft was towed to a hangar for further investigation.

The accident was reported to the Danish Aircraft Accident Investigation Board by the Control Centre at Copenhagen Airport, Kastrup. Report (HCL form 1) submitted by the pilot.

Personnel Information
Commander, 39 years of age, ATPL. Flying experience: 19500 hours of which 10000 were on type

Investigations made by the Aircraft Accident Investigation Board

Description of the part of the electrical systems of the aircraft relevant to this incident

a. Appendix 1 shows a schematic diagram of Boeing 737´s DC Power System. This shows that Battery Bus (bottom right-hand corner) is normally supplied by either Battery / Battery Charger or by Transformer Rectifier 3, and that it is the position of the Battery Bus Relay R1 (R1) which determines which source of current powers the Battery Bus.
In normal circumstances the system works in such a way that when Transformer Rectifier 3 does not supply current, Battery Bus is supplied with current from Battery / Battery Charger via R1. When Transformer Rectifier 3 supplies current R1 changes position, whereupon Battery Bus is supplied with current from this source.

b. Battery Bus supplies current to 56 essential systems.

c. In case of Battery Bus becoming currentless, there are no warning lights which directly relate to the currentless Battery Bus. The only indication of the fault will be incorrect or lacking indications in the cockpit due to the 56 systems becoming currentless.

d. In case of R1 not supplying Battery Bus with voltage, it would be possible to reestablish supply of current by selecting the STANDBY POWER switch on panel P5-5 to the BAT position.

e. The relevant manuals and checklists for the aircraft do not contain the fault indications which would be caused by a currentless Battery Bus, and there are no procedures to remedy them.

Examination of the electrical system

a. It was established that it was a fault on R1 which had caused the incorrect or lacking indications in the cockpit. The fault on R1 was such that R1 did not supply Battery Bus with current, neither from Battery / Battery Charger nor from Transformer Rectifier 3, whereupon Battery Bus and the 56 essential systems became currentless.

b. R1 was dismounted and sent to Boeing Commercial Airplane Group for closer inspection. From *Equipment quality analysis report* it appears:

Relay data: Part no. DH-7JA
Ser. no. CL10062
Manufacturer: Hartman Electric
Dismounted from: Aircraft PT170 (EI-CDT)

Extract from summary and results:

The B1 movable contact blade was at a right angel to the B1 stationary contact.
The relay had evidence of the B2 contacts being welded. The welding of these contacts is suspected of causing electrical arcing which melted the contact arm. (AAIB: contact blade) (See appendix 2).

Examination of relays from other aircraft

In order to determine whether the fault on R1 from EI-CDT was an isolated occurrence three relays of the same type were dismounted from two other B 737. Two of these relays were dismounted from the R1 position and the third from the position R326.

These relays were also sent to Boeing Commercial Airplane Group for closer inspection. From *Equipment quality analysis report* it appears:

a. For the relays dismounted from position “R1":

Relay data: Part no. DH-7JA
Ser. no. CK76102 and CK95106
Manufacturer: Hartman Electric
Dismounted from: Aircraft PT168 and PT169

Extract from summary:
The two relays had contact wear similar to the R1 relay that had been removed from airplane PT170. (AAIB: EI-CDT)

b. For the relay dismounted from position “R326"

Relay data: Part no. DH-7JA
Ser. no. CL10055
Manufacturer: Hartman Electric
Dismounted from: Aircraft PT170 (EI-CDT)

Extract from summary:
The examination of the internal components of this relay revealed normal wear.

Relevant information from Boeing

a. Boeing has supplied the following information in respect of the amount of current through R1:

Our testing on 737 airplanes with extended standby power configuration shows the in-rush current is consistently about 114 amps. The steady state current is approximately 20 amps. Note that airplanes with the standard standby power system power the static inverter from the battery bus and the in-rush current is closer to 500 amps.

b. Boeing states the following about the history of the relay:

The Battery Bus Relay (R1) installed on aircraft PT170/EI-CDT at the time of the subject event was a Hartman P/N DH7JA. This relay was first installed in production airplanes that delivered in March, 1992. It replaced Antex relay P/N 419-055335-05, which had been implicated in previous reports of intermittent Battery Bus problems. Although the Hartman DH7JA relay was never formally qualified to any Boeing Specification, it was tested in Boeing's 737 Electrical Power Test Rig in the late 1991/early 1992 time frame. A test sample was subjected to a 50,000 cycle switching test with simulated airplane loads.

Results were satisfactory, and subsequent in-service experience indicates a good history in terms of failure rates.

Subsequently, Boeing Specification 10-1722-3 was created to specify a relay with improved in-rush current tolerance. The Leach P/N H-X9A-101 relay was formally qualified to this specification and replaced the Hartman relay in production in mid-1994. It has been used exclusively since that time and is the preferred part.

c. Concerning smoke development:

Loss of the battery bus causes ground sense relay R320 to drop out, which prevents the pack cooling turbofans from turning on and causes the Air Cycle Machine (ACM) to overheat. Smoke is produced by oil and dirt in the ACM and adjacent ducts.

Other similar occurrences

The most likely time when a fault in R1 would occur, is when the relay changes position which is normally in connection with start up and shut down, that is before and after a flight. R1 will then normally be replaced during the airline company's technical trouble-shooting without further investigations being carried out. This type of fault will therefore in most cases not be reported to records which are accessible to the public.

The Aircraft Accident Investigation Board inquired of the National Transportation Safety Board (NTSB), USA, whether they knew of any other Boeing 737 aircraft which had suffered a similar fault to R1. NTSB reported that they had two occurrences in their database.

a. NTSB Report number: 830523028679C
From *Narrative* it appears:

Smoke in cabin while taxiing. Smoke came from an overheated air conditioning pack. Malfunctioning Battery Bus Relay.

b. NTSB Report number: DEN90IA189
From *Narrative* it appears:

Shortly after pushback it was noticed that the #2 eng door right handle was not flush. The engine was shut down and ground maintenance personnel closed the door from the outside. The cabin then began to fill with dense smoke. The captain, using radio and an open window, was unsuccessful in getting a jetway to the airplane, and the crew and pax exited using slides. It was later determined that the battery bus relay (R1) and Battery Transfer relay (R2) had failed.

Boeing has stated that their database lists eight such relay faults since 1980, of which three were after 1994.

*Flight Data and Cockpit Voice Recorder*s

The aircraft was equipped with

Flight Data Recorder (FDR)	part no. 980-4100-DXUN	ser. no. 326
Cockpit Voice Recorder (CVR)	part no. 93-A-100-80	ser.no. 52354

FDR and CVR were dismounted and sent to Air Accidents Investigation Branch, UK, where they were downloaded.

The readouts added no new information to the investigation but corroborated the statements of the crew.

Conclusions

It was an internal fault in relay R1 which caused Battery Bus to become currentless and caused the incorrect and lacking indications in the cockpit.

Furthermore the fault caused the Pack Cooling Turbofan to stop, leading to the overheating of the Air Cycle Machine. This overheating caused oil from the Air Cycle Machine and dirt in the adjacent ducts to develop smoke which spread to cockpit and cabin.

Closer inspection of the relay revealed that a contact blade had melted and bent at an angle of 90º. The contact blade showed signs of welding caused by arcing, which had caused so much heat that the contact blade had melted and bent.

When the Aircraft Accident Investigation Board considers the following facts

- R1 was defective due to generation of heat caused by welding / arcing.

- Two other relays from the position R1, dismounted from two other B-737, showed the same signs of welding.

- NTSB knew of two other instances and Boeing of eight others.

- When R1 becomes defective it will normally be replaced by the airline company in the course of technical trouble shooting without further investigations being made, and the occurrence is not reported to accessible records.

- Boeing has stated that the amount of current through R1 during steady state will be about 20 ampere (A), but that “in-rush current” through R1 can reach over 114 A and that in some aircraft “in-rush current” can reach 500 A.
-

The Board is of the opinion that it can be called into question whether this type of relay in position R1 is designed to transfer the currents which exist in the circuit.

Based on the incorrect and lacking indications in the cockpit and the fact that they are not contained in the relevant manuals and checklists for the aircraft it is the opinion of the Aircraft Accident Investigation Board that the crew were not and could not be in possession of information to verify that it was a case of a Battery Bus Failure.

The crew were not aware that they could reestablish normal functions and indications by switching STANDBY POWER (P5-5) to the BAT position , as the relevant manuals and checklists for the aircraft did not contain procedures concerning this problem.

Recommendations and actions taken

1. Following the incident the airline company issued a Flight Crew Instruction to their pilots in August 1997 (appendix 3).

2. Based on the preliminary investigations and the inherent safety risk of R1 not supplying Battery Bus with current, the Aircraft Accident Investigation Board made the following recommendations to the Civil Aviation Administration on 22 December 1997.

   a. The Civil Aviation Administration takes the necessary actions to seek a reevaluation of the performance of the Battery Bus Relay (R1) in its installation in the Boeing 737 series aircraft to ensure proper function. (REC-04-97).

   b. The Civil Aviation Administration takes the necessary action to ensure that the crew of Boeing 737 series aircraft has the proper information readily available to quickly restore the electrical power supply in the event of the failure of the Battery Bus Relay (R1). (REC-05-97).

3. Re recommendation “a” :
   On 11 June 1998 Boeing issued Service Letter 737-SL-24-120 concerning *Battery / Standby / DC Power System Relays - Preferred Spare.* (See Appendix 4)

   In this Service Letter Boeing recommends that the relay with Boeing part no. 10-1722-3 (Leach part. no. H-X9A-101) be used in preference to the Antex relays with part no. 419-055335-05 and G55355-1 and the Hartman relays with part no. DH-7JA formerly used.

4. Re recommendation “b”:
   On 4 August 1998 Boeing issued Flight Operations Technical Bulletin 737-300/400/500 98-1 concerning *Battery Bus Failure*. (See appendix 5)

In this Flight Operations Technical Bulletin Boeing describes (as described in this report) how a loss of Battery Bus will become evident in the cockpit.

Furthermore Boeing explains that these incorrect and lacking indications will vary depending on the specific type of extra equipment installed in the aircraft, and the phase of operation of the aircraft.

Boeing concludes its Flight Operations Technical Bulletin by writing:
Boeing has no technical objection to an airline incorporating a loss of Battery Bus procedure in their Operations Manual. However, since there are so many different electrical configurations throughout the 737 fleet, Boeing is unable to publish a generic procedure in the Boeing Operations Manual which will work for all 737-300/400/500 airplanes.

5. In the new types of B737 (-600 / -700 / -800) the warning system has been modified so that the warning light *STANDBY Power OFF Light* is switched on in case of Battery Bus failure.

Similarly there is a procedure in *Operations Manual* for reestablishing current to Battery Bus.

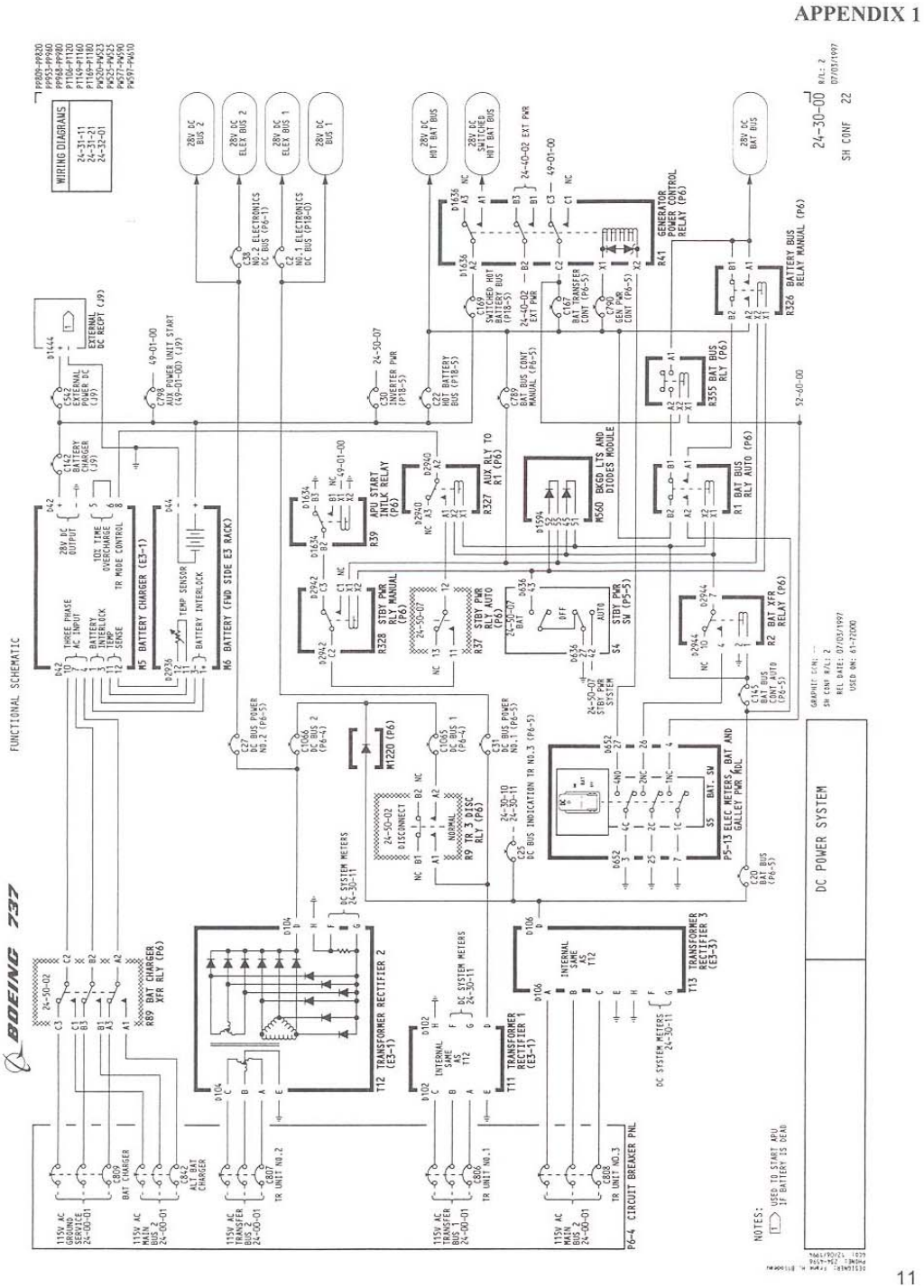
Appendices

Appendix 1	Schematic diagram of *DC Power System*.
Appendix 2	Photograph of the defective relay.
Appendix 3	The airline company's *Flight Crew Instruction*
Appendix 4	Service Letter 737-SL-24-120
Appendix 5	Flight Operations Technical Bulletin 737-300/400/500 98-1

Achnowledgement

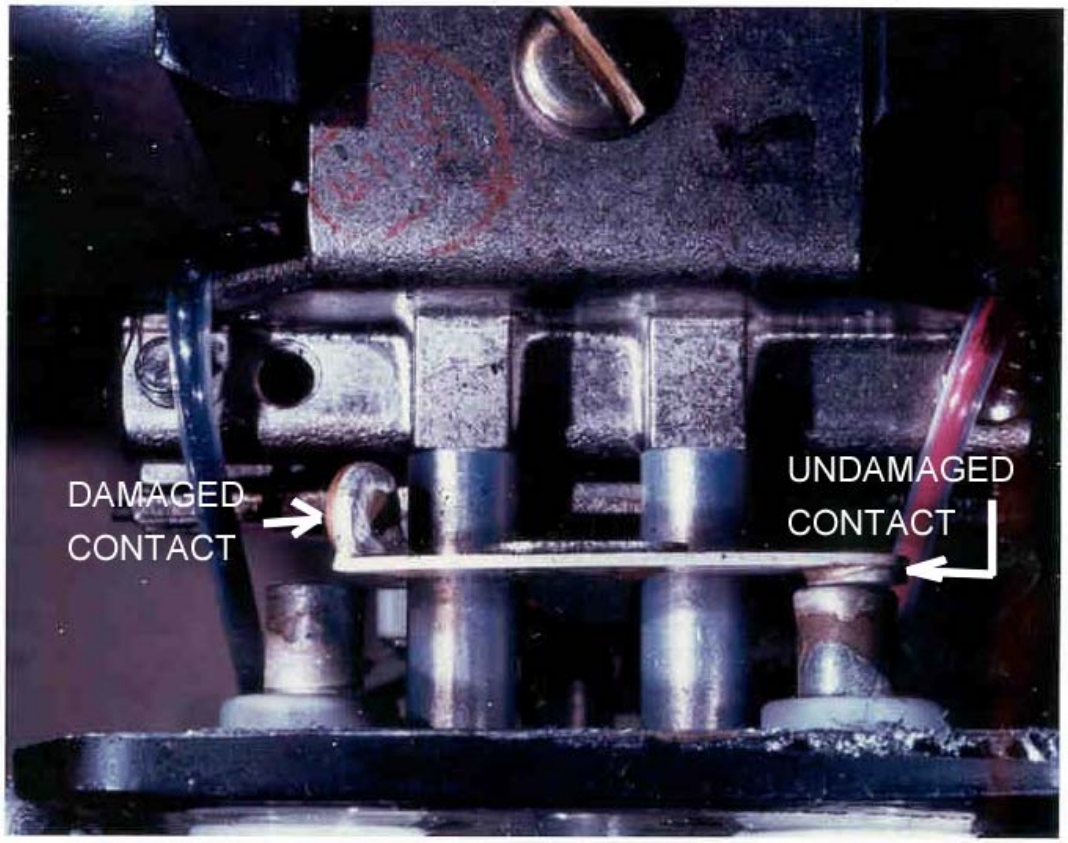
Air Accident Investigation Unit, Ireland for the contribution to the investigation.

APPENDIX 1



Schematic diagram of *DC Power System*.

APPENDIX 2



VIEW OF DAMAGED RELAY

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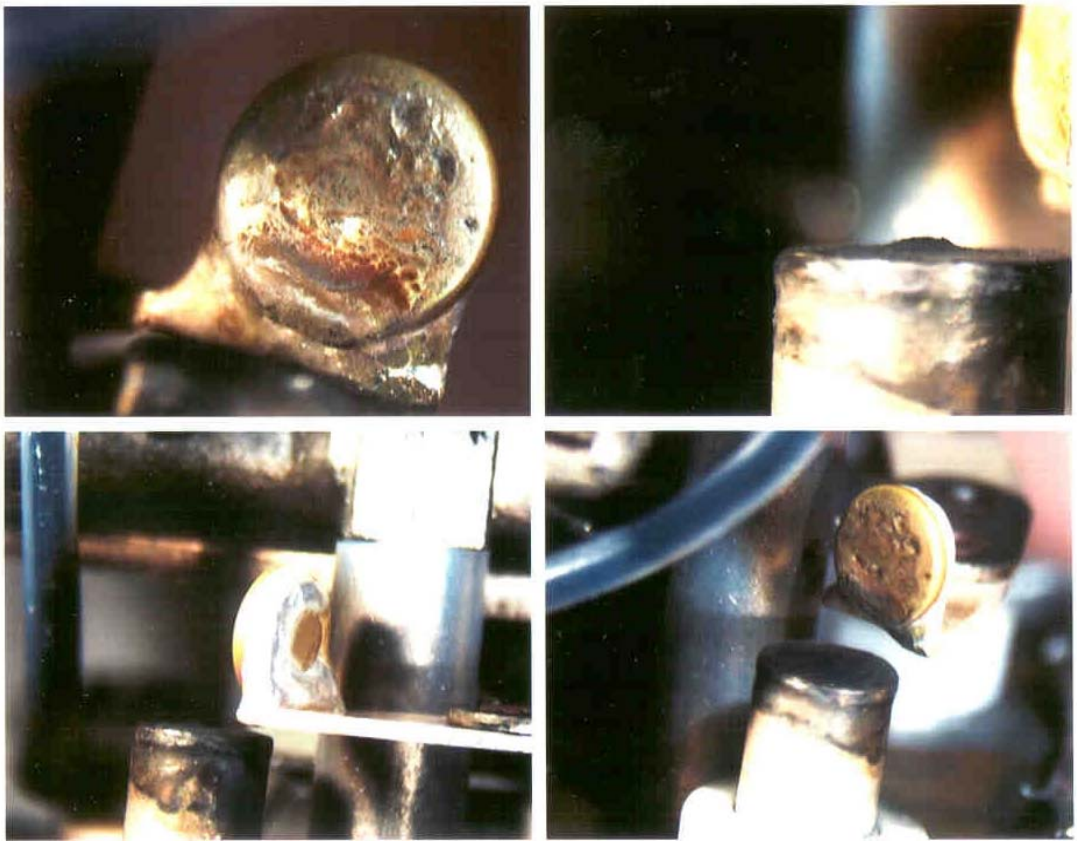

CLOSE UP VIEWS OF DAMAGED RELAY

APPENDIX 3

HCL
Information **9199**

APPENDIX 3

Flight Crew Instruction B737

Subject

BATTERY BUS FAILURE

Information

Action

When power to the Battery Bus fails the resulting system malfunction indications will vary depending on the phase of flight. If the Standby Horizon both NI's and both Fuel Flows fail, suspect Battery Bus failure, Other indications could include, Speed Trim Fail, Main Trim Fail and Auto Slat Fail. On approach the Speedbrake Do Not Arm light will be illuminated and the Landing Gear lights will not illuminate.

If you suspect Battery Bus failure the following procedure should be carried out.

- Select DC meter to Battery Bus and confirm power loss.
- Select Stby Power Switch to Bat and confirm restoration of power to Battery Bus.
- Operate Normally.

Note: With one or both Generator Busses powered and the Standby Power Switch selected to Battery, the Battery charger reverts to a TR mode and will supply the Battery Bus indefinitely while maintaining the Battery charge.

Action Pilots should note the procedure to be followed in the event of Battery Bus failure, as outlined above.

APPENDIX 4

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BOEING 737

-Customers **SERVICE LETTER**

Organisation - SERVICE ENGINEERING BOEING COMMERCIAL AIRPLANE GROUP
PO BOX 737 SEATTLE WASHINGTON 98124-2207

737-SL-24-120
ATA: 2433-20
11 June 1998

SUBJECT: BATTERY / STANDBY / DC POWER SYSTEMS RELAYS - PREFERRED SPARE

MODEL: 737-100 to -500

APPLICABILITY: All 737-100 through -500 Airplanes

REFERENCES: a) Service Bulletin 737-24-1096 dated 18 February 93

b) Service Bulletin 737-24-1O89 dated 18 March 93

SUMMARY:

This service letter informs operators of the preferred replacement relay for five battery / standby /dc power system applications on 737-300 /-400 /-500 airplanes, and three applications on 737-100/ 200 airplanes. Service experience has shown a need for a relay with improved inrush current handling capability in several system applications. The Boeing specification P/N 10-1722-3 relay (Leach P/N H-X9A-101) has been installed on all 737-300/-400/ 500 airplanes delivered since June 1994. This is the preferred part to replace Antex relay P/N's 419-055335-05 and G55355-1, and Hartman. relay P/N DH-7JA on previously delivered airplanes.

BACKGROUND:

Antex relays P/N 419-055335-05 and G55335-1 have been in use on Boeing airplanes for over 30 years Operator reports of deterioration of relay performance no reliability from 1988 to 1992 resulted in a joint investigation by Antex, the relay manufacturer, and Boeing This investigation produced evidence of chemical contamination in the contact material which adversely

affected the service life of the relay contact surface. Antex implemented process changes in an attempt to improve contamination control.

Starting with airplane line position 2247, which was delivered in March 1992, model 737 airplaines were delivered with Hartman relay P/N DH-7JA in applications which had previously used Antex relay P/N 419-055335-05. All applicable drawings were revised to show the Hartman relay interchangeable with the Antex relay.

The reference A) and reference b) service bulletins provided modification instructions for 737-300/ -400/-500 airplanes with the large and small battery systems, respectively. Both bulletins replaced the existing Antex relays with the Hartman relays in an effort to improve system reliability. The battery system relays are the R.1 Battery Bus Auto Relay, the R326 Battery Bus Manual Relay, and the R355 Battery Bus Relay. The dc power system relay is the R9 Transformer Rectifier No 3.

Disconnect Relay. For airplanes with the large static inverter, the R389 Inverter Control Relay in the standby power system was also replaced,

On 737-100/-200 airplanes, Antex relays P/N G55335-1 and P/N A419-055335-05 were installed for the R1 Battery Bus Relay, R2 Battery Transfer Relay, and R9 Transformer Rectifier No 3 Disconnect Relay.

DISCUSSION:

Boeing specification 10-1722-3 added requirements for relays to meet an improved inrush current tolerance of 500 amperes, and to be subjected to life cycle testing. Leach relay P/N H-X9A-101 is manufactured to Boeing specification 10-1722-3, and has replaced the Hartman and Antex relays in all applications on 737-300/-400/-500 airplanes delivered since mid-1994.

BOEING ACTION:

The Illustrated Parts Catalogue (1PC) will be revised to show interchangeability of these relays. Boeing specification relay P/N 10-1722-3 (Leach P/N H-X9A-101)is the preferred part to replace P/N 10-1722-2 relay (Hartman P/N DH-7JA) and P/N 10-1722 (Antex P/N A419-055335-05 and G55335-1) in all applications.

SUGGESTED OPERATOR ACTION:

To optimize battery, standby, or dc power system relay reliability, we recommend operators install relay P/N 10-1722-3 *(*Leach P/N H-X9A-101), on an attrition basis, in all applications (R1, R9, R326, R355, and R389) for 737-300/-400/-500 aiplanes, and (Rl, R2, and R9) for 737-100/-200 airplanes. In support of our effort to optimize power system reliability, we encourage all operators to advise us of any relay P/N 10-1722-3 removals due to system problems.

WARRANTY INFORMATION:

Boeing warranty remedies are not available for the change discussed in this service letter.

INTERCHANGEABILITY INFORMATION:

Boeing specification relay P/N 10-1722-3 (Leach P/N H-X9A-101) is the preferred replacement for Boeing specification relay P/N 10-1722 (Antex relay P/N A419-055335-05 and P/N G55335-1) and Bocing specification relay P/N 10-1722-2 (Hartman P/N DH-7JA)

Wayne Maxey
Fleet Support Chief
707/727/737-100 to -500

APPENDIX 5

Information 9/99
HCL

BOEING COMMERCIAL AIRPLANE GROUP

FLIGHT OPERATIONS TECHNICAL BULLETINS

NUMBER: 737-300/400/500 98-1

DATE: Aug. 4, 1998

These bulletins provide information which may prove useful in airline operation or airline training. The information provided in these bulletins is not critical to flight safety. The information may not apply to all customers; specific effectively can be determined by contacting The Boeing Company. This information will remain in effect depending on production changes, customer-originated modifications, and Service Bulletin Incorporation. Information in these bulletins is supplied by the Boeing Company and may not be approved or endorsed by the FAA at the time of writing. Appropriate formal documentation will be revised, as necessary to reflect the information contained in these bulletins. For further information, contact Boeing Commercial Airplane Group, Chief Pilot, Training, Technical & Standards, P.O. Box 3707, Mail Stop 14-HA, Seattle, Washington 98124-2207, Phone (206) 655-0878, Fax (206) 655-3694. SlTA: SEAB07X Station 627.

SUBJECT: Battery Bus Failure

ATA NO:

APPLIES TO: All 737-300/400/500 AIRPlANES

Background

Over the last few years several operators have reported in-flight loss of battery bus due to electrical system relay failures. Relay contacts have electrically opened and/or arced, resulting in loss of, or erratic: voltage on, the battery bus.

Several improvements have been made to these relays to improve their reliability and eliminate poor electrical contact performance. Despite improvements these relays Still occasionally fail. The Booing database contains 8 failures since 1990, three of those since 1994.

Failure Indications

737-600/700/800
The STANDBY POWER OFF light illumination indicates one or more of the following busses are unpowered: AC Standby bus, DC Standby bus, or Battery bus. The QRH procedure calls for taking the Standby Power Switch to --- Bat.

737-300/400/500
The STANDBY POWER OFF light will only illuminate for loss of the AC Standby bus. No light or message will tell the flight crew that the Battery bus has failed. The only indication to the crew that this failure has occurred is the loss of various instrument indications or observing a zero indication on the BAT BUS DC Meters. These instrument indications will vary depending on specific airplane options installed and phase of flight. For example: the Standby Attitude Indicator may fail; the Landing Gear down green lights will be inoperative, but the crew will not see this until the landing gear is lowered.

All 737-300/400/500's will lose at least 1 primary engine display**.** The following matrix shows which bus powers the primary engine displays for both EIS and Non EIS airplanes.

Parameter	Non EIS	EIS
NI	BAT	BAT
N2	MAIN or STBY	STBY
EGT	BAT or STBY	STBY
FF	MAIN	BAT

Operating Information

In the past, Boeing has not written Non-Normal procedures unless there is a Master Caution or specific light which indicates the problem. Loss of only the battery bus is not considered a hazardous situation. Normal AC power will provide sufficient instrument indications to the aircrew for continued safe flight and landing.

If an operator wants to provide its aircrews with a procedure to cover a relay failure resulting in loss of the Battery bus, the following information is provided as a starting point.

Loss of both engine NI indicators is the only indication of a Battery bus failure common to all 737-300/400/500 airplanes. Most airplanes will lose an additional primary engine Indication (see matrix above). Additional indications will vary depending on the specific electrical configuration of the airplane. Once a Battery bus failure is suspected, it should be confirmed with the overhead DC indicators. Once confirmed, taking the Standby Bus Switch to BAT should restore the Battery bus.

With one or both Generator Busses powered and the Standby Power switch selected to BAT, the Battery Charger will supply power to the Battery indefinitely.

Boeing has no technical objection to an airline incorporating a loss of Battery Bus procedure in their Operations Manual. However, since there are so many different electrical configurations throughout the 737 fleet, Boeing is unable to publish a generic procedure in the Boeing Operations Manual which will work for all 737-300/400/500 airplanes.