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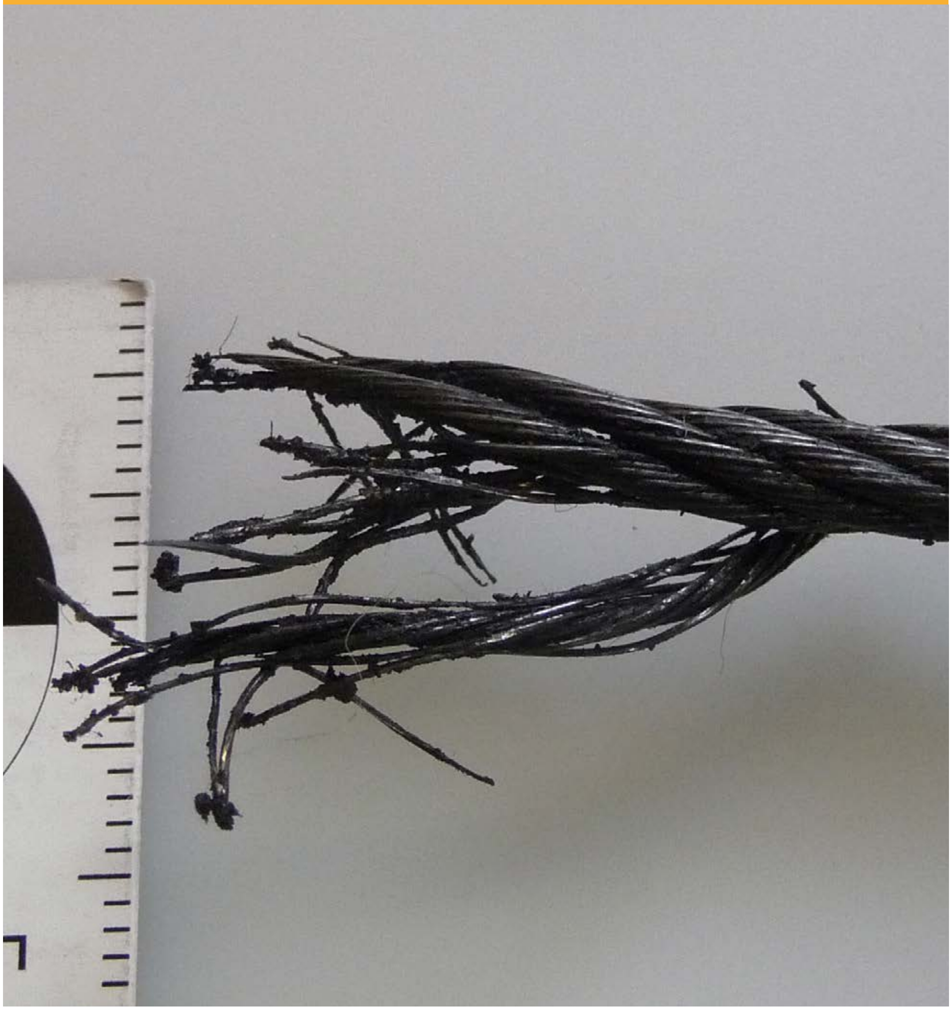
Failure of aileron flight control cable Boeing 737-804



Failure of aileron flight control cable Boeing 737-804

The Hague, July 2024

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Cover photo: Dutch Safety Board

The Dutch Safety Board

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N.B: This report is published in the English language, with a separate summary in the Dutch language. If there is a difference in interpretation between the Dutch and English version, the English text will prevail.

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SUMMARY

On 8 July 2022, a Boeing 737-800 registered as PH-CDF, took off for a commercial flight from Heraklion International Airport "Nikos Kazantzakis" on Crete, Greece, to Amsterdam Airport Schiphol, the Netherlands. Six crew members and 179 passengers were onboard the aircraft. During take-off, immediately upon lift-off, the flight crew experienced an uncommon roll effect to the left.

The aircraft remained controllable as the flight crew managed the roll effect by applying rudder and aileron input. The flight deviated to Athens, Greece, without further anomalies. Post-flight inspection showed that an aileron cable had failed. In close consultation with the Air Accident Investigation and Aviation Safety Board (AAIASB) of Greece, representing the State of Occurrence, it was decided that the Dutch Safety Board, representing the *State of Registry and State of the Operator*, would conduct a safety investigation according to the principles of ICAO Annex 13.

In smooth air the flight crew was able to cope with the roll effect of the aircraft, but in case of turbulent weather the controllability of the aircraft may become difficult which can further impair safety. Therefore, the Dutch Safety Board classified the occurrence as a serious incident, as the (partial) system failure of a primary flight control resulted into a degraded state of safety of the aircraft. The United States' National Transportation Safety Board, representing the State of Design and Manufacture, and its technical advisor (Boeing Commercial Airplanes), assisted in the investigation.

Detailed investigation revealed that the location where the flight control cable had failed, was between the feel and centering unit and the ailerons. Given the flight control system configuration on PH-CDF, the '*Before taxi checklist*' is not effective in detecting a deteriorating or failed flight control cable at that position. A timely detection of a defect therefore depends on an adequate maintenance process.

The failed aileron cable was the original cable since aircraft delivery in January 2000 and was in accordance with the material specifications. According to the maintenance documents, the Detailed Visual Inspection (DVI) had been accomplished. However, the Dutch Safety Board cannot rule out that the cable had not been treated and lubricated in accordance with applicable maintenance procedures.

In view of the Dutch Safety Board, it is important that - in particular for cables that have aged in cycles and flight hours like on PH-CDF – ground engineer timely detect defects since aging contributes to normal wear anyway. For ground engineers, the detection and determination of the extent of wear during a Detailed Visual Inspection (DVI) of the cables is a difficult task because of the small size of the cable inspected 'on condition'. It could not be determined that aging (in terms of normal wear) of the aileron cable was a more dominant factor than the effect of lack of lubrication, which promoted more than

normal wear and corrosion. Consequently, it could not be determined that the inspection interval of the DVI (4,000 flight cycles or 24 months) valid at the time of the event, was set too broadly.

The aileron cable failures with the PH-CDF in 2022 and another Boeing 737-800 aileron cable failure in 2019 were investigated. Since 1997 three other cable failures were reported to Boeing, for which no ICAO Annex 13 investigations have been initiated. Reviewing the last three decades with hundreds of millions of flights, there is no immediate reason to doubt the effectiveness of the maintenance procedures based on a DVI interval of 4,000 flight cycles or 24 months as applicable in June 2022. DSB concludes that a safety recommendation is therefore considered not to be appropriate.

It is noted that since June 2023 the industry has increased the interval of the DVI to 6,600 flight cycles and 36 months.

ABBREVIATIONS

Abbreviation	Description
AAIASB	Air Accident Investigation and Aviation Safety Board
AD	Airworthiness Directive
ATL	Aircraft Technical Log
ATPL	Airline Transport Pilot Licence
BMS	Boeing Material Specification
CVR	Cockpit Voice Recorder
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
FL	Flight Level
ILS	Instrument Landing System
ISC	Industry Steering Committee
ITSB	Icelandic Transportation Safety Board
MAC	Mean Aerodynamic Chord
METAR	Meteorological Aerodrome Report
MPD	Maintenance Planning Document
NTSB	National Transportation Safety Board
UTC	Coordinated Universal Time

GENERAL OVERVIEW

Synopsis	Explanation
Identification number:	2022086
Classification:	Serious incident
Date, time of occurrence:	8 July 2022, 08.58 hrs[1]
Location of occurrence:	Heraklion International Airport, Crete, Greece
Operator:	Corendon
Registration:	PH-CDF
Aircraft type:	Boeing 737-804
Aircraft category:	Fixed wing aircraft
Type of flight:	Commercial Air Transport - Passenger
Phase of operation:	Take-off
Damage to aircraft:	Minor (aileron cable broken)
Flight crew:	2
Cabin crew	4
Passengers:	179
Injuries:	None
Other damage:	None
Light conditions:	Daylight

1 All times in this report are in UTC, unless otherwise specified. The local time in Greece was UTC + 3 hours.

1 INTRODUCTION

On 8 July 2022, the flight crew of a Boeing 737-800 experienced a roll effect to the left immediately after take-off from Heraklion International Airport "Nikos Kazantzakis" on Crete, Greece. The aircraft remained controllable as the flight crew managed the roll effect by applying aileron and rudder input. The flight crew diverted to Athens International Airport "Eleftherios Venizelos" and landed the aircraft safely. Post-flight inspection revealed that one of the aileron cables was broken.

The occurrence was reported by the operator to the Dutch Safety Board. As the occurrence took place in Greece, the Dutch Safety Board contacted the Air Accident Investigation and Aviation Safety Board (AAIASB) in Greece. In close consultation with the AAIASB, it was decided that the Dutch Safety Board, representing the *State of Registry and State of the Operator*, would conduct a safety investigation.

The Dutch Safety Board classified the occurrence as a serious incident, as it was a (partial) system failure of a primary flight control, which " … caused or could have caused difficulties controlling the aircraft (ICAO annex 13, attachment C)". With an absence of adverse weather (like turbulence), the aircraft remained controllable in this event. In a similar event with a Boeing 737 but with turbulence – also described in this report – the crew flying a Boeing 737 encountered turbulence and declared an emergency as it had difficulty controlling the aircraft.

The investigation aimed at answering the following questions:

1. What caused the failure of the aileron cable?
2. What was the effect of the failed aileron cable on flight safety for the remainder of the flight?

The United States' National Transportation Safety Board, representing the State of Design and Manufacture, and its technical advisor (Boeing Commercial Airplanes) assisted in the investigation. In addition, the Dutch Safety Board gathered information from the pilots and the operator. The Dutch Safety Board received information from the Icelandic Transportation Safety Board, because it had investigated a similar event.

Chapter 2 presents the relevant factual information. In Chapter 3, the analysis is presented. Findings and conclusions are summarised in Chapter 4.

2 FACTUAL INFORMATION

2.1 History of flight

On 8 July 2022, the captain and first officer prepared the aircraft for a passenger flight from Heraklion International Airport "Nikos Kazantzakis" (LGIR, hereafter Heraklion) on Crete, Greece to Amsterdam Airport Schiphol (EHAM, hereafter Schiphol). There were 179 passengers and six crew members on board. The flight was conducted with a Boeing 737-804 registered as PH-CDF. Earlier that morning, the same crew had flown the aircraft from Schiphol to Heraklion uneventfully.

The first officer was pilot the flying from the right seat and the captain was the pilot monitoring. Both flight crew members stated that when the *Before taxi checklist* – which includes a check of the aileron flight controls - was carried out and no anomalies were detected.

At 08.58 hrs the aircraft took off from Runway 27. The first officer stated that until rotation the flight was normal. After lift-off, however, he immediately had to apply a significant roll input to the right to keep the aircraft wings level and during the climb he experienced that the aircraft needed a lot of correction to counteract the roll effect. He characterised the corrective steering input as uncommon but manageable. The first officer and captain shortly swapped flight controls so the captain could also experience the unusual controllability of the aircraft. The flight crew did not declare a Mayday or Pan-Pan call.
The first officer experienced that additional rudder input was necessary to attain a more or less wings level attitude. The Flight Data Recorder (FDR) data showed that the rudder input was approximately five degrees. The crew used the aileron trim in order to attempt to get the control wheel back into the neutral position, which was not possible. The flight crew observed that the flight control was no longer coordinated as the slip-indicator was not in the middle.

The autopilot was temporarily engaged once the aircraft had been levelled off at Flight Level (FL) 180. The flight crew disengaged the autopilot after some time. According to the first officer, when flying manually the aileron control system did not feel heavy nor did it feel sloppy. Rudder input remained necessary to keep the control wheel in an approximately neutral position. The flight crew statements indicated that - given the current airspeed of 280 knots at FL180 - the aircraft was controllable. The flight crew did not know the consequences for the controllability if it would increase air speed and/or flight level. It discussed the 'jammed aileron' checklist and concluded that since the aileron controls were free, it was not necessary to carry out this checklist and to land with a flap setting of fifteen degrees.[2]

Bound to the north in good visibility and smooth weather conditions, Athens was in sight. The flight crew considered that due to the slip condition – with higher fuel consumption - an insufficient fuel state might occur before reaching destination Schiphol. As it was unclear what caused the flight control problem, the flight crew decided to divert to Athens International Airport "Eleftherios Venizelos" (LGAV, hereafter Athens). According to the pilots no further problems occurred during the diversion and instrument landing system (ILS) approach. At 09.35 hrs the aircraft landed at Athens without further event where FDR analysis confirmed a flap setting of thirty degrees during landing.

After the flight, a passenger showed the flight crew a video recorded on a mobile phone showing the left aileron in an upward position. Post flight troubleshooting by a ground engineer immediately after arrival at Athens revealed that a cable of the left aileron of the flight control system - cable ABSA-L1 - was broken, see Figure 1. There was no other damage to the aircraft.

▲ *Figure 1: One side of the broken aileron control cable, see circle. (Source: local ground engineer at Athens)*

2.2 Personnel information

The captain, age 62 years, held a valid Airline Transport Pilot License (ATPL) issued on 10 March 10 2016 with type ratings for Boeing 737 (range -300 through -900), Multi Engine and Instrument Ratings (IR) valid till 31 July 2023.. He held a valid class 1 medical certificate, issued 22 March 2022 valid till 28 August 2022, with the limitation that a correction for defective distance vision is needed.

2 The flight and flight control systems parameters are detailed in Appendix C.

A review of the operator's records indicated that the captain had about 15,900 hours total flight time, of which 4,800 hours were on the Boeing 737.

The first officer, age 46 years, held a valid ATPL license issued on April 25th 2022 with – as far as relevant - type ratings for Boeing 737 (range -300 through -900), Multi Engine and Instrument Ratings (IR) valid till 25 April 2023. He held a valid class 1 medical certificate, issued 25 May 2022 valid till 29 June 2023 with no limitations.
A review of the operator's records indicated that the first officer had about 3,680 hours total flight time, of which 3,402 hours were on the Boeing 737.

2.3 Aircraft information

2.3.1 General

PH-CDF is a tricycle geared Boeing 737-804 with two turbofan engines (CFM International, CFM56-7B27) and configured for passenger transportation with 189 passenger seats. The aircraft is normally operated by two pilots - a captain and a first officer - and four cabin crewmembers. It may be flown either manually or automatically to maintain the flight path. During take-off the pilot flying always operates the aircraft manually.

The aircraft, with serial number 28227, was manufactured in 1999 and delivered on 15 January 2000. Since May 2012, the aircraft had been in use with the operator. At the time of the incident, the aircraft had a valid Certificate of Registration and a valid Certificate of Airworthiness. The accompanying Airworthiness Review Certificate was valid till 28 April 2023.

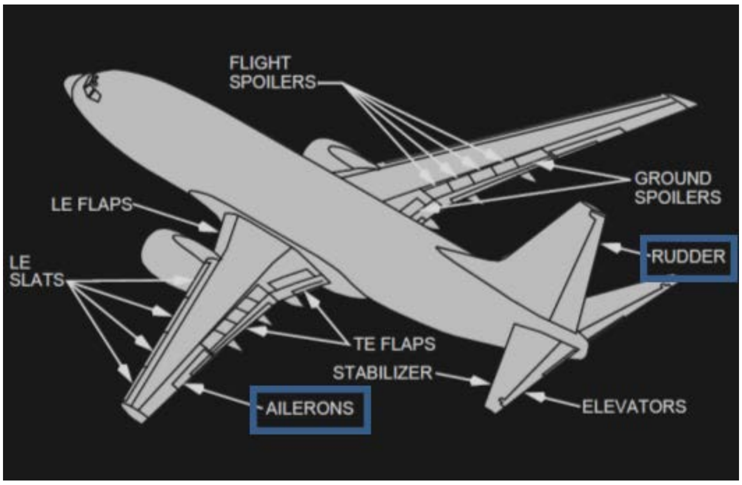
The aircraft had been in service for 8,242 days, with 75,776 airframe hours and 24, 202 landings since manufacturing.

Aircraft Technical Log entries of the ten previous flights showed no information in relation to the aileron flight control system. The Load and Trim Sheet showed that the centre of gravity (CG) for take-off was within the flight envelope at 23,2 percent Mean Aerodynamic Chord (MAC).

2.3.2 The flight control system description

The Boeing 737 series have a primary flight control system that uses a conventional control wheel for aileron, column for elevator and pedals for rudder input. These are mechanically linked to hydraulic power control units, which operate the primary flight controls: the aileron, rudder and elevator control surfaces. The flight controls are powered by redundant sources, being either hydraulic system A or hydraulic system B. The rudder system may also be powered by the standby hydraulic system. For this investigation, only aileron and rudder control are relevant as primary flight controls[3], see also Figure 2.

3 The elevator is also a primary flight control, which plays no role in this event.



▲ *Figure 2: Flight control surfaces, indicating the ailerons and rudder. (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

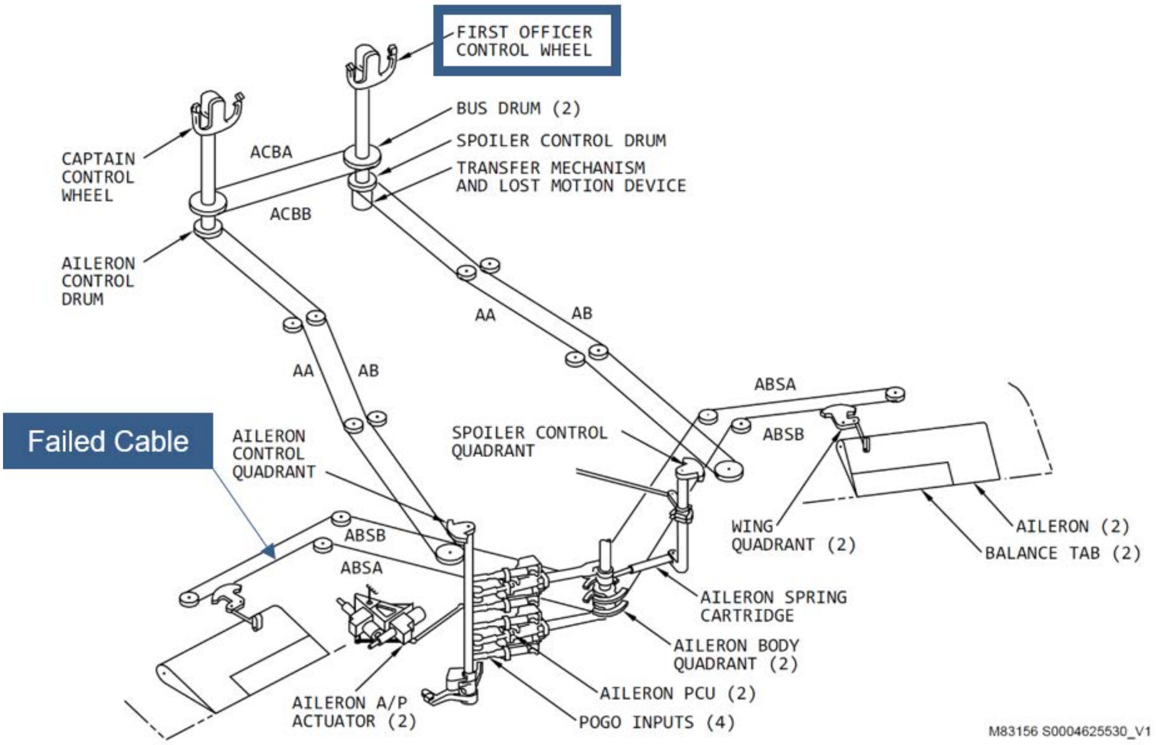
Aileron control system

For steering the aircraft, it requires the aircraft to roll around the longitudinal axis, which is accomplished by positioning the pilots' control wheels to the left or right in order to move the aileron surfaces. When the control wheel is displaced more than 10 degrees, flight spoilers deflection is initiated on the wing with up aileron to supplement roll control.

The aileron trim is used to relieve the pilot from continuous steering forces which are necessary to keep the aircraft in a wings level attitude. The trim electrically repositions the aileron feel and centering unit, which back-drives the control wheels, causing them to rotate and redefine the aileron neutral position.

When hydraulic pressure is available, the control wheel rotation input is transferred into a cable movement to the aileron feel and centering unit, see the schematic presented in Appendix B. The feel and centering unit drives the input rods that connect to the A and B system Power Control Units. These two Power Control Unites (PCUs) hydraulically drive both the left and right wing cable systems to deflect each aileron.

The aileron cable system consists of two paired cables per wing, where one cable (ABSB) pulls the aileron up and the other (ABSA) pulls it down. The location of the cable ABSA-L1 failure is depicted in Figure 3.



▲ *Figure 3: Schematic for aileron (roll) control. The aileron feel and centering unit is not shown. The location of the cable failure is indicated in the picture. (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

When carrying out the *Before taxi checklist*, the flight crew verifies that it can move the control wheel fully to the left and fully to the right. The flight crew verifies whether the cable system from the cockpit to the aileron feel and centering unit moves free and easy. This input to the feel and centering unit results into hydraulically driven deflections of the ailerons to the full up and down positions. Given the flight control system configuration of the PH-CDF, the pilots cannot verify the aileron deflections in the cockpit.

Rudder control system
The rudder is controlled by displacing the rudder pedals. The rudder is hydraulically deflected via a power control unit. In case of asymmetric conditions (i.e. engine failure or yaw due to asymmetric drag effects as seen on the incident flight) opposite rudder is used to compensate the yaw. Without evident anomalies, the rudder trim may be used for keeping the aircraft in an aerodynamically coordinated state (no slip).

2.3.3 Maintenance history of the aileron system

For a safe operation of commercial air transport, maintenance is performed by certified technical personnel. Maintenance performed on the aircraft is documented by the operator's technical department. The Dutch Safety Board has reviewed the maintenance records[4] of the aileron cable system on the aircraft and assessed the status of current airworthiness directives (ADs) related to aileron control cables. No ADs were found.

4 The records contain maintenance task (process steps) to be accomplished. The ground engineers have to sign off once the task has been completed. As for the aileron control cable, its technical state and findings are usually not recorded.

Both the broken and the paired cable of the left wing (ABSA-L1 and ABSB-L1) had been installed in the aircraft since the delivery in 1999.

On 4 November 2020, the last Detailed Visual Inspection (DVI) was performed by the operator[5] on the aircraft's wing and wheel-well flight control cables and cable runs, which includes the aileron cables. This detailed inspection is a regular maintenance task according to the manufacturer requirements. This inspection is scheduled for the interval of 24 months (730) days or 4000 cycles, whichever comes first. During this inspection at station AMS (Schiphol) no findings were reported.

On 12 December 2021, during a scheduled maintenance check performed by a maintenance organization in the United Kingdom[6], a flight control cable tension check was carried out and according to the documentation the results of it were within the required limits and no adjustments were made.

On 8 July 2022, the aircraft was 624 days in service, with 1,004 cycles and 2,919 flight hours since the last DVI on the aileron cable system had been performed.

Following the incident, according to the operator no anomalies were found during a fleet inspection.

2.4 Meteorological information

The relevant *Meteorological Aerodrome Reports* (METARs) are depicted in Table 1. The METAR of Heraklion indicated a 6 knots wind from the northwest and cloud ceiling and visibility OK (CAVOK). The latest weather observation at Athens prior to landing showed 10 knots wind from the northeast, few clouds and a visibility of 10 km or more (indicated by 9999).

▼ *Table 1. Relevant METARs for 8 July 2022. (Source: Ogimet)*

Location	Time (UTC)	METAR
Heraklion	08,50	LGIR 080850Z 33006KT CAVOK 28/19 Q1012 NOSIG=
	09.20	LGIR 080920Z 35006KT CAVOK 28/19 Q1012 NOSIG=
Athens	09.20	LGAV 080920Z 04010KT 9999 FEW030 29/15 Q1012 NOSIG=
	09.50	LGAV 080950Z 05011KT 010V070 9999 FEW030 30/14 Q1012 NOSIG=

5 The operator has an EASA Part-145 Maintenance Organisation Approval.
6 This maintenance organization is a Part-145 approved Maintenance Repair and Overhaul facility.

2.5 Flight data

The aircraft was equipped with a digital Flight Data Recorder (FDR). The data from this FDR was used for the investigation. The Dutch Safety Board could not use information from the Cockpit Voice Recorder (CVR), as it did not secure the data.

The Dutch Safety Board reviewed the FDR parameters of the deflections of the flight control surfaces, flight control steering inputs, aircraft altitude, aircraft attitude and magnetic heading. The graphics with the derived parameters are depicted in Appendix C.

The flight data of the flight from Schiphol to Heraklion show that the left and right aileron deflections were in accordance with the steering wheel inputs and no anomalies occurred. Roll angles during cruise and approach were in the range of ten degrees.

Flight data show that - after the flight control check for the return flight to Schiphol had been completed – the left aileron remained in a maximum up-deflection (approximately twenty degrees up) when the control wheel was turned. The data show that the deflection of the right aileron was in accordance with the control wheel input during the flight control check. During the takeoff – where air speed increased - the left aileron deflection decreased to approximately ten degrees up.
Flight data show that during the diversion from FL180 until landing the roll angle values varied in the range of 12 – 22 degrees. During approach and subsequent landing in Athens the airspeed decreased and the left aileron deflection increased to the maximum up position.

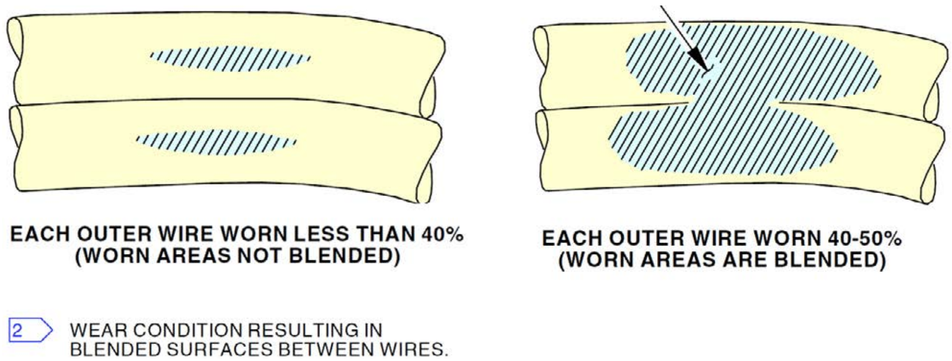
2.6 Maintenance inspection procedure

The formal inspection requirements
The Boeing 737 Aircraft Maintenance Manual (AMM) describes the procedure[7] for the DVI of the flight control cable system. The flight control cable system must be inspected on a regular basis, by means of a DVI carried out by a certified technician. The manufacturer has determined an inspection interval of 24 months (730 days) or 4,000 flight cycles, whichever comes first.

The inspection is divided into three parts. The first part states to check the integrity of the aileron cable routing including pulleys, fair leads and seals. Secondly, the condition of the control cable is inspected. According to the Boeing inspection procedure, the cable must be replaced by a new cable when:
- a wear pattern exists where the individual wires in a strand appear to blend together (outer wires worn by more than 40 percent)
- a kink is found

7 TASK 20-20-31-200-801 Control Cable Wire Rope – Inspection/ Boeing task card 27-226-00-01 Flight Control Cables – Left Main Gear Well

- corrosion is found.
- for the aileron carbon steel cable (7x19): four or more wires are broken over a length of 12 inches, or when there are six or more wires broken in the total cable assembly.



▲ *Figure 4: Wear patterns. (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

As final part of the inspection, it must be ensured there is sufficient lubrication on the control cable, by means of a light even coat of grease. Carbon steel steering cables require sufficient lubrication for three main reasons:

- To reduce internal friction between the wires in the composition of a strand and between the different strands of the cable. The cable of a flight control system is installed with a cable tension and moves over pulleys along its routing during flight control steering inputs by the pilot or auto pilot. With tension on the cable the strands are forced together. The moment the cable turns over a pulley, the strands of the cable shift internally to bent during the turn over the pulley.
- To reduce external friction between the cable and for example pulleys.
- To protect the cable against corrosion. To lubricate the steering cables, the AMM[8] prescribes/ mentions the procedure.

To lubricate the steering cables, the AMM prescribes the procedures. This procedure mentions to *not apply* grease directly to the following areas, because they will receive grease during cable movement: on the pulleys, on the quadrants and on the drums.

According to the Boeing Material Specification (BMS) as included in the 737-800 AMM for Control Cable Lubrication, the ground engineer has to use an absorbent cotton wiper[9] for cleaning. The cleaning should remove old grease and dirt from the cables. The procedure contains warnings to not use solvents or heat to thin the grease for cleaning. After application of new grease[10] on the cables, the surplus of grease has to be removed with a clean cloth leaving a thin visible film.

Conducting the DVI from the perspective of the ground engineer

For a ground engineer carrying out a DVI of the control cable is with difficulty to detect any wear, as the cable is still installed on the aircraft. Under this condition an inspection light and mirror are necessary to assess those positions of the cable which are not

8 AMM 12-26-00-600-801.
9 The cotton wiper is specified as AMS3819 Class 1 Grade A or B Form 1.
10 The grease is specified as BMS3-33.

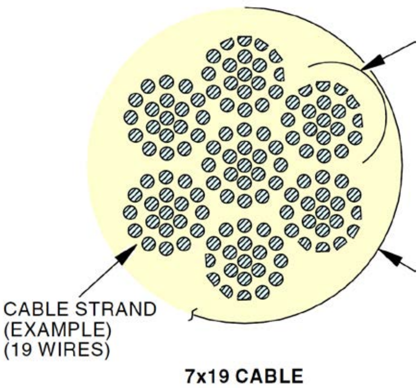
directly visible from the position of the ground engineer. The conditions of light intensity and light incidence can affect the ability to observe defects.

In addition to these restricting conditions and sight on the cable, in daily practice the real size of a flight control cable is small, which makes it difficult for ground engineers to make a good estimate of the 40 percent external wear. To establish the loss of cross section (as an indication of internal wear) is nearly impossible.

Provided that the ground engineer has cleaned the cable sufficiently, obvious anomalies like corrosion, kinks, and broken wires are relatively easy to observe. The AMM is helpful in prescribing the allowed broken number of wires over a certain length. The figures - as shown in Figure 10 – are depicted with a sufficient magnitude.

2.7 Examination of aileron cables and pulley

The aileron cables ABSA L1 and ABSB L1 have a diameter of 4.78 mm and consist of seven strands of nineteen wires. The cables have one core strand and six outer strands, see Figure 5. All wires are made of carbon steel with a zinc coating. In accordance with the Boeing material specifications, each wire of the cable must be coated with friction-preventative, non-corrosive lubricant by the manufacturer of the cable.



▲ *Figure 5: Composition of a the aileron cable. (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

Both the broken and the paired cable of the left wing (ABSA-L1 and ABSB-L1) and the pulley closest to the cable fracture position were removed from the aircraft for further examination. The cables, as shown below in Figure 6, were sent to the laboratory for metallurgical examination[11]. Section 2.7.1 describes the findings of the metallurgic examination with reference to the terminal of the concerned cable. Appendix D describes the findings in more detail. In Chapter 3 the Dutch Safety Board uses the findings of the laboratory for its own analysis on how the cable failed and which factors contributed to this failure.

11 The Dutch Safety Board does not have an own laboratory and equipment in house for metallurgical examination. In this case DSB opted to outsource the metallurgical examination.

The pulley located close to where the cable failed, was assessed by the Dutch Safety Board (and not sent to the laboratory), see Section 2.7.2.

▲ *Figure 6: Left, the two cables to be examined in the laboratory; Right, one part of the failed cable in detail.*

2.7.1 Examination of the cables

Both the broken and the paired cable were examined in a laboratory of the company Element in Amsterdam, the Netherlands. The examination consisted of a visual examination and a more detailed examination using a stereo microscope, a scanning electron microscope and optical microscopy. In addition, a chemical analysis of products on and between the strands was conducted. This section presents the main results and conclusions of the examination of the laboratory.

The examination determined that the aileron cables were in accordance with the specifications in the Aircraft Maintenance Manual (AMM).[12] The laboratory states that both cables showed corroded parts over the entire length. The corrosion was present up to the core strand. The presence of corrosion indicated that the cable was insufficiently lubricated with grease, making the cable subject to corrosion and increased wear. During the examination of the wires, no trace of a zinc layer was observed. According to the metallurgical report of Element, this indicates that the zinc layer was completely dissolved in the (contaminated) grease.

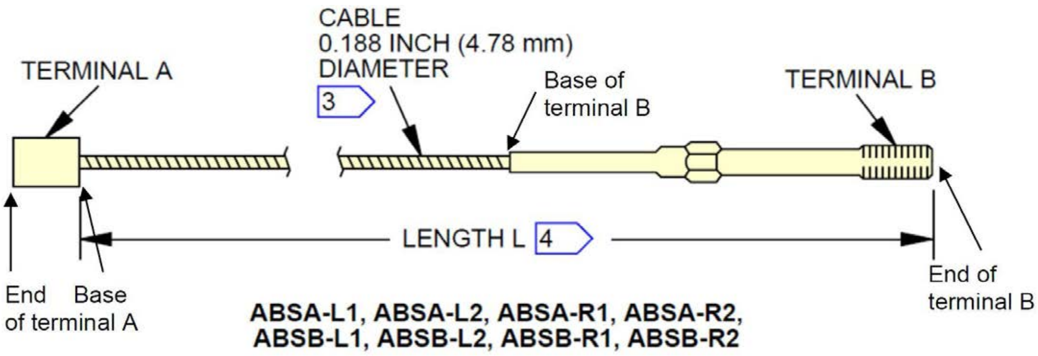
At the position of the cable fracture, both squeezed and worn wires were observed. Most observed broken wires were squeezed to very thin thicknesses.

The report further states that in case of insufficient lubrication, frictional resistance between the strands increases. If corrosion also occurs between the strands, they will become fixed relative to each other. When the cable is heavily loaded or must bend over a pulley, the strands may experience difficulty shifting over each other. As a result, high compression forces will occur between the strands. The laboratory concludes that these compressive forces squeezed the individual strands, deforming them into very thin wires.

According to the laboratory the wear pattern on the worn surfaces indicate that wear has occurred in the near-angled direction of the cable as well as in the longitudinal

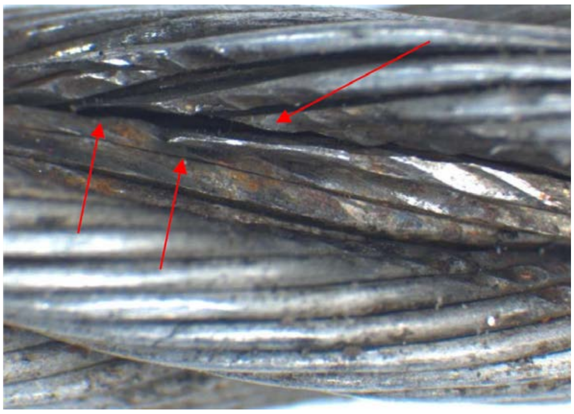
12 Cable specification AMM 27-09-14-860-801 as Boeing Material Specification (BMS) 7-265.

direction. The inability of the strands in the cable to slide smoothly over each other results in the cable being partly flattened when bending and, in the process, it does widen. This will cause the sides of the cable to press against the sidewalls of the pulley or even possibly no longer fit properly in the groove of the pulley. Longitudinal wear of the cable at the same position as transverse wear indicates that the cable was dragging through the pulley. This is an indication that the pulley was no longer rotating smoothly, which also might have been the result of improper greasing of the mechanism.



▲ *Figure 7: schematic overview of cable and its terminals. (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

The laboratory measured the fracture of the cable at 1,081 cm distance from the terminal A, see figure 7. Figures 8 and 9 show broken wires and deformation due to squeezing at different positions on this cable. For the complete list of measurements of the failed cable (ABSA-L1) and the paired cable (ABSB-L1), which had not failed, see Appendix D.



▲ *Figure 8: Failed cable at position 1,020 cm from the terminal reference position. The wires were broken (arrows) at the thinnest positions. (Source: Laboratory)*

▲ *Figure 9: Broken cable at position 832 cm from the reference position. (Source: Laboratory)*

The laboratory concludes the following:

- As far as could still be determined, the cables originally conformed to specification.
- Both examined cables were affected by corrosion, and over their length parts had also been affected by significant abrasive wear (including squeezing) on contact with a pulley.
- Evidence was also found of increased wear due to one or more pulleys that have not been properly rotating[13].
- The occurred abrasive wear and squeezing of wires has finally led to cable fracture.
- The root cause of the occurred failure is lack of proper lubrication (greasing) of the cable and pulleys.

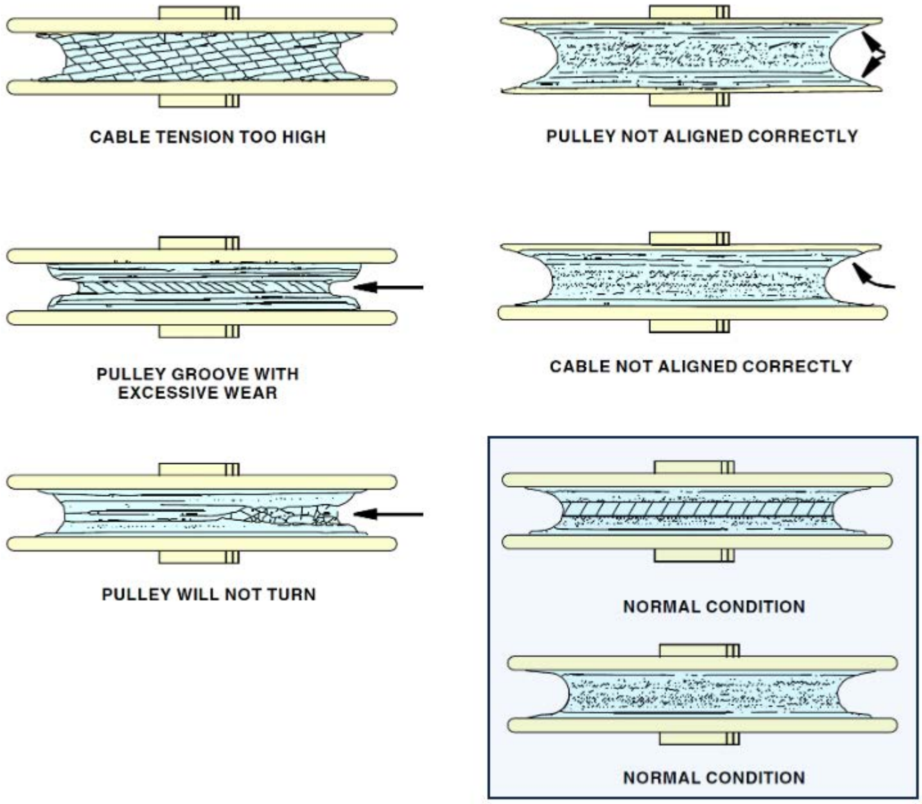
2.7.2 Pulley assessment

The pulley closest to the position of the fracture was removed preventively on behalf of the operator and made available for investigation by the Dutch Safety Board, see below in Figure 10. According to the operator the pulley has not been replaced since the aircraft got into service in May 2012.

▲ *Figure 10: The removed pulley located near the cable fracture.*

The Dutch Safety Board assessed the pulley in accordance with the Boeing 737 Aircraft Maintenance Manual (AMM)[14]. The AMM describes different wear patterns for the pulley, see Figure 11. Detailed visual examination of the pulley at the office of the Dutch Safety Board showed that the pulley rotated freely with normal wear patterns, as indicated in the framed figure below. It is noted that the functioning of the pulley 'as installed' – when it rotated under the load of the aileron cable being under tension - is unknown.[15]

13 The laboratory did not examine the pulley, see also Section 2.7.2 and for Analysis Section 3.3.
14 TASK 20-20-31-200-805 Inspection of pulleys.
15 The replacement of both the failed cable and the paired cable at Athens were corrective maintenance actions to regain aircraft serviceability and airworthiness. These works on the aircraft were not part of an investigation.



▲ *Figure 11: Damage patterns for various conditions. (Source: Aircraft Maintenance Manual) (Source: Boeing. Image Copyright © Boeing. Reproduced with permission.)*

2.8 Previous Boeing 737 aileron cable failures

The Dutch Safety Board gathered information regarding other events involving aileron cable failures on Boeing 737 aircraft. It found that the United States' National Transportation Safety Board (NTSB) investigated two events that occurred in 1993 and 1997. The Icelandic Transportation Safety Board (ITSB) investigated an event that occurred in 2019.

2.8.1 Boeing 737-130, registration N14212, 15 March 1993

In summary, the National Transportation Safety Board (NTSB) wrote in its report[16] that the aircraft rolled left immediately after lift-off, but the pilot controlled the roll with right aileron and was able to return to Newark and landed without further incident.
Examination of the airplane's aileron controls revealed that the aileron cable that controlled the downward deflection of the left aileron was broken at the point where the cable travels over a pulley in the main gear wheel well.
Metallurgical examination of the broken left "down" aileron cable revealed that 98 of the 133 total wires in the aileron cable showed wear through their entire cross-sectional areas. The remaining 35 wires exhibited a reduction of their cross-sectional areas by as much as 90 percent prior to failure.

16 Factual Report Aviation, NTSB ID: NYC93IA059.

The NTSB determined the probable causes of the incident to be the inadequate maintenance/inspection by the company, the inadequate inspection and/or replacement procedures of the manufacturer for the aileron cables and the subsequent failure of the 'down' aileron control cable due to wear.

In 1994, the NTSB issued three safety recommendations to the Federal Aviation Administration (FAA) as follows:
<u>*A-94-64:*</u> *Issue an Airworthiness Directive (AD) to operators of Boeing 727 and 737 airplanes requiring periodic inspection of the aileron cables for both internal and external wear, and for broken wires, with particular attention to the area of the cable contacting the pulleys. The inspection should include releasing cable tension to better detect cable wear and wire breakage and establishing a maximum allowable reduction in cable diameter where pulley contact occurs. Based on the inspections, develop specific flight hours interval for replacement of the cable.*
<u>*A-94-65:*</u> *Require that the Boeing Company examine the consequences of a 737- 100 aileron cable failure, and provide appropriate flight crew operational guidance for the best landing configuration in the event of such a failure.*
<u>*A-94-66:*</u> *Conduct a comprehensive study to determine the frequency of spoiler, rudder, and aileron cable failures on airplanes weighing 12,500 pounds or greater. Where the study reveals flight control inspection procedures to be inadequate, require appropriate revisions to those inspection procedures and/or issue Airworthiness Directives to mandate service life limits to assure greater reliability of those control cables.*

Follow-up to NTSB's safety recommendations
In response to the issued recommendations, the FAA conducted flight simulations in which it determined that the Boeing 737-100 was controllable with a broken aileron cable, that no additional flight crew guidance was necessary with regard to this condition, and that it did not consider an AD requiring periodic inspections in addition to the existing regular maintenance inspections to be necessary.

Also, the FAA stated that some inconsistencies were found in some of the procedures in the maintenance manuals for Boeing aircraft and that Boeing had eliminated these and developed one standard inspection procedure for the Boeing family of airplanes. Aileron cables may be replaced based upon an 'on-condition' assessment with wear criteria for replacement. The new standard procedure involved rubbing a cloth along the cable length to catch on broken cable strands and lock-to-lock control wheel rotation to expose cable hidden on the pulleys. Additionally, instructions for checking cable diameter wear were provided as an option. The FAA stated the inspection was to be performed every 12 to 18 months and the Aircraft Maintenance Manual recommended inspection of the exposed cables every "C" check, which is every 3,200 flight hours.

As for the recommendation A-94-66, the FAA reported in August 1995 that after a comprehensive study it was found that there had been six aileron cable failures on Boeing 737 aircraft in the ten years preceding the study.

In 1996 and 1997 the NTSB has closed all three recommendations as Acceptable (Alternate) Action taken, noting that the NTSB remained concerned that inspecting aileron cables without releasing cable tension may not provide adequate assurance of detecting internal broken cable wires.

2.8.2 Boeing 737-3TO, registration N13331, 27 September 1997

In summary, the NTSB wrote in its report[17] that after becoming airborne large amounts of aileron and rudder input were required to maintain wings-level flight and at least five units of left rudder trim were required when aileron input was reduced to zero. Upon returning to the gate, it was noted that the right aileron remained up with the control wheel centered. The aircraft had accumulated 34.633 airframe hours.
Post-flight inspection revealed that the ABSB aileron bus cable was broken and the ABSA cable was frayed. The break and fraying occurred where the cables ride over a pulley in the wheel well area. Examination of the cables concluded that the ABSB cable failure was the result of severe internal wear due to normal movement of the cable over a pulley for an extended period of time. Examination also noted several areas of severe external wear on the cables.

The NTSB determined the probable cause(s) of this incident to be separation of the ABSB-4 aileron bus cable, resulting in reduced lateral controllability of the aircraft. Related factors were wear in the cable and inadequate inspection of the cable.

2.8.3 Boeing 737-800, registration TF-HHB, 18 August 2019

In summary, during a ferry flight from Abidjan, Ivory Coast, at FL360 the aircraft entered moderate turbulence, where the flight path changed by 200-300 feet and the speed varied by 20-30 knots. In the turbulence, the crew had to apply aileron control to the left. Shortly later, the autopilot disengaged and the flight crew had to apply manual aileron input to the left to keep track. The crew declared an emergency and decided to divert to Casablanca, Morocco. Post-flight inspection showed that a right aileron cable had failed.

The Icelandic Transportation Safety Board (ITSB), representing the state of Registry, conducted a safety investigation and published a bulletin. Reportedly, three months prior to the incident the cable had been inspected and approved for continued use.

The investigation concluded that the cable failure was the result of both internal and external wear. Areas of corrosion were also found, indicating that the maintenance and/or inspection of the cable was not adequate.

17 Factual Report Aviation, NTSB ID: SEA97IA219.

2.8.4 Other events

Boeing indicated that there were three other similar events reported to Boeing since 1997, for which no ICAO Annex 13 investigation have been initiated.

2.9 Revised inspection interval

In the June 15/2022 revision, the Boeing Maintenance Planning Document (MPD) for the 737-600/700/800/900/900ER, which showed the required interval of inspection for exposed portions of flight control cables was 4,000 flight cycles and 24 months[18]. Over the summer, in the June 15/2023 revision, Boeing changed the interval[19] for this to 6,600 flight cycles and 36 months.

The change was approved by the Industry Steering Committee (ISC) in 2021. The ISC approval includes approval from Boeing maintenance engineering as well as airline and FAA approval. Note that the MPD is an FAA approved document and all changes to it are subject to their approval. This change was a result of a statistical analysis of a sample of inspection results collected from January 2012 - September 2019 from the Boeing 737 fleet worldwide.

According to the ISC Task Review Report[20] summary of Boeing, for this period it concerned 6,707 aircraft of the type Boeing 737 (-600, -700, -800), which had accumulated a total of 106,360,000 flight hours. Boeing reviewed maintenance data for flight control cables from 65 operators with 1,294 Boeing 737 aircraft for analysis.

18 Maintenance Planning Document (MPD Item 27-226-00).

19 In September 2023 the Dutch Safety Board asked Boeing why and when the limit of 3,200 flight cycles and 12-18 months were stretched to 4,000 flight cycles and 24 months. Boeing explained that the NTSB recommendations in early '90 for the 737 not be directly applicable to the 737NG, as control cable materials and vendors have changed during that time period.

20 Boeing ISC Task Review Report, Analysis Name 27-226-00, Analysis Title Flight Control Cables.

3 ANALYSIS

3.1 Cable failure

The roll effect to the left upon lift-off and afterwards was caused by the non-functioning of the left aileron of the aircraft, which came and remained in an upward position. This was caused by a failure of the aileron cable for the left aileron down input in the wheel well. As revealed by Flight Data Recorder (FDR) data, the aileron cable failed when the crew performed the flight control check as part of the '*Before taxi checklist*'. The original aileron cable, installed since aircraft delivery on 15 January 2000, was still in place, meaning that the cable had accumulated 75,776 flight hours when it failed.

Laboratory analysis shows that the composition of the broken cable was according to the prescribed Boeing Material Specification (BMS) and Aircraft Maintenance Manual (AMM) specifications. However, both the failed and paired cable were affected by corrosion and significant abrasive wear, including squeezing, and showed a lack of sufficient lubrication.

The signed off maintenance documents - like task cards – only show that the Detailed Visual Inspection (DVI) had formally been accomplished. It does not describe – nor is this required - a detailed condition of the inspected cables. Furthermore, the Dutch Safety Board did not find peculiarities that could relate to the corrosion and non-lubricated condition of aileron control cables when it reviewed the maintenance and aircraft tech log documents. Therefore, the Dutch Safety Board decided not to continue an in-depth reconstruction of the DVI or other circumstances, as it would likely not reveal why the cables showed a lack of sufficient lubrication.

Referring to Section 2.7.2, as the DSB assessed the pulley itself (hence, the pulley was not sent to the laboratory for examination), the DSB needs to address the conclusion of the laboratory that the pulley near the cable fracture was not properly rotating. Since the operator had the aircraft in service from May 2012, the assessed pulley had been installed at least more than 10 years. The DSB found that a normal contact pattern of the aileron cable was in accordance with the AMM. It is therefore assumed that the assessed pulley had no adverse effect on the cable other than that cable displacement over the pulley affected normal wear. The history of the pulley(s) and the effect on the condition of the aileron cable were not further investigated, as it would not explain the lack of lubrication of the aileron cable anyway.

3.2 Non-detection of cable failure prior to departure

Flight crew statements revealed that during the flight from Schiphol to Heraklion no flight control difficulties were experienced and flight data showed normal aileron behaviour of both ailerons. Data analysis revealed that the cable had failed prior to taxi, explaining the flight crew information that abnormal behaviour of the left aileron occurred after lift-off from Runway 27 at Heraklion.

The flight control check by the pilots prior to taxi particularly focused on the functioning of the flight control systems. Flight data reveals that the left aileron cable happened to fail during the aileron flight controls check. This check could not have detected the aileron cable discontinuity between the aileron feel and centering unit and the ailerons[21], as there is no aileron position (deflection) feedback for the pilot, nor are the ailerons visible from the cockpit.

The Aircraft Technical Log (ATL) showed no entries that could be related to the cable failure.

3.3 Detection of defects during maintenance

3.3.1 Required inspections

History of the Detailed Visual Inspection (DVI)
The cable failed about 20 months and 1,004 flight cycles since the last DVI. The required maintenance interval limits (4,000 flight cycles and 24 months) valid at that time had not been exceeded.
Taking into account the limits of 3,200 flight hours (C-check) or the 12 - 18 months as mentioned in Section 2.8.1, the applicable AMM interval limits at the time of the aileron cable failure were 6 to 12 months more and 800 flight hours more than in October 1996, when the NTSB closed recommendation A-94-64 as 'Acceptable Alternate Actions' taken by FAA and Boeing. Eventually, since 15 June 2023 the industry increased the inspection interval to 6,600 flight cycles and 36 months (whichever comes first) based on statistical information.

Based upon the AMM, no life time limits exist for aileron control cables. The cables are monitored 'on condition', where the AMM provides inspection criteria for replacing them. The work card, signed off on 4 November 2020, indicates that during the last DVI no defects were found. When compliance with AMM requirements is assumed, it nevertheless did not prevent the aileron cable failure of PH-CDF. Taking into account that the flight control check by the pilots (Before Taxi checklist) could not reveal an (imminent) failure, a timely detection of a deteriorating flight control cable in that part of the aileron flight control system depends on an adequate maintenance process.

21 This also applies to the elevator and rudder flight controls 'behind' their respective feel and centering units.

As far as known, it was not before 2019 (TF-HHB) and subsequently 2022 (PH-CDF) that in-flight cable failures occurred with Boeing 737 aircraft since 1997. As such, there is no immediate reason to doubt the effectiveness of the current AMM procedures.

3.3.2 Limitations to detect defects

External wear
The pictures depicted in the AMM (see 2.6 figure 4) show a magnified cable to make clear how to check the percentages of external wear. In practise, however, the cable and its strands are small (thin). Blended spots on the cable are not always easy to detect. During an 'on condition' DVI it is nearly impossible for ground engineers to reasonably estimate the percentage of external wear. Furthermore, it is imaginable that during the last DVI of the PH-CDF an engineer accidently overlooked that the allowed number of broken wires was exceeded.

Internal wear
Internal wear was considerable in both the events previously investigated by the NTSB and the occurrence with PH-CDF. However, it is noted that these measured losses of cross-section area (surface) have been established in a laboratory. The degree of loss of cross section area could not reasonably be visually determined during a DVI on the aircraft by a ground engineer. This can result in imminent wire failures remaining undetected.

The broken aileron cable of PH-CDF had been in use twice as long and more than double in airframe hours than the cable of the Boeing 737 investigated by the NTSB (see Section 2.8: *N13331, 27 September 1997*). Consequently, due to normal wear (both internal and external) chances increased that the cable of PH-CDF could suffer substantial wear and/or more broken wires than allowed in the AMM.

When knowing the limitations of the DVI, in particular for cables that have aged in cycles and flight hours (as was the case for PH-CDF), the maintenance method and DVI maintenance limits (4,000 flight cycles or 24 months as applicable during the cable failure event) become more critical.

Cable tension check
The cable tension check took place seven months prior to the cable failure. Though the aileron cable tension check has a different goal than a DVI, damaged wires (if any) in the cable could have been noticed, since the ground engineers may have worked on the cable in the proximity of where the cable fractured. No striking defects (like a frayed aileron cable) have been observed 13 months after the last DVI.

3.4 Effect lubrication and aging on wear

Since both the failed and the 'paired' cable were found without proper lubrication, it cannot be ruled out that both cables have not been treated and lubricated in accordance with the AMM, or not lubricated at all.

The absence of sufficient lubrication was an important factor in the failure of aileron cables in the PH-CDF and TF-HHB events. Given the maintenance limits (24 months or 4,000 flight cycles at the time of event), the interpretation to what degree aging and (normal) wear of the aileron posed a risk, was impeded by the fact that there was insufficient lubrication for the PH-CDF aileron cable, which accelerated the wearing process.

3.5 Flight safety consequences of cable failures

When one of the cables of the left aileron failed, the system design still allowed the right aileron to function and flight spoilers assisted the roll movement when the control wheel was turned more than 10 degrees. Though the aircraft was in a degraded state due to the loss of a primary flight control, the flight crew kept control over the aircraft attitude and flight path.

Flight data shows no excessive roll angles after lift-off as the pilot flying anticipated the first roll effect. As for the remainder of the flight, including the moment when flaps were set for landing at Athens, flight crew statements and data confirm no excessive values of roll angles (varying 12 – 22 degrees) or other flight parameters. Without understanding what caused the flight control problem, the flight crew managed the roll effect by applying rudder and aileron input including adjusting rudder trim and aileron trim.

Without detailing the operational circumstances, the general aircraft behaviour and response by the flight crew of PH-CDF seemed comparable to two occurrences in 1993 and 1997 with manageable controllability. The aircraft flew in fair weather all the time. The atmosphere was smooth during take-off and enroute towards Athens (the diversion). The weather conditions had no adverse effect on controlling the aircraft with the left aileron not working. Because of the decision by the flight crew to divert to Athens with good weather, flight safety was not further compromised.

However, weather conditions can have a negative effect on flight safety when flying with an aileron cable failure, as is demonstrated in the cable failure event of TF-HHB in 2019. Under moderate turbulence conditions the flight crew declared an emergency due to problems in controlling attitude, flight path and airspeed.

3.6 Considering the safety issue and recommendation

The failure of a primary flight control is considered as a serious incident. As shown by the events in 2019 (TF-HHB) and 2022 (PH-CDF), the consequences for the controllability (roll function) following the failure of an aileron control cable during flight depend upon the circumstances like the weather.

There are limitations to what ground engineers can determine regarding the degree of wear of cables - as assumed in the AMM - that are inspected 'on condition' during DVI. Taking into account the effect of normal wear, after each DVI without findings (compliant with AMM) there will be less margin to a potential cable failure till the next DVI as long as the inspected cables remain installed.
Therefore, the Dutch Safety Board takes the view that for aging cables the maintenance process becomes more important. The investigation revealed that - compared to the N13331 event investigated by NTSB (see Section 2.8.1) - the failed aileron cable of PH-CDF had accumulated more than double in airframe hours.

The metallurgical examination demonstrates a lack of lubrication, which had an adverse effect on the condition of the cable. Because of that, it is not possible to conclude what contributed to the cable failure the most: aging (in terms of normal wear relating to airframe hours with proper lubrication) of the original aileron cable on PH-CDF, or lack of lubrication which promoted more than normal wear and corrosion. Accordingly, it cannot be determined if the interval of the DVI (4,000 flight cycles or 24 months) valid at the time of the event, was a relevant factor. Besides, the lack of lubrication indicates a deficiency in the maintenance process, which is not accounted for in the AMM.

On the other hand, reviewing the last three decades, Dutch Safety Board concludes that against the background of hundreds of millions of airframe flight hours, the serious incidents with the PH-CDF and TF-HHB cannot be seen as an indication of a structural safety problem. A safety recommendation for the Boeing 737 aileron flight control cables is therefore not considered to be appropriate.

Since 15 June 2023 the industry – with reference to statistics and the approval of the FAA - has further stretched the inspection interval up to 6,600 flight cycles or 36 months.

4 CONCLUSIONS

Due to a failure of the left aileron control cable, the aircraft got into a degraded state of safety, as it partially lost a primary flight control causing a continuous roll effect to the left.

The aircraft remained controllable as the flight crew managed the roll effect by applying rudder and aileron input. The aircraft flight control system design aided in keeping control over the aircraft attitude and flight path. It is to be noted however that the serious incident occurred during favourable weather conditions as the atmosphere was smooth.

For the system configuration on the PH-CDF, the flight control check performed by the flight crew (as part of the *Before taxi checklist*) is not effective in detecting a deteriorating or failed flight control cable between the feel and centering unit and the ailerons. A timely detection of a defect depends on an adequate maintenance process.

The failed aileron cable was according to material specifications and it was the original cable since aircraft delivery in January 2000. Detailed examination showed that both the failed and paired cable were affected by corrosion and wear and lacked sufficient lubrication. The absence of sufficient lubrication promotes wear and corrosion.

The Dutch Safety Board could not determine why the cables were not properly lubricated. The maintenance documentation shows that the required inspections were performed and that the tasks were signed off as completed. However, it cannot be ruled out that both cables have not been treated and lubricated in accordance with applicable maintenance procedures.

In view of the Dutch Safety Board, it is important that - in particular for cables that have aged in cycles and flight hours – a ground engineer timely detect defects. In general, for ground engineers, the detection and determination of the extent of wear during a Detailed Visual Inspection (DVI) of the cables is a difficult task because of the small size of the cable inspected 'on condition'.

Insufficient lubrication was the case for PH-CDF, but the overall effect of wear over lifetime of the aileron cables contributed to the failure as well. It could not be determined that aging (in terms of normal wear) of the aileron cable was a more dominant factor than the effect of lack of lubrication which promoted more than normal wear and corrosion.

The required interval limits for the DVI have been stretched from every 12 to 18 months in 1996 to 4,000 flight cycles or 24 months as applicable in June 2022. Given the effect of corrosion due to lack of lubrication as found on PH-CDF, it cannot be determined that the inspection interval of the DVI (4,000 flight cycles or 24 months) valid at the time of the event, was set too broadly.

Reviewing the last three decades with hundreds of millions of flights, there is no immediate reason to doubt the effectiveness of the current maintenance procedures. The Dutch Safety Board concludes that - despite the serious incidents with PH-CDF and TF-HHB – a safety recommendation is therefore considered not to be appropriate.

APPENDIX A

Responses to the draft report

In accordance with the Dutch Safety Board Act, a draft version of this report was submitted to the parties involved for review. The following parties have been requested to check the report for any factual inaccuracies and ambiguities:

- Corendon Dutch Airlines B.V.
- Captain
- First Officer
- NTSB
- Boeing Commercial Airplanes
- EASA
- Ministry of Transport and Water Management
- ITSB

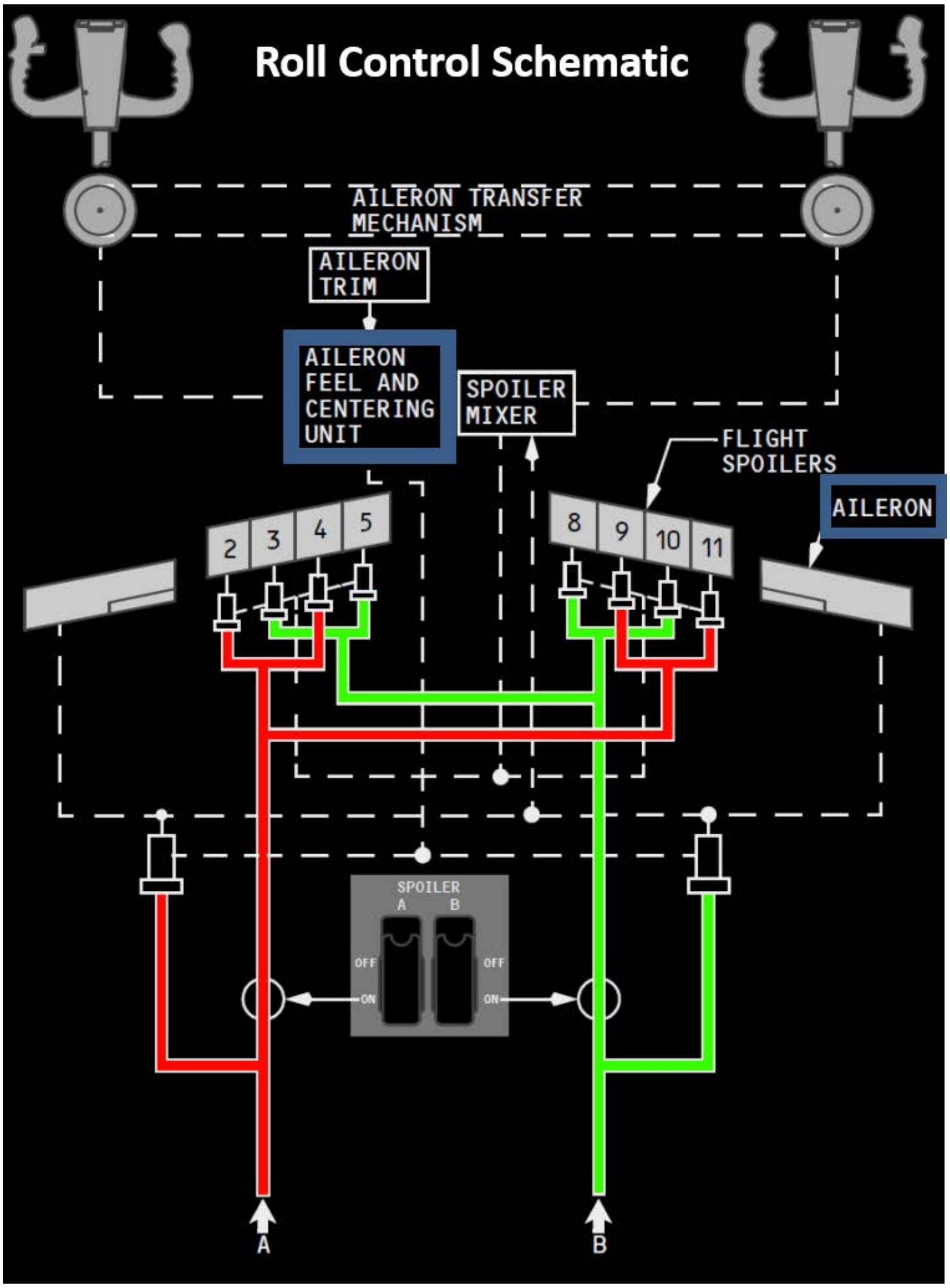
The responses received, as well as the way in which they were processed, are set out in a table that can be found on the Dutch Safety Board's website (https://www.safetyboard.nl).

The responses received can be divided into the following two categories:

- Corrections and factual inaccuracies, additional details and editorial comments that were taken over by the Dutch Safety Board (insofar as correct and relevant). The relevant passages were amended in the final report.
- Responses that were not adopted by the Dutch Safety Board. The reason for this decision is explained in the table.

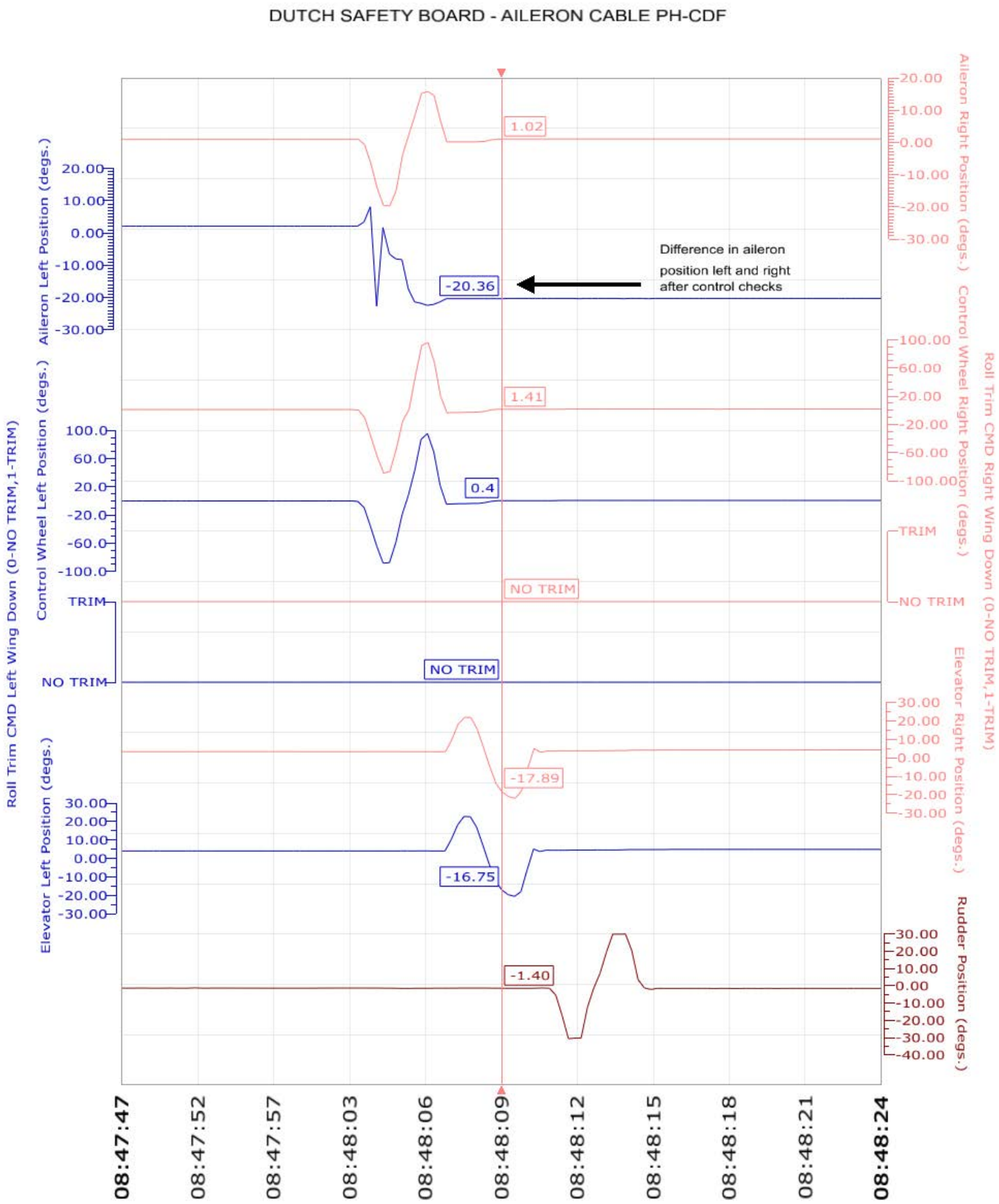
APPENDIX B

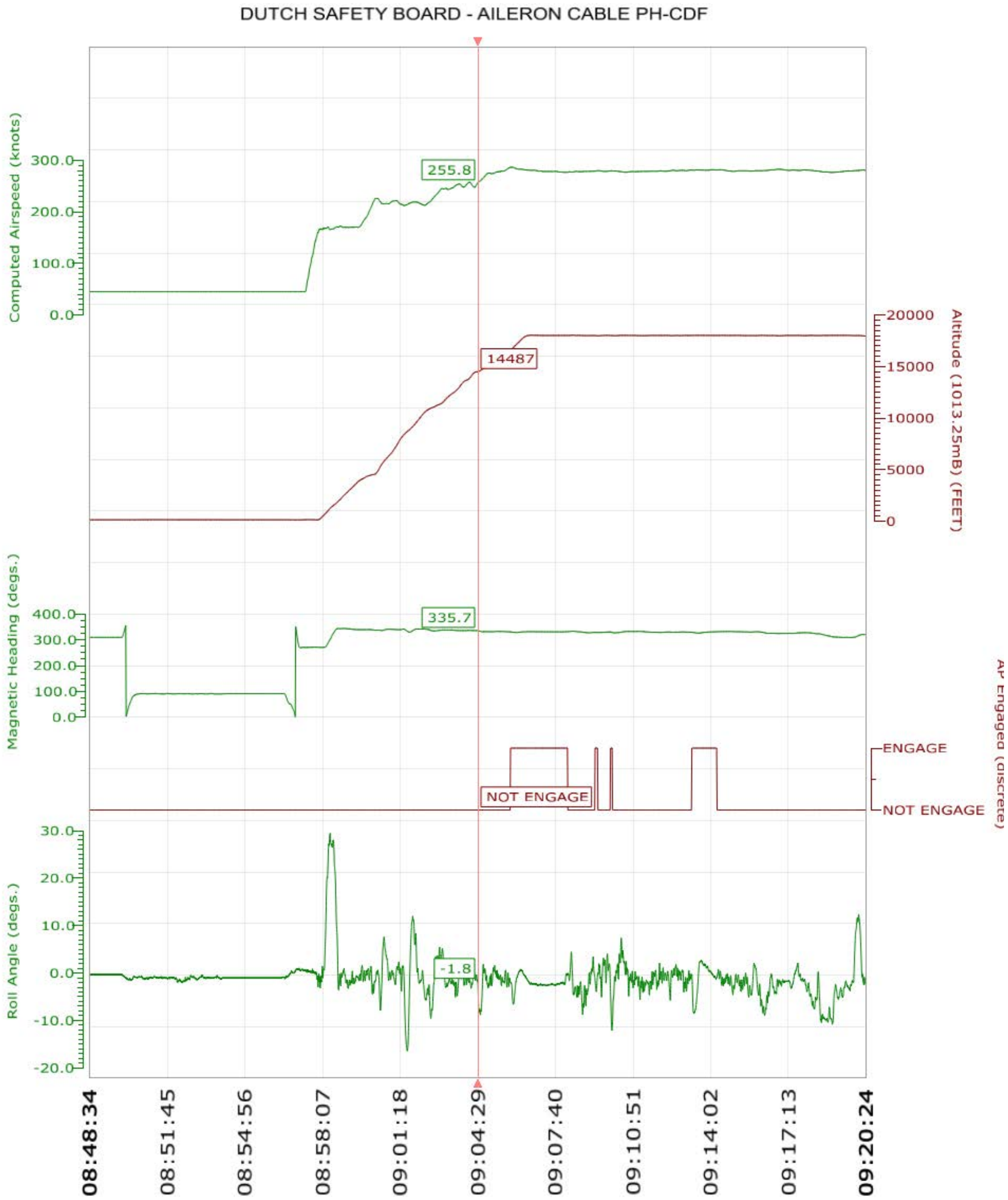
Aileron feel and centering unit and aileron control



APPENDIX C

Flight data





DUTCH SAFETY BOARD - AILERON CABLE PH-CDF
Computed Airspeed (knots)
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200.0
100.0
0.0
255.8
Altitude (1013.25mB) (FEET)
20000
15000
10000
5000
0
14487
Magnetic Heading (degs.)
400.0
300.0
200.0
100.0
0.0
335.7
AP Engaged (discrete)
ENGAGE
NOT ENGAGE
NOT ENGAGE
Roll Angle (degs.)
30.0
20.0
10.0
0.0
-10.0
-20.0
-1.8
08:48:34
08:51:45
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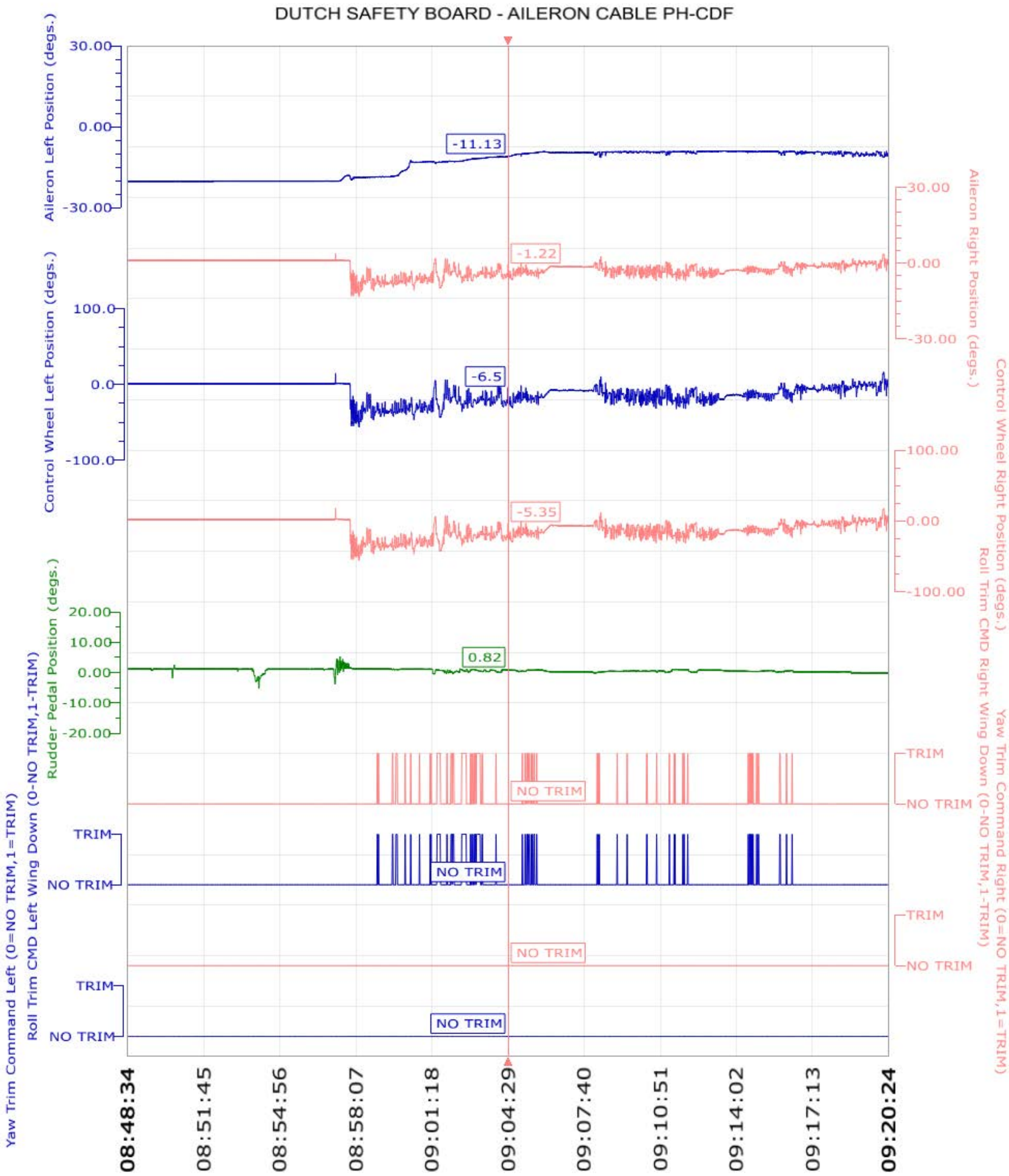
09:20:24


DUTCH SAFETY BOARD - AILERON CABLE PH-CDF
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-30.00
-11.13
Aileron Right Position (degs.)
-1.22
Control Wheel Left Position (degs.)
100.0
0.0
-100.0
-6.5
Control Wheel Right Position (degs.)
100.00
-100.00
-5.35
Rudder Pedal Position (degs.)
20.00
10.00
-10.00
-20.00
0.82
Roll Trim CMD Right Wing Down (0-NO TRIM,1-TRIM)
Roll Trim CMD Left Wing Down (0-NO TRIM,1-TRIM)
Yaw Trim Command Right (0=NO TRIM,1=TRIM)
Yaw Trim Command Left (0=NO TRIM,1=TRIM)
TRIM
NO TRIM
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08:54:56
08:58:07
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09:07:40
09:10:51
09:14:02
09:17:13
09:20:24

APPENDIX D

Overview laboratory measurements:

Failed cable ABSA-L1:

Distance from begin terminal A [cm]	Remark
3	Near terminal A the cable diameter was 5,00 mm
16	Corrosion of the outer cable surface over a distance of 5 cm
51	Wear of the outer strands over a distance of about 3 cm, diameter 4.93 mm
174	Wear of the outer strands over a distance of about 6 cm, diameter 4.88 mm
300	Wear of the outer strands over a distance of about 4 cm, diameter 4.95 mm
346	Wear of the outer strands over a distance of about 3 cm, diameter 4.72 mm
445	Wear of the outer strands over a distance of about 5 cm, diameter 4.65 mm
675	Corrosion of the outer cable surface over a distance of 8 cm
720	Corrosion of the outer cable surface over a distance of 10 cm
765	Wear of the outer strands over a distance of about 6 cm, diameter 4.65 mm
832	Wear of the outer strands over a distance of about 5 cm, diameter 4.15 mm
832	Broken wires
1020	A birdcage and slightly corrosion at the outer cable surface over a distance of about 10 cm.
1020	Broken wires
1081	Cable fracture. The diameter just before and after the fracture was about 4.3 mm
1008	Near terminal B the cable diameter was 5,00 mm

Paired cable ABSB-L1:

Distance from begin terminal A [cm]	Remark
3	Near terminal A the cable diameter was 5,00 mm
45	Corrosion of the outer cable surface over a distance of 20 cm
135	Corrosion of the outer cable surface over a distance of 5 cm
530	Corrosion of the outer cable surface over a distance of 20 cm
530	Wear of the outer strands over a distance of about 4 cm, diameter 4.82 mm
683	Wear of the outer strands over a distance of about 3 cm, diameter 4.78 mm
730	Wear of the outer strands over a distance of about 3 cm, diameter 4.67 mm
740	Corrosion of the outer cable surface over a distance of 38 cm
790	Corrosion of the outer cable surface over a distance of 13 cm
808	Corrosion of the outer cable surface over a distance of 12 cm
842	Wear of the outer strands over a distance of about 3 cm, diameter 4.81 mm
909	Wear of the outer strands over a distance of about 4 cm, diameter 4.79 mm
1112	Corrosion of the outer cable surface over a distance of 10 cm
1171	Near terminal B the cable diameter was 5,00 mm

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