DRAFT FINAL REPORT

Crash of Malaysia Airlines Boeing 777-200, 9M-MRD, flight MH17

Hrabove, Ukraine, 17 July 2014

The Hague, 2 June May 2015
The reports issued by the Dutch Safety Board are open to the public.
All reports are also available on the Safety Board's website www.safetyboard.nl

Dutch Safety Board

The aim in the Netherlands is to reduce the risk of accidents and incidents as much as possible. If accidents or near-accidents nevertheless occur, a thorough investigation into the causes of the problem, irrespective of who is to blame for it, may help to prevent similar problems from occurring in the future. It is important to ensure that the investigation is carried out independently from the parties involved. This is why the Dutch Safety Board itself selects the issues it wishes to investigate, mindful of citizens' position of dependence with respect to public authorities and businesses. In some cases, the Dutch Safety Board is required by law to conduct an investigation.

	Dutch Safety Board		
Chairman:	T.H.J. Joustra E.R. Muller M.B.A. van Asselt		
General Secretary:	M. Visser		
Visiting address:	Anna van Saksenlaan 50 2593 HT The Hague The Netherlands	Postal address:	PO Box 95404 2509 CK The Hague The Netherlands
Telephone:	+31 (0)70 333 7000	Fax:	+31 (0)70 333 7077
Website:	www.safetyboard.nl		

Contents

Appendicies

2.11 Flight recorders, satellite and other data

2.11.1 Recovery of Cockpit Voice Recorder and Flight Data Recorder

The Cockpit Voice Recorder and Flight Data Recorder were not recovered from the wreckage site by investigators of the Annex 13 investigation team, but individuals unknown to the team removed the two recorders from the accident site. On 21 July 2014, the recorders were handed over to a Malaysian official in Donetsk by representatives of the armed group controlling the area. No evidence or indications of manipulation of the recorders were found. On 22 July 2014, the recorders were handed over to the Dutch Safety Board in Kiev. Appendix K contains further information on the Cockpit Voice Recorder and Flight Data Recorder.

It should be noted that the images for both recorders show two sets of texts, one in Cyrillic text and one in French. The label in French, repeated in English on the other side of the unit, is placed there by the manufacturer, Honeywell. The Cyrillic text on the sticker on the unit states "*The Prosecutor General's Office of the Donetsk People's Republic*" This was not added by the Dutch Safety Board but was on both data recorders when they were handed over to the Safety Board.

2.11.2 Cockpit Voice Recorder

The housing of the Cockpit Voice Recorder (Figure 8) was damaged and, although the model and serial numbers are unreadable on the datum plate, the serial number 1366, matching the one provided by Malaysia Airlines, is stamped on the underside of the chassis. The external damage on the Cockpit Voice Recorder is consistent with impact damage; the internal memory module was intact. The Cockpit Voice Recorder was successfully downloaded and contained valid data from the flight.

Figure 8 – Cockpit Voice Recorder (Source: DSB)

The replay of the Cockpit Voice Recorder matched Air Traffic Control communications with flight MH17 (see Air Traffic Control transcript). The recording also included crew communication which gave no indication that there was anything abnormal with the flight. The Cockpit Voice Recorder audio recording ended abruptly at 13.20:03 (15.20:03 CET). A replay of the Cockpit Voice Recorder did not identify any aeroplane aural warnings or alerts of system malfunctions. It was noted that on one of the four channels of audio, the cockpit area microphone, the sound quality was poor. The relevant parts of the Cockpit Voice Recorder recording are integrated with the Air Traffic Control transcript in Appendix K of this report.

Crew communication gave no indication that there was anything abnormal with the flight. At the very end of the recording, two peaks of sound were identified on the last 20 milliseconds of the recording. A graphic representation of the two peaks of sound for the four Cockpit Voice Recorder microphones are shown here.

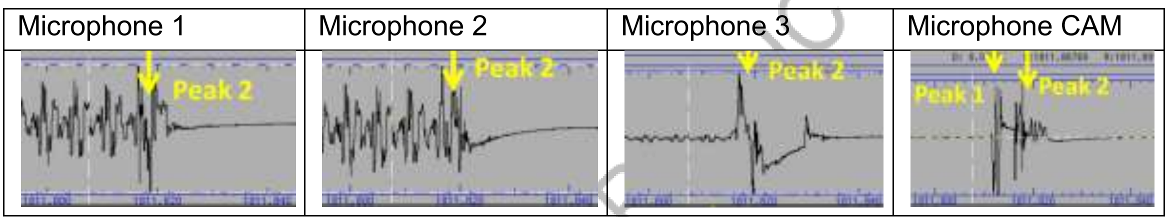

Figure 9 – Sound peaks recorded at the end of the CVR recording (Source: DSB)

The time period shown on each image is four hundredths of a second. It is noted that peak of sound ‘peak 1’ is only recorded on the CAM.

2.11.3 Flight Data Recorder

The housing of the Flight Data Recorder (Figure 10) Allied Signal Model Number 980-4700-003, has Serial Number 2196. The details match the details provided by Malaysia Airlines. The recorder that was given to the Dutch Safety Board had no Underwater Locator Beacon attached. As this beacon is activated by submersion in water, its activation is not expected.

The recorder is damaged but the internal memory module is intact. The external damage on the Flight Data Recorder is consistent with impact damage. The Flight Data Recorder, which can record 25 hours of operational data, was successfully downloaded and contained valid data from the occurrence flight.

2.12 Wreckage and impact information

The following paragraphs describe the geographic area of the accident and wreckage as it was found. Details are provided on the location, identification and observed damage of the wreckage pieces.

2.12.1 Accident site access

Due to the security situation within the geographic area of the crash, the Dutch Safety Board was unable to start the collection and preservation of the wreckage directly after the crash.

Under escort of the OCSE, air accident investigators from Australia, Ukraine and Malaysia, the Australian Federal Police and journalists had access to the crash area in the days following the accident. During these visits, the wreckage was photographed extensively and showed the locations mostly undisturbed.

It was not until 4 November 2014 that the Dutch Safety Board was able to visit the various locations where the wreckage was located, under the protection of the Dutch Ministry of Defence's Recovery Mission. On 15 November, after receiving permission from local authorities, wreckage parts were collected during 6 days and transported to the Netherlands for the investigation and partial reconstruction of the fuselage. It was necessary to cut some parts into smaller pieces for transport.

It was not until 20 March 2015 that it was possible to gain access to the area northwest of the village of Petropavlivka for the first time. From 19 April until 2 May more pieces of wreckage were recovered with the assistance of the local residents.

It should be noted that many parts of the wreckage were not physically examined by the Dutch Safety Board until four months after the accident. During this period parts were also removed, taken away or collected. Wherever possible, the photographs taken immediately after the accident were used in conjunction with the wreckage found.

2.12.2 General distribution of wreckage and distribution diagrams

The wreckage parts of the aeroplane were identified in six concentrated areas to the west and south-west of the village of Hrabove, within an area of approximately 50 km^2. Figure 12 shows the geographic location of the six wreckage areas. Each wreckage area has an associated colour, depicted in figures 13 and 14.

Figure 12 – Overview wreckage areas with wreckage parts

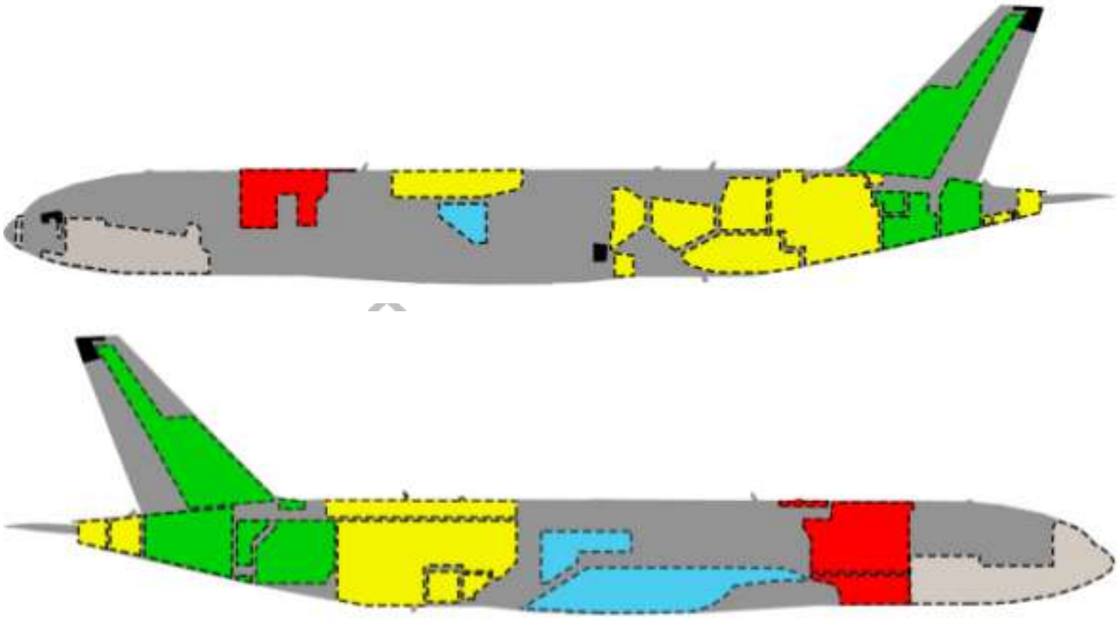

Figure 13 – Side view left and right. Identification of wreckage retrieved from the wreckage areas (Source: DSB)

The following table gives an overview of the wreckage areas that are described in this paragraph. A detailed description of the primary wreckage parts and their location is presented in Appendix O.

Wreckage site no.	Colour code	Notes	Paragraph	Appendix O
1	Orange	An open area of farming land	2.12.2.1	Fig. O.1
2	Red	Residential area of Petropavlivka	2.12.2.2	Fig. O.1
3	Light grey	An area of farming land south of the village of Rozsypne	2.12.2.3	Fig. O.1
4	Yellow	A built-up area partially surrounded by a forest in a gully	2.12.2.4	Fig. O.2
5	Green	An area of farming land separated by an elevated road	2.12.2.5	Fig. O.3
6	Blue	An area of farming land separated by an elevated road southwest of the village of Hrabove	2.12.2.6	Fig. O.4
0	Black	Parts of wreckage of which the initial location could not be verified	2.12.2.7	-

Table 12 – Overview description of wreckage sites in this report

It was noted that no parts of wreckage were identified between the areas 3 and 4.

For each wreckage area, a description of the wreckage parts relevant for the analysis is given. A more detailed description of the wreckage pieces of interest can be found in Appendix O.

In the description of the damage to the aeroplane Boeing references such as sections and stations (STA) are used. Information on these two means of reference is provided under Abbreviations & Definitions.

2.12.2.1 Wreckage area 1 (orange)

Parts of the fuselage originating from section 41, including parts of the cockpit fuselage, the fuselage above the business class, cockpit and cabin furnishing, and fragments of two cargo containers, were located in area 1. This area of approximately 3 km^2, is located 8.8 km west of the village of Hrabove. Parts of wreckage were distributed over three agricultural fields which were separated by roads and vegetation. No fire nor infrastructure damage was observed in this area. Due to shelling, the Dutch Safety Board was unable to access area 1 during the recovery mission in November 2014.

2.12.2.2 Wreckage area 2 (red)

The pieces of wreckage of the forward section of the aeroplane, including the doorframe and surrounding fuselage of doors 1L, 2L, 1R and 2R and the cargo floor, originating from section 43 of the aeroplane, were located in area 2. This area of approximately 2.5 km^2, covers a large part of the village of Petropavlivka and is located 8 km west of Hrabove. As a result of fallen debris, several structures within the village of Petropavlivka had sustained damage. Due to shelling access to area 2 was restricted. The Dutch Safety Board was unable to retrieve all parts identified in area 2 during the recovery mission in November 2014.

Fuselage with negative pressure relief valves

The fuselage containing door 2R was identified in the south-eastern region of area 2. The passenger door was positioned in its doorframe and the fuselage had sheared below the frame of the left negative pressure relieve valve. The left negative pressure relief valve was attached to the upper portion of the frame and the door was pinned in its open position between the casing and the ground. Neither the frame nor the valve of the right negative pressure relieve valve were found in area 2.

Engine Inlet ring

The leading edge of the left engine casing was found in the south-eastern region of area 2. The ring showed penetration damage on approximately the 40, 50, 60, 135, 180, 200, 290 and 300 degree positions, looking forward.

Figure 14 – Damaged left engine nacelle leading edge (left) and impact marks at the 200 degree position shown from the rear side (right) (Source: DSB)

2.12.2.3 Wreckage area 3 (light grey)

The cockpit and surrounding fuselage of section 41 was found in area 3, 6.2 km south-west of Hrabove. The area, approximately 67 x 37 m, was located in a sunflower field situated on the southern corner of the village of Rozsypne. Within a relatively concentrated area, cockpit instruments, avionics equipment and fragments of cabin- and cargo furnishing were found. Aside from flattened vegetation, shallow impact marks were observed on the ground

Photographic- and video evidence from the days after the crash indicated that area 3 had been disturbed and aeroplane parts and cargo had been removed from the site. A number of avionics units, photographed by third parties following the days of the accident, were no longer present during the recovery mission of the Dutch Safety Board in November 2014.

General description cockpit and surrounding fuselage.
The forward portion of the aeroplane, part of the cockpit including the forward bulkhead, was found in a tilted nose down position facing in easterly direction. The cockpit and surrounding fuselage had separated in longitudinal direction of the aeroplane revealing cockpit and cabin furnishing.

Within the relatively concentrated area, a number of wreckage pieces, varying in size, lay in a heap. The nose landing gear wheel bay and the avionics compartment had penetrated the cockpit and cabin floor pushing it in an upward direction. The adjacent cabin floor had separated in the longitudinal direction of the aeroplane after which two portions of the floor existed. The left portion of the cabin floor was still attached to the fuselage and fragments of the left galley were observed. Other than the severe structural damage of the fuselage, the bottom portion of the fuselage was found as a whole. The fuselage on the right side of the aeroplane had sheared behind the large cargo door and the adjacent cargo floor was visible.

On the left side of the cockpit, between STA132.5 and STA220.5 of the aeroplane, no pieces of fuselage were observed. The left Angle of Attack sensor, still attached to a portion of the fuselage, was located in the vicinity of the wreckage.

Aside from damage, the right side of the cockpit remained fairly intact. In contrast to the left side of the cockpit, the lower right side showed little signs of penetration from the outside as shown in Figure 15. It was noted that the upper portion of the right side of the fuselage was penetrated and the windshield of the right cockpit windows was still in place.

Figure 15 – Upper right hand side of the cockpit as found on the crash site (Source: DSB)

Within close proximity of the wreckage, cockpit furnishing, including pilot seats and cockpit instruments were identified. Together with the parts of the cockpit floor, the throttle quadrant and pedestal had been pushed in an upward direction. The remainder of the cockpit instruments such as the Mode Control panel and a number of cockpit display units were found in a heap.

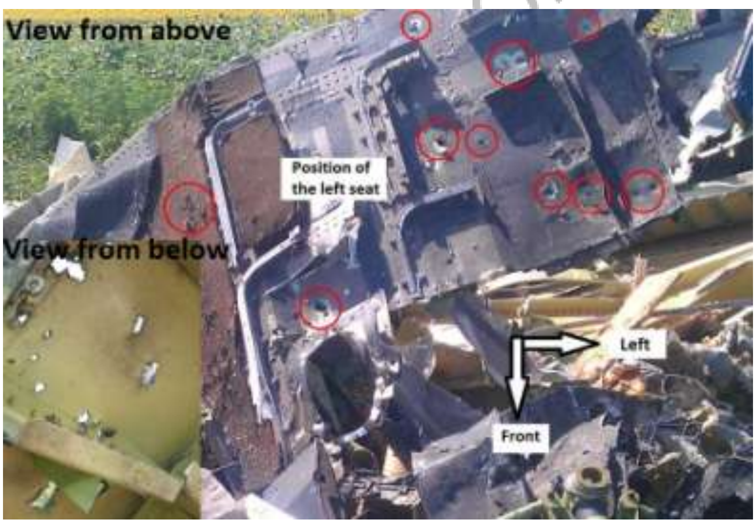

Figure 16 - Cockpit floor with floor parts showing penetration holes (red circles) coming from above the floor, penetrating downwards (source: NBAAI)

A large part of the cockpit floor was recovered, Figure 16, broken up in several parts, and stripped from most of its contents. Seats, centre console, wall structure and most of the control mechanics were separated from the floor structure; only part of the co-pilot control mechanism remained attached. Figure 17 shows an overview of the recovered floor parts.

Figure 17 - Cockpit floor overview partially reconstructed in Gilze-Rijen (Source: DSB)

The outer left side, effectively left of the captain's seat, is covered in soot and has a large number of holes of different sizes are noted. The curved metal parts on the floor are the forward and aft tracks of the captain's seat. Smaller numbers of impact holes were present in other locations, including just left of the first observer seat and below the second observer seat.

2.12.2.4 Wreckage area 4 (yellow)

The fuselage of the aeroplane between the wing- and the tail section was primarily located in Area 4, approximately 2 km south-southwest of Hrabove. Parts of wreckage, including both stabilizers and both wingtips were distributed over an area of approximately 540 x 650 m. The area contains a number of buildings surrounded by a fence. The area was partially surrounded by a forest which was located in a gully. The right stabilizer was found in a pond in the south-easterly part of the area.

Right wing tip

The right wingtip was located near the buildings in the south westerly region of area 4. The wing tip was facing in a south easterly direction and was lying upside down. The wing tip had sheared from the wing at the fourth fuel tank vent hatch, counting from the tip towards the root. The Safety Line Attach Points were visible on the top side of the wing tip. The aileron was missing.

Left wing tip

The left wing tip was located near the pond in the south easterly region of area 4, with its top side facing upwards and the tip in a north westerly region. The Safety Line Attach Points were visible on the top side of the wing tip. The tip showed signs of impact damage on the top side and the leading edge. The wing tip broke off from the wing at the fourth fuel tank vent hatch, counting from the tip towards the root.

Figure 18 – Left wing tip with impact damage (Source: ATSB)

Rear pressure bulkhead

The rear pressure bulkhead was separated into four pieces. A small portion of the rear pressure bulkhead was still attached to the fuselage surrounding door 4L. The largest piece was found in the forest in the gully in the northern region of area 4. The remaining part of the rear pressure bulkhead is missing.

2.12.2.5 Wreckage area 5 (green)

The aft section of the aeroplane including the vertical tail and the surrounding fuselage was primarily located in area 5, situated approximately 730 meters south of Hrabove. Within the area, pieces of wreckage were distributed over approximately 600 x 800 metres. On the western side of the elevated road a concentrated debris area was identified. Within this area cabin items and cargo were found. These parts were consumed by fire. Parallel to the elevated road on the west side, there were power lines. It was noted that one of the power lines on the west side of the elevated road had been clipped.

Photographic evidence and satellite imagery showed that the wreckage site was disturbed on 17 July 2014 and pieces of wreckage were repositioned.

Horizontal stabilizer - front spar

The horizontal stabilizer front spar was detached from its housing and was situated on the elevated road besides the aft portion of the tail. Fragments of the right horizontal stabilizer were still attached to the front and rear spar of the horizontal stabilizer. The front part of the stabilizer box showed impact marks in a lateral direction. The left bushing of the horizontal stabilizer jackscrew fitting was missing.

Vertical stabilizer

The vertical stabilizer was located on the east side of the elevated road with the top part of the stabilizer facing in the south-south-westerly direction. The left side of the vertical stabilizer was facing upwards. The upper part of the leading edge including the horn balance and rudder control surface were missing. A small portion of the fuselage of the left hand side of the aeroplane was still attached to the vertical stabilizer.

2.12.2.6 Wreckage area 6 (blue)

Wreckage area 6 is situated in the south-westerly corner of the village of Hrabove and measures approximately 240 x 290 metres. Within this area, a smaller region with a higher intensity fire was observed, measuring approximately 40 x 60 metres. This smaller region contained all large pieces of wreckage except the forward keel chord. Pieces of wreckage were distributed over two sub-areas, a northern and southern area, separated by an elevated road. Photographic evidence and satellite imagery showed that the wreckage site was disturbed on 18 July 2014 and pieces of wreckage were repositioned. The centre section of the aeroplane, including parts of the wings and both engines were located in area 6.

A fire occurred on the corner of the residential area on the east side of area 6. Both sub-areas included vegetation, infrastructure and pieces of wreckage that showed signs of fire damage. A wooden fence and a haystack were damaged by fire.

Fragments of the wings were primarily located on the southern region of area 6. The remains of the wings showed extensive fire damage. The wings were found upside down with the tank hatches, including the screws holes and placards and markings, showing on the upward facing side of the wings.

The left wing was situated parallel to the elevated road in the western corner of area 6. The remains of the wing contained partial markings of the aeroplane's registration; "9" and "M". The tank hatches as well as the screw holes were visible. The left wing near the partial registration was relatively intact. Further along the wing, towards the root, melted aluminium was observed. Based on the partial registration, the presence of the tank hatches and the screw holes, it was determined that the left wing was situated in the south side of area 6 with its wing tip facing in south westerly direction.

The right wing was situated perpendicular to and across the road. The wing contained placards and markings stating "Fuel Tank Vent Right Wing" indicating the right wing. The portion of the wing, below the tip, was relatively intact and no fire damage was visible. Further along the wing, towards the root, the tank hatches were no longer visible. Pieces of melted aluminium suggest that parts of the wing were consumed by fire. Based on the sequence of the tank hatches, the presence of placards and markings and the visibility of the tank hatch screws, it was determined that the right wing was situated across the elevated road with its tip facing north.

Both the left and right engines were separated from the wing and had impacted the ground in a slightly inverted attitude. Both fans were found detached and the fan blades of both engines remained in place in their discs. The engines were located in the southern region of area 6.

The left engine was located near the left wing. The main core of the left engine had split into two sections. The front part of the engine was facing north and the aft part of the engine was facing west. As the fan blades and the intermediate compressor blades of the left engine showed little evidence of any rotation at impact.

The right engine was located on the south side of area 6, parallel to the elevated road. The main core of the right engine was relatively intact with its forward side facing west. The right engine was located near the right wing and was separated from the wing. Both main landing gear legs were located on the side of the elevated road. With the landing gear bogies still attached. All the tyres on the main landing gear were consumed by fire and the wheel rims were visible.

2.12.2.7 Wreckage area 0 (black)

Pieces of wreckage of which the initial location of impact on the ground cloud not be verified due to insufficient photographic and video evidence are listed in area 0. These wreckage pieces may have been moved or photographed at a different location within the geographic area. The wreckage pieces of which the initial location is uncertain are listed below.

Fuselage with a partial window frame

The fuselage, originating from the left hand side of the cockpit, was located at the side of the road, in the central region of area 2, the village of Petropavlivka. Residents of the village reported that the wreckage piece had been moved to expedite the search and recovery mission (Figure 19). The fuselage contained numerous puncture holes and pitting and showed traces of soot. Frames on the inner side of the fuselage had been sheared.

Figure 19 – Handover of the left cockpit window to the DSB by members of the SES. (Source: DSB)

Fuselage cockpit

A portion of the fuselage, originating from the left hand side of the cockpit, was identified in a field in the central region of area 2 (the village of Petropavlivka).

Centre cockpit window left hand side

One of the layers of the centre window (window number 2) on the left hand side of the cockpit was collected by local residents. The cockpit windows are made of multiple layers of glass and plastic. The window had a total of 102 puncture holes and marks, varying in size and shape, as seen in Figure 20. Parts of the window frame were still attached to the window.

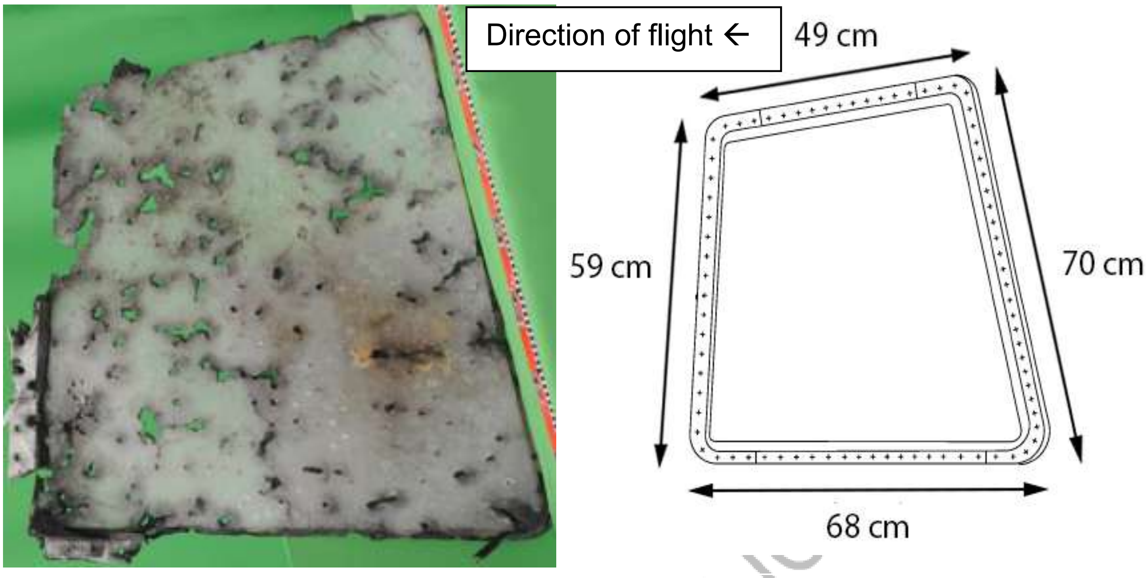

Figure 20 – Centre cockpit window left hand side (Source: DSB)

The left nose landing gear door

Photographic evidence indicated that the left landing gear door had been placed in front of the village hall in Petropavlivka, area 2. Nose landing gear related components were all identified within or in close proximity of area 3. This included the nose landing gear itself and the right nose landing gear door.

The rudder horn balance

The rudder horn balance was photographed for the first time in area 4 during the recovery mission of the Dutch Safety Board in November 2014. Prior to this mission, no photographs of this part were available.

2.12.2.8 Wreckage not recovered

As a result of shelling within the geographic area of the accident, the Dutch Safety Board was not able to retrieve al identified wreckage pieces during the recovery mission in November 2014. The area in which these wreckage pieces were located was either not accessible to the Dutch Safety Board or the pieces were no longer present at their impact location. Table 13 indicates the wreckage pieces not recovered by the Dutch Safety Board.

Wreckage piece	Section	Location
Cockpit fuselage top section	Section 41	Area 1
Fuselage top near business class (2 pieces)	Section 41	Area 1
Fuselage left hand side with positive pressure relief valves	Section 43	Area 1
Fuselage with windows and door frame of door 1L	Section 41	Area 2
Fuselage with door frame of door 1R and surrounding fuselage	Section 41	Area 2

Table 13: Wreckage parts not recovered

Summary of the wreckage information

Within the geographic area, approximately 50 km^2, six concentrated areas with wreckage were identified. The areas were located west and south-west of the village of Hrabove.

Area 1 is north of the village of Petropavlivka which is situated 8.8 km west of Hrabove. Area 2 is the residential area of Petropavlivka and area 3 is southern corner of the village of Rozsypne, 6.2 km of Hrabove.

Pieces of wreckage originating from section 41 and 43 of the aeroplane were found in area 1, 2, and 3. Top portions of the fuselage of section 41 mostly located in area 1. Parts of the fuselage originating from section 43 were mainly found in area 2. The fuselage of the cockpit and cockpit interior were primarily located in area 3.

The damage observed in the forward area of the aeroplane indicated that the aircraft was penetrated by a large number of high energy objects from outside the aeroplane.

Area 4, located southwest of Hrabove was adjacent to area 5, located 730 m south of Hrabove. Area 6 was located in the south-westerly corner of Hrabove.

The mid and aft sections of the aeroplane were distributed over area 4, 5 and 6. Area 4 contained mostly pieces of wreckage originating from section 44, 46 and 47. Both wingtips and both stabilizers were also found in this area. In area 5, pieces of section 48 were found, including the vertical stabilizer. This area was partially subjected to fire. Both the wings and engines were found in area 6. Parts of the aeroplane in this area were damaged or consumed by fire.

2.13 Medical and pathological information

2.13.1 Flight crew autopsy

Identification of the flight crew members was based on clothing and general appearance during the recovery process. Post-mortem examination was performed on four possible flight crew members. Given the injury pattern, a full examination including a body scan and toxicological examination was performed on two flight crew members designated as body 1 and body 2. The post-mortem examination revealed that both of the crew members sustained multiple fractures of the skull, spine, pelvis, ribs, arms and legs. The injury pattern on torso, hands and feet was consistent with flight crew seating and aeroplane control related injuries at impact with the ground. In body 2 an aeroplane part, which was identified as belonging to the right hand side of the aircraft, was found during the post-mortem examination. The other two possible flight crew members (body 3 and body 4) showed dissimilar injury patterns and are therefore considered not to have been seated in the front two flight deck seats.

A body scan detected approximately 200 fragments in body 1 and approximately 120 fragments in body 2. In both cases the majority of the fragments were found in the upper torso and very few fragments were found in the legs and lower torso. A majority of the fragments were found on the left hand side of body 2. The fragment scatter for body 1 was more uniform. A number of fragments were sent to the Netherlands Forensic Institute (NFI) for further examination (See 2.16 Test and Research) and this examination indicated that all but one of the fragments examined corresponded to high-energy objects.

Summary of injury of the operating flight crew

Both operating pilots sustained multiple injuries associated with high-energy objects.

2.13.2 Toxicological examination of flight crew

Material was collected for toxicological research from the bodies of the two flight crew members that were, in all probability, operating the aeroplane at the time of the accident. The toxicological examination was performed by the NFI.

It should be noted that the period of time between the accident and the toxicological examination being conducted greatly affected the results of that examination.

For body 1 and body 2 there were no indications of the presence of medicines (including sedatives), drugs or pesticides in the body. The results also show no indication of Gamma-Hydroxybutyric acid or a substance from which this acid can be formed. In both body 1 and body 2 traces of ethanol and metabolites of ethanol (Ethyl Glucuronide and Ethyl Sulphate) were found in liver and muscle tissue. These may have been formed, in whole or in part, post-mortem. There is insufficient research data available on these metabolites in liver and muscle tissue. No blood was available for toxicological analysis as a result of change post-mortem.

On the basis of the results of the toxicological it is not possible to determine when or how the ethanol was formed.

Summary of the toxicological examination

A large number of high-energy objects were found in the operating flight crew's bodies.

Traces of medicines, drugs or pesticides were not found either body 1 or body 2.

Traces of ethanol and its metabolites were found in liver and muscle tissue which may be formed, in whole or in part, post-mortem. No blood was available for toxicological analysis as a result of change post-mortem. It is not possible to determine when or how the ethanol was formed.

2.14 Fire

2.14.1 Pre-accident fire

No evidence was found in the wreckage or the recorded data for the ignition or proliferation of an on-board fire prior to the aeroplane breaking up in flight.

2.14.2 Post-accident fire

Wreckage site number 6 contained evidence of a large fire that consumed much of the fuselage in the centre section of the aeroplane. The two main landing gear legs and wing centre box show evidence of fire damage. In addition, the engines show signs of having been partially exposed to a fire.

A second, smaller, fire was found to have burned at the location of the Auxiliary Power Unit at wreckage site 5.

Summary
Fires erupted at two locations.

2.15 Survival Aspects

2.15.1 First responders

The human remains and corpses were initially recovered by the local State Emergency Service (SES). The organisation received assistance in this from local fire departments, emergency services, police and local inhabitants.

2.15.2 Survivability

The accident was not survivable.

2.16 Tests and research

During the investigation, forensic examinations of a large number of foreign objects were undertaken by the Netherlands Forensic Institute (NFI). This work is described in the following paragraphs.

2.16.1 Forensic examination

In the course of the investigation over 500 foreign objects were recovered. In the wreckage of the aeroplane and in the bodies of the flight crew members a number of non-aircraft fragments were found that were suspected to be high-energy objects, or parts of them. A number of these fragments had a distinct butterfly or bow-tie shape, such as the one shown in the images below, and were magnetic.

Figure 21 – Fragments found with butterfly or bow-tie shape. The right hand fragment was found in the body of a flight crew member (Source: NFI)

Forensic examinations were executed on a number of the selected objects as well as on numerous objects that were taken as reference from the wreckage. The selection was based on size, shape, mass and ferrous properties. In total 72 selected objects were further examined; 16 foreign objects found in the bodies of the flight crew members and one passenger, together with 56 foreign objects recovered from the wreckage.

2.16.2 Examinations of the selected objects

The origin and the qualitative elemental composition of 72 of the selected objects, together with 21 reference objects (e.g. aeroplane metal structure, cockpit glass) were examined by the NFI using a scanning electron microscope and an associated energy dispersive X-ray analysis system.

The elemental composition of these objects was determined qualitatively and it was found that 43 of the recovered objects consisted of unalloyed steel. Other fragments were found to be non-metallic (coal-slag) or made of stainless steel. On 8 selected objects of unalloyed steel a glass deposit (consisting of sodium, aluminium, silicon, oxygen, and zirconium) was found. On other unalloyed steel objects deposits in the form of molten and re-solidified aluminium were found. Both aluminium and glass deposits were found in the form of thin layers having a thickness from a few micrometers to tens of micrometers. On a small number of objects thin layers containing traces of copper and plastic were found.

The elemental composition of the aluminium traces found was consistent with the elemental composition of the aluminium obtained from the aeroplane as reference material. The investigation did not analyse each trace of aluminium to identify which aluminium alloys were present.

The glass deposits present on the surface of the 8 selected objects had an elemental composition of sodium, aluminium, silicon, oxygen and zirconium. This is similar to that of cockpit window glass from a reference piece held by the NFI and with the cockpit glass obtained from the wreckage. The other pieces of glass that were secured from the wreckage contained no zirconium. It is noted that common types of glass, such as window glass, car windshields and glass on mobile telephones do not contain zirconium.

The chemical composition of 22 selected objects from the bodies of the flight crew members and one passenger as well as from the wreckage was determined by means of laser-ablation inductively coupled plasma mass spectrometry. These objects had either a very distinctive shape (e.g. butterfly or bow-tie) or a layer of deposits was present.

A comparison between the objects and their composition was made using a statistical analysis method; Principal Component Analysis. The analysis showed that the 22 selected objects from the wreckage and the bodies can be divided in two distinctive groups. Within such a group, no statistical difference could be determined between the objects, indicating that the objects originated from the same source. In other words the objects within a group were made from the same low alloy steel plate. Two of the analysed objects could not be linked to a distinctive group.

The result of the examination was that from the 22 selected objects, 20 objects were assessed to be high-energy objects; 8 originated from the flight crew and 12 from the wreckage. The other 2 objects of which one was found in a passenger were not high-energy objects.

2.16.3 Explosive residue analysis

In addition to these examinations, the NFI took over 500 swab samples on various locations of the wreckage of the aeroplane and analysed these for explosive residues.

The investigation into the origin of the objects was made more difficult by the amount of time that the objects had been outside. The possibility of contamination during transport and by the fact that the wreckage lay in an area of armed conflict was a concern for the explosive residue analysis.

Approximately 30 of the more than 500 swab samples showed traces of two different explosives; nitro amine (RDX) and tri-nitro toluene (TNT).

2.16.4 Results of the NFI's examinations

The following results are obtained from the forensic examinations:

- Some of the over 500 objects recovered had distinctive shapes; cubic and in the form of a butterfly or bow-tie, and were made of ferrous metal;
- Of the 22 selected objects found in the bodies of the operating flight crew members, one passenger and the cockpit area, 20 objects could be divided in two distinct groups of low alloy steel. Within each group, the objects originate from the same source. Two objects could not be linked to either group, one originated from the passenger;
- The 20 objects that originate from the flight crew members and the cockpit had aluminium and glass deposits indicating that these fragments originated from outside the aeroplane and penetrated the cockpit with high energy, and

- Some of the fragments recovered showed traces of explosive residues.

Summary of forensic investigation: high-energy objects

Some of the objects recovered have distinctive shapes; cubic and in the form of a butterfly or bow-tie and were made of ferrous metal.

Traces of aluminium and glass were found on 20 objects, both in the bodies of the flight crew and in the cockpit area of the wreckage. No such objects were found in the bodies of the passengers.

The aluminium and glass deposits found indicate that the objects originated from outside the aeroplane and penetrated the aeroplane with high energy leaving traces of both aircraft aluminium and cockpit glass.

Some of the fragments recovered showed traces of explosive residues.

2.17 Organisational and management information

Factual information and its analysis relating to the decision making processes around the flight routes is contained in the separate Dutch Safety Board report entitled *"Flight MH17 and flying over conflict zones".*

In that report, the following subjects relevant to this accident were investigated:

- the selection of flight routes by Malaysia Airlines, with particular attention to the route across Ukraine;
- the oversight by the Malaysian authorities, and
- the management of airspace in Ukraine, with particular attention to the restriction of airspace made by the Ukrainian authorities.

2.18 Additional information

This paragraph contains a number of relevant subjects that have not been addressed elsewhere in Section 2. These relate to:

- a description to two different aeroplane systems; cabin pressurisation and cabin emergency oxygen system;
- background information on possible external sources of damage, and
- the preventative actions taken following the accident.

The weather is consistent with storms around which it is reasonably expected that a flight crew would request to circumnavigate.

With the exception of a deviation requested by the flight crew to avoid bad weather, the aeroplane followed the planned route, airway L980 across Ukraine, not leaving the width of the airway by more than approximately 1.5 NM.

3.3 The moment of high-energy object penetration

3.3.1 Aeropolane data recorders

According to the information in Section 2.11, the following Flight Data Recorder parameters as recorded 13.20:03 (15.20:03 CET) were:

- Aeroplane position
    - Latitude: 48.12715 N
    - Longitude: 38.52630538 E
    - Pressure[10] altitude: 32,998 feet
    - Indicated airspeed: 293 knots
    - Magnetic Heading: 115 º
    - Drift angle: -4 degrees
- Weather
    - Wind direction: 219 º
    - Wind speed: 36 knots
    - Static temperature: -44 ºC
    - Air temperature: -12/-13 ºC

Small variations in the data are possible due to differences in resolution from the various data sources.

Detailed analysis of the Cockpit Voice Recorder for the last 20 milliseconds of the recording at 13.20:03 (15.20:03 CET) as described in paragraph 2.11.2 showed that two peaks of sound were identified in this timeframe. Using specialised audio recording analyses software a graphical representation of the sound over time, its waveform, could be established. The wave form analysis will assist in determining the signal's characteristics; for example, time duration and energy.

The first sound peak had a duration of 2.1 milliseconds and the signal was recorded on the CAM channel only. As no other channels recorded this signal the direction of the signal could not be established. Wave spectrum analysis suggests that the

[10] Altimeter set to the standard pressure of 1013.25 hPa

sound peak is representative for an ‘electrical spike’ as it shows the form of an electro-magnetic pulse that could have been caused by static discharge, or similar.

The time difference between the first and second sound peak was determined to be 2.3 milliseconds. The second peak had a duration of 2.3 milliseconds and was recorded by all 4 channels, but not all at the same time as some recordings had a different timestamp. The phase difference between the channels shows that the sound was recorded by the CAM and P1 microphones first, then the P2 one before, lastly, the Observer microphone. The wave spectrum is representative for a sound wave. This difference in time shows that the sound wave originated outside the aeroplane starting from a position above the left hand side of the cockpit, propagating from front to aft.

It is concluded that the event was highly energetic in nature based on the short time duration of the event.

Signal triangulation was used to determine the origin of the second sound peak recorded on the Cockpit Voice Recorder. It was determined that the sound originated outside the aeroplane on the left hand side. The fact that the microphone cap of the CAM channel was missing did not influence the calculation. However, during the investigation, the Safety Board noted that the sound peaks are of such short time duration that any minor differences in recording will cause the signal triangulation to be erroneous. For example, signal latency (refers to a short period of delay between when an audio signal enters and when it emerges from a system) can be influenced by the Cockpit Voice Recorder microphone wiring. When one microphone wire is ‘longer’ compared to others this may affect the time for the signal to reach the Cockpit Voice Recorder. Nonetheless, the signal triangulation is consistent with the impact damage on the left side of the cockpit. Therefore it is likely that the origin of the sound peak recorded on the Cockpit Voice Recorder is a recording of the detonation of the warhead outside the cockpit.

The point of detonation, the impact damage and the type of warhead are analysed elsewhere in Section 3 of this report.

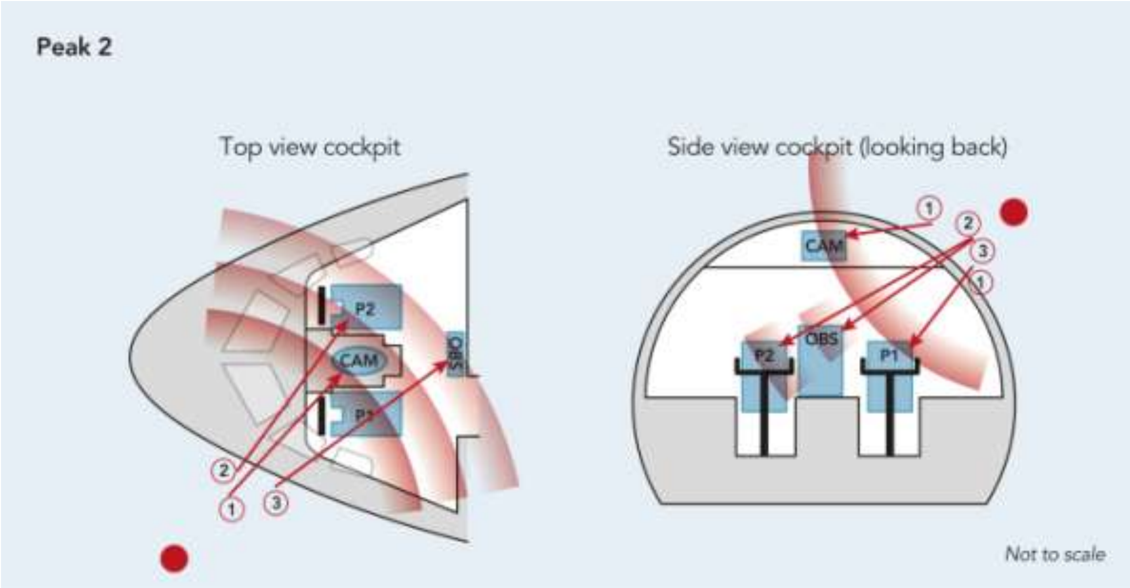

Figure 24 – second sound peak – graphic representation

The poor sound quality on the CAM channel noted during the investigation was probably due to the missing microphone cap from the CAM. The fact that the microphone cap was missing was noted on the deferred defects list for the subject aeroplane.

The Flight Data Recorder data as described in paragraph 2.11.3 and Appendix K was examined to try and identify any acceleration associated with the sound wave that had been recorded on the Cockpit Voice Recorder. The following three axes of acceleration with their sampling rate are recorded on the Flight Data Recorder:

- Longitudinal acceleration: 4 times a second (4 Hz)
- Vertical acceleration: 8 times a second (8 Hz)
- Lateral acceleration: 4 times a second (4 Hz)

The damaged area of the forward pressure bulkhead has very limited apparent evidence of high-energy object damage on the bulkhead.

It is noted that the damage to the cockpit appears to be centred on the left hand forward side, near the left hand seat position, where there is evidence of blast deposit, direct pressure damage, and extensive fragmentation damage. The apparent fragment damage pattern extends from the captain's seat from the left forward to the right hand aft side of the cockpit, and appears to be sharply bounded. This matches the damage found on the outside parts of the nose of the aeroplane.

A number of parts are covered in soot, an indication of explosive residue on the aeroplane. 'Sooting' is noted on the inside of the right hand cockpit windows 2 and 3 and on parts of the outside left hand cockpit fuselage.

The panel, a part of the fuselage to the right of the nose landing gear, between STA250 and STA330, that shows damage considered to be 'dishing'; a form of damage associated with the effects of blast. Figure 23 shows that the panels' skin between the structural elements is deformed. The reason that an adjacent part of the nose gear door (STA184) had no detectable blast damage is that this part is made of a honeycomb construction that is highly resistant to the effects of excess pressure.

3.11.3 Failure analysis

Paragraphs 3.11.3.1 to 3.11.3.7 contain an analysis of the way the aeroplane's structure failed after the impact of the high-energy objects. A number of definitions of the types of failure displayed on the wreckage parts; essential to a better understanding of the analysis, have been included in Appendix N.

3.11.3.1 General

Analysis indicates that, following the separation of the cockpit from the fuselage, the cockpit descended with a steep angle. The distance between the last known position of the aeroplane, recorded on the Flight Data Recorder, and the location of the cockpit, including the nose wheel bay is about 2.3 km. There is general evidence of overload break up, deformation by aerodynamic forces, impact damage such as crushing, folding and bending, and in some cases burning.

Based on paragraph 2.12.2, examination of the wreckage parts of the fuselage stiffened skin structures and their fracture surfaces has revealed the following observations (see Figure 41):

- The upper left cockpit structure is missing, but the available pieces indicate penetration holes. Starting from the cockpit window a rupture runs downward toward to the passenger floor (stringer L27) at STA236.5.1.
- The upper right cockpit section appears intact and exhibits a primary fracture approximately along STA236.52. This fracture runs towards the passenger floor (stringer 27R). This fracture seems to align with fractures observed with photographic evidence obtained from Ukraine where panels contain failures along STA236.50. These fractures develop approximately at the level of the passenger floor backward parallel to the stringers 273L and 274R.
- Another rupture has been observed at the circumferential joint at STA655.50 which seems to run almost entirely in the circumference of the fuselage with intersections with the horizontal fractures along the passenger floors at STA655.
- This circumferential fracture follows STA655 straight to the passenger floor in a predominantly tensile mode. Below the passenger floor the direction of the fracture at the left hand side initially continues towards the longitudinal joint at stringer 34L6 after which its path is unclear. The fracture at the right hand side seems to deviate from its path, heading slightly backward until it reaches the longitudinal joint at stringer 34R after which it turns forward towards the bottom of the fuselage panel 7.
- Although certain pieces of the lower left structure were missing, the two lower fuselage panels before and aft of STA613 indicate that this general rupture at the location of the circumferential joint has continued entirely along the full circumference of the fuselage. This rupture has led to separation of the forward fuselage from the remainder of the fuselage. The outward bending of the lower fuselage panel aft of STA613.80 indicates that final separation of the forward fuselage section occurred at the bottom of the fuselage.

For the forward fuselage section up to about STA1032 a digital two-dimensional reconstruction was made. The approach was to first generate a grid consisting of all fuselage frames and stiffeners positions. Subsequently, the green-screen photos that were made of structural parts were positioned onto the grid at the right scale and orientation. The resulting final image is shown in Figure 52.

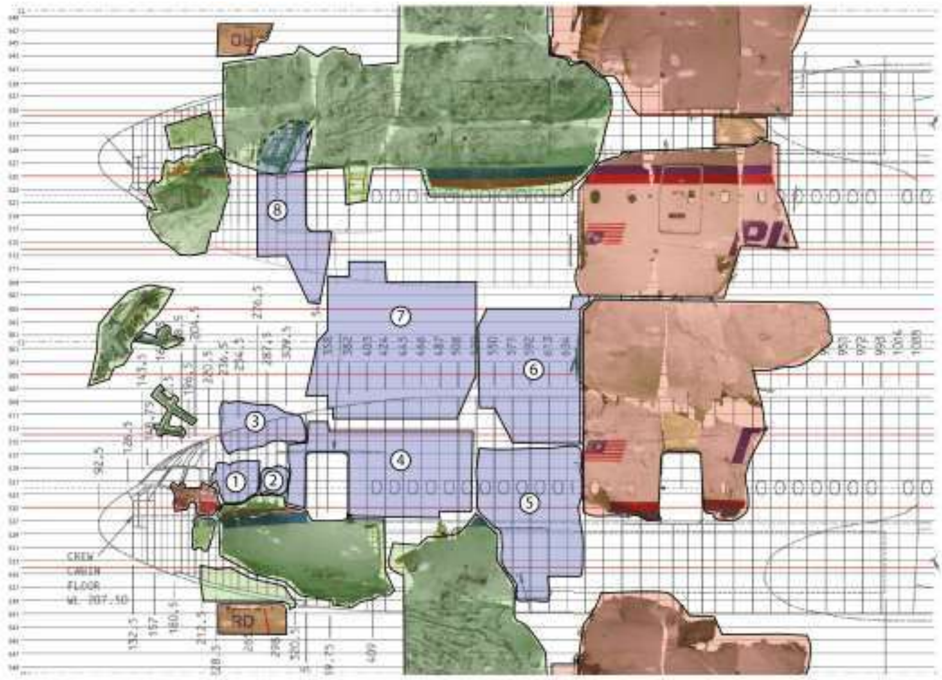

Figure 52 – Grid reconstruction of the outside skin of the forward fuselage. Overlaid outline indicates approximate boundary of the piece prior to dismantling for transport to the Netherlands. Colour indicates wreckage site.

Note:
Unrecovered pieces are highlighted in blue and were reconstructed based on accident scene photos. Piece A indicates a piece of skin attached to the nose landing gear bay for which photographs are not available. All show tearing and peeling damage. Close examination of the wreckage parts available revealed no evidence of pre-existing structural faults (such as fatigue, corrosion or mechanical damage) that could have contributed to the in-flight break-up.

For the forward fuselage section it was verified that the forward cargo door was still closed.

Examination of the available wreckage pieces forward of STA888 revealed several features that manifested during break-up of this section. These features include:

- Tensile overload failure;
- Isolated bending/peeling of wreckage pieces;
- Regions of skin/sub-structure separation, and
- Gross buckling damage.

The overall distribution of these observed features is illustrated on the reconstruction grid in Figure 53. It is noted that some of these features are indicated for wreckage pieces not available to the investigation team for direct inspection. Only features that were clearly visible in wreckage site photographs have been included for those unavailable parts.

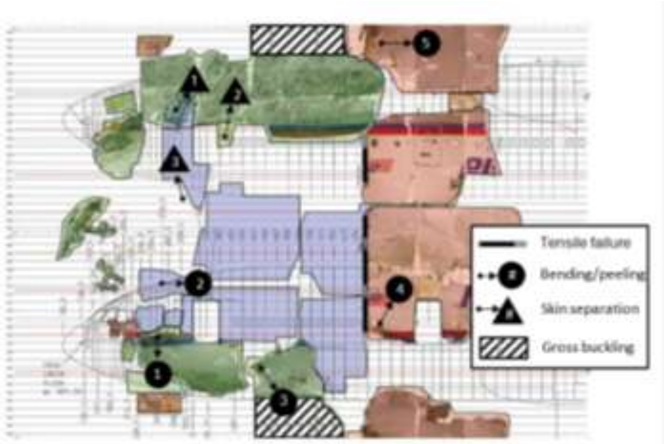

Figure 53 – Overview of the forward fuselage wreckage parts indicating major break-up features

Each of these features will be briefly described and illustrated with representative photographic evidence.

An example of tensile overload failure this type of fracture is given in Figure 54.

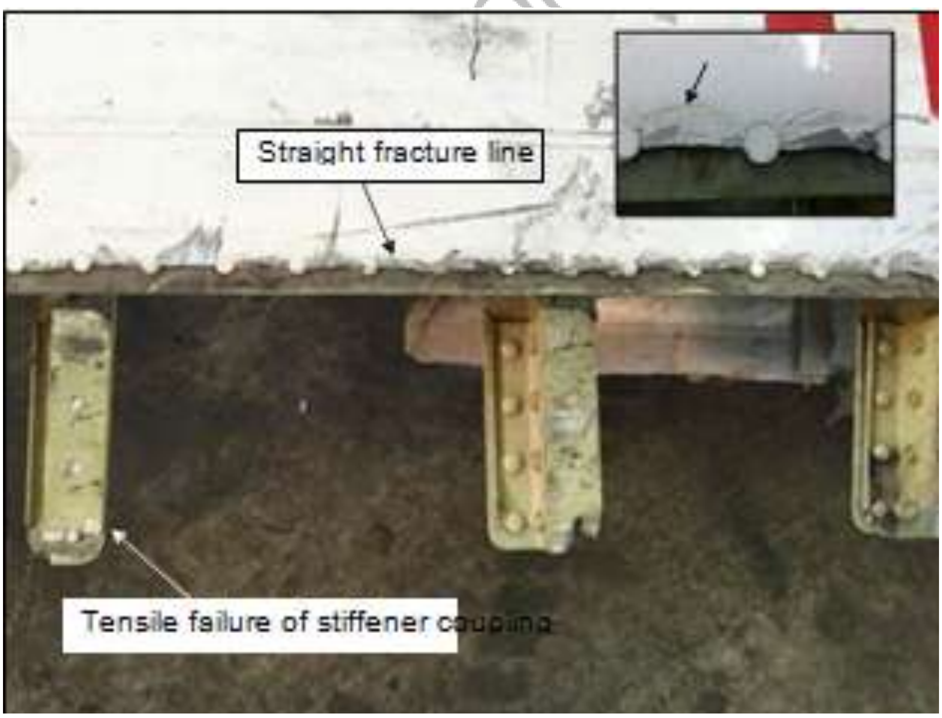

Figure 54 – Typical case of pure tensile overload failure; straight cracks in net-section, paint cracks aligned with skin crack, stiffener coupling failure at the first fastener

A representative example of isolated bending/peeling is given in Figure 55. Note, the arrow in the figure indicates the direction of peeling.

Figure 55 – Example of bending/peeling at a fracture line located along STA655 associated with the final separation between two pieces of wreckage.

A representative example of skin/sub-structure separation is given in Figure 56.

Figure 56 – Example of skin/sub-structure separation in the nose section immediately forward of the door 1R.

A representative example of gross buckling is given in Figure 57.

Figure 57 – Example of gross buckling of the lower fuselage skin panel near STA487.

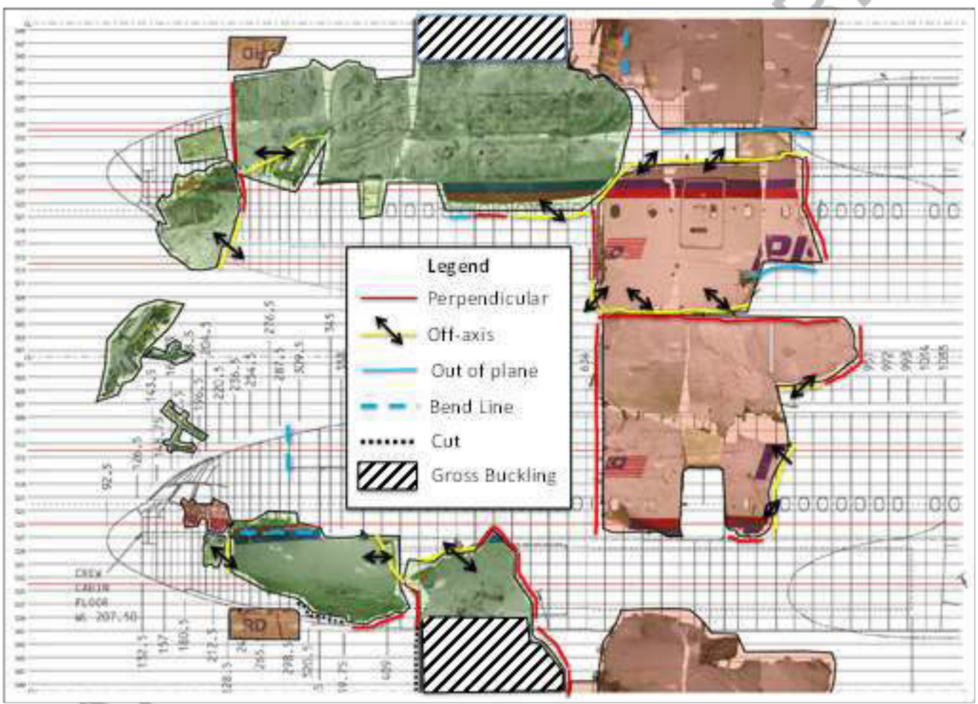

Figure 58 – Overview of forward fuselage wreckage parts indicating the modes of fracture in detail

Based on the different locations of wreckage parts found, it was concluded that the separation between the centre part and the rear part of the fuselage occurred at approximately fuselage station STA1546.5. This location coincides with the aft door frame of passenger doors 3L and 3R.

A study of the fuselage parts, available in the data base, showed that a large skin panel on the left upper side of the fuselage, extending from half way the main landing gear wheel bay in front of doors 3L & 3R to about 1.5 meters aft of door 3L & 3R, was found at the same location as the parts of the rear fuselage (in wreckage area number 4). This part probably separated just before the fuselage rear part broke away. As this part separated, the section at the doors was weakened. The weakened fuselage section then broke and the rear part separated. Top and bottom panels were missing on the left hand side.

On the right hand side a larger severe deformed panel was available, running from the top, about stiffener 11R, to about stiffener 40R at the bottom.

The fracture surfaces that were deemed to interface with the panels in the main wreckage site were examined.

3.11.3.2 Fuselage left hand side

Only a panel of the side shell has been found and was examined. For the left panel, this concerns fractures from the upper right door corner of passenger door 3L upward, and fracture from the lower right corner downward. Both fractures together align into a vertical fracture. Both fracture surfaces exhibit fractures consistent with tensile overstress facture.

Figure 59 – Tensile overstress fracture at the upper right door corner of passenger door 3L

Figure 60 – Tensile overstress fracture at the lower right door corner of passenger door 3L

3.11.3.3 Fuselage right hand side

At the right hand side, a single fracture starting at the lower left corner of the passenger door 3R was present and has been examined. In figure 61, the lower corner shows an overstress fracture mainly tensile (about 45 degrees with the horizontal combined with some outward bending).

Figure 61 – Overstress fracture at the inside of the lower left door corner of passenger door 3R (Source: DSB)

Upper door corner 3R

Figure 62 shows the structure aft of door 3R. The skin plus stiffeners far above the door level show a tensile fracture. The fracture near the top of the door is more complicated. It shows peeling of the skin combined with a complicated fracture of the door frame adjacent to the door just above the door.

Figure 62 – Tensile overstress fracture at the outside of the lower left door corner of door 3R (source: DSB)

Lower door corner 3R

The fracture at the door corner is consistent with a tensile loading direction upper left to lower right plus some out of plane bending. The fracture appears to be a complex fracture surface consistent with tensile overstress, of which the load case is not evident. The skin fracture surface directs in the vertical and under an angle of 45 degrees heading aft, with out-of-plane deformations of the sheet material, together with fracture of the frame at STA1546.5. This frame fracture is, it was concluded, the result of a combination of tension and bending in a direction opposite to the frame curvature. The determination of the direction is based on the alignment of the fracture surface.

In the area investigated, no repairs were observed. Traces of fatigue or corrosion were not found.

Figure 63 – Severely deformed fuselage structure aft of passenger door 3R, including aft cargo door surrounding structure (source: DSB)

3.11.3.4 Cockpit and front fuselage

The rupture along the circumferential joint at STA655 appears to be consistent with a downward bending moment applied unto the cockpit section causing tension in the upper fuselage and compression in the lowest shells. The fracture surfaces in the upper and side shells are consistent with tensile overstress fracture, while the lowest shells exhibit indications of compression and bending, like for example stringer crippling.

The forward fuselage section has separated approximately along the passenger floor into a cockpit section connected to the lower fuselage sections until STA655, and upper fuselage sections above stringers 27L and 27R.

The upper part between frame stations STA246 and STA655 was found at a different site near Petropavlivka, whilst the cockpit section, mostly attached to the lower fuselage sections, was found near Rozsypne. The upper fuselage sections have not been retrieved and could therefore not been examined, while most of the structure of the cockpit and lower fuselage section have been found and examined for the fracture patterns and fracture surfaces.

After the full rupture of the forward fuselage at STA655, the remainder of the fuselage in front of the wing seems to have developed fractures in longitudinal direction at locations between stringer R4 and R79, and near stringer R2910 and R3411 (longitudinal joint). At the left hand side a fracture has developed along stringer L2912 with evidence of out-of-plane deformation of the skin. These fracture orientations seem consistent with a radial opening of the fuselage. Many cases of peeling and tensile fracture have been observed; the longitudinal joint at R34 failed by separation rather than shear, and the skin near STA825 separated in tension from the back-up structure.

All evidence and ruptured fuselage panels observed was limited to the area before STA951.

Based on the position that the wreckage was found in, it has been determined that the centre part of the aeroplane landed upside down facing aft. Given the positions of the engines and the parts of the wings, this part tumbled forward during its descent. It ois noted that this conclusion was confirmed on location after NBAAI investigators had come to a similar conclusion on 18 July 2014 using a photographic reconstruction.

3.11.3.5 Rear fuselage

The separation of the rear fuselage probably took place after the separation of a large skin panel on the left upper side of the fuselage, (data base number 40) extending from half way the main landing gear wheel bay to about 1.5 meters aft of door 3L & 3R) and possible of other upper fuselage parts at that area, not recovered, immediately followed by the separation caused by failure of the remainder of the fuselage at STA1546.5.

This last separation was caused by a bending moment to the right, as seen from the direction of flight, that resulted in a shear load acting on the damaged, incomplete aft fuselage at STA1546.6.

The distortion to the parts of the vertical stabilizer (indicated by two arrows in Figure 64) provides direct evidence of the overload that the aeroplane was subjected to during its fall. The way that the parts are bent shows that these forces were from the side, pushing the vertical stabilizer over to the right, as seen from the direction of flight.

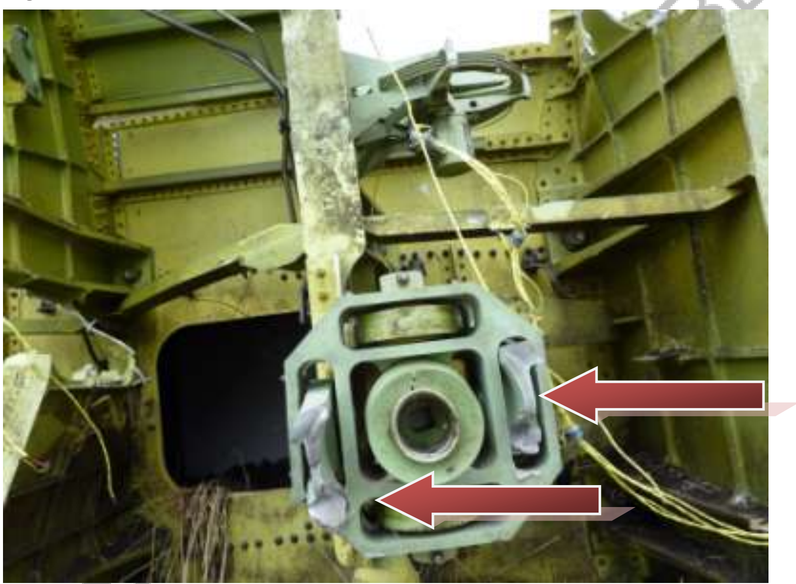

Figure 64 – Overload failure of the vertical stabilizer (Source: DSB)

3.11.3.6 Rear pressure bulkhead

The parts available belonging to the rear pressure bulkhead as discussed in 2.12.2.4 were examined. The fractures in circumferential direction followed the intersection with either the fuselage, or at the stiffening straps. These fractures are predominantly tensile overstress fractures in the net section.

In addition, circumferential fractures were observed at the centre element of the dome. Also these fracture surfaces are consistent with overstress fractures as result of combinations of tension and out of plane bending.

In radial direction fractures were observed also consistent with tensile overstress fractures. These fractures follow the fastener row underneath the radial stiffeners. The plate in the vicinity of the fracture, as well as the stiffener, exhibits significant deformations.

At some locations along the connection between pressure bulkhead and fuselage the fractures deviated from their circumferential path, towards adjacent stiffening straps. A few irregular fractures were also observed.

The fractures observed in the bulkhead were consistent with tensile overstress, caused either a pressure difference or a disintegrating fuselage structure, where a relatively flexible, thin, walled dome is pulled apart by the surrounding structure.

There are indications that there was no sudden failure by overpressure of the rear pressure bulk head:

- No damage or deformation consistent with an overpressure in the fuselage tail cone structure.
- Rear pressure bulkhead parts and parts of surrounding fuselages structure were found at the rear end of the debris pattern, not at the beginning of it.

In the bulkhead dome no repairs were observed. Traces of fatigue or corrosion were not found.

3.11.3.7 Wings and empennage

A review of the two wingtips and the horizontal stabilizers indicated the direction of the failure. In the case of the wingtips, the stringers and ribs on both sides showed signs of having been torn backwards.

The two horizontal stabilizers both showed evidence of having failed after bending upwards. On the left stabilizer bolts and brackets exhibited the signs of the bending. The evidence of upwards bending on the right stabilizer was seen in the way that the stringers had been bent. The extensive use of composite materials in the stabilizers made further analysis impossible.

The high-energy object penetration on the inboard flaperon on the left wing was analysed as part of the analysis in the effects and origin of the high-energy objects.

3.11.3.8 Negative pressure relief valve

A pressure relief valve from the right forward side of the aeroplane was found opened into the extreme position. As the negative pressure difference over the pressure relief valve is normally relatively small and builds up gradually, the observed damage (See Appendix O) has to be the result of an unusual condition. Because the valve is designed for the relief of small pressure differences, it cannot be ruled out that the damage might have been the effect of a shock wave, caused by the external detonation, which occurred on the left hand side of the aeroplane. However, the relief valve found was from the right side of the fuselage. It might have come into the extreme position due to ground impact or due to transportation and handling.

3.11.3.9 Main landing gear

As evidenced by the recovered main landing gear assemblies there were no intact lock links to secure the side/drag braces; both were sheared off. In addition, in an in-flight breakup, air loads from the fall, collision with other debris, ground impact and disturbance during recovery/transportation, could all randomise the motion of unsecured side/drag braces. The Flight Data Recorder data indicated that the landing gear was in the retracted position at the last recorded position of the aeroplane. Therefore it is likely that landing gear extention of one of the gears is a result of the in-flight break-up and/or the following ground impact.

Findings

The failure sequence is consistent with the failure initiating near the left hand side of the cockpit.

There was an almost simultaneous separation between the cockpit with the lower fuselage and upper fuselage at stringer 27 from nose to Station 655 and the heavily damaged cockpit with lower and upper forward fuselage at Station 655, followed by the fuselage between STA655 and STA951 opening in a radial fashion and separating.

The fracture of the rear fuselage section near doors 3L and 3R at STA1546.5 (to the rear of the wing) indicates a high lateral bending moment to the right on the fuselage. The fractures in the rear pressure bulkhead are consistent with overstress fractures.

The wingtips both failed, tearing rearward. After this, the stabilizer and fin separate from the rear fuselage again with a high lateral bending moment to the right.

It is likely that landing gear extention of one of the gears is a result of the in-flight break-up and/or the following ground impact.

The investigation did not indicate the presence of pre-existing damage, such as fatigue, corrosion or inadequately performed repairs.

3.11.4 In-flight break-up scenario

Following the separation of the cockpit from the fuselage, the cockpit descended with a steep angle. The horizontal distance between the last known position of the aeroplane, recorded on the FDR, and the location of the cockpit, including the nose wheel bay is about 2.3 km.

The distribution of the aeroplane wreckage parts over a large area indicates that the aeroplane broke up in the air. The forward parts of the aeroplane were found closest to the last Flight Data Recorder point, indicating that these parts broke off from the aeroplane first. Since the centre and aft parts of the aeroplane were discovered significantly further to the east, this indicated that these parts continued in a down and forward trajectory and disintegrated later.

The failure analysis of the aeroplane's structure, as described in paragraph 3.11 shows a sequence whereby the aeroplane's fuselage separates at STA655; a point towards the rear of the business class section of the aeroplane. A second structural failure occurs at STA1546.5 behind the wing, causing the rear fuselage and tail to separate. The three parts of the aeroplane fell in different locations. The debris locations of the remainder of the aircraft (near Hrabove) cannot be explained by a 'simple' ballistic trajectory, suggesting that part still had some lift and thus continued 'flying' for some time.

Aerodynamic stability

If one flies straight and level in an aeroplane, with the forces trimmed out and the pilot makes no control inputs, the aeroplane will maintain a constant path through the air (assuming still air). Moving the controls to a new positioning and holding them there will cause the aeroplane to deviate slowly from the straight and level flight. If only the ailerons are moved, the aeroplane starts slowly to bank and will turn to the left or right as commanded. As it banks, it also slips so as to not only deviate from its flight path but also it will start to descend. These movements intensify over time. The bank angle and the roll angle will increase over time whilst the radius of the turn will decrease over the same time; the aeroplane flies in a tighter and ever steeper spiral. The slipping flight causes lateral loads on the vertical stabilizer and on the fuselage. This lateral load increases over time. Without correction by the pilot, this continues until structural failure of the aeroplane in flight or impact with the ground.

When the fuselage forward of STA888 separated from the aeroplane it caused the centre of gravity of the rest of the aeroplane to move rearward. The influence of the moment around the aeroplane's lateral axis is considered to be relatively small. There were no more control inputs from the flight crew possible and the control surfaces would have been in their neutral positions. As a result of this, the behaviour of the aeroplane, rotations round the three axes and thus the flight path, were determined by the dynamic stability of the aircraft.

The flight path with respect to the ground will depend on the wind speed and direction at the heights between the start of the event and impact with the ground. In a situation without control inputs, the behaviour of the aeroplane is determined by the dynamic stability of the aeroplane. In such a situation, the behaviour of the aeroplane's movement can be periodic, known as Dutch Roll, or be a-periodic; *spiral mode*. The spiral mode is caused by the fact that, for most aeroplanes, the static directional stability is larger than the absolute value of the static roll stability.

In the case of the accident aeroplane, a bank angle slowly increased after the separation of the cockpit, causing the side slip angle to increase. From the positions of the wreckage on the ground, it is certain that the aeroplane turned to the left in slowly following an increasingly curved path.

Due to the tightening spiral and slip angle, the lateral load on the vertical fin and the fuselage increased. This loading caused an increasing bending moment to the right on the fuselage behind the wing, that eventually resulted in a structural failure of the fuselage by a vertical bending moment. The failure occurred at a point close to the passenger doors, 3L and 3R. As all of these parts aft of STA888 were found on the ground closely spaced, it can be concluded that the structural failure described here happened at a relatively low altitude.

The examination of the wreckage distribution also shows that the final heading of the wreckage was to the north. This suggests that the final part of the descent trajectory had a decreasing radius. This is consistent with a change to the dynamics of the wreckage as the tail separates.

After the separation at STA1546.5, passenger doors 3L and 3R, the wing with the centre fuselage section, without the tail plane, is longitudinally unstable but the roll stability is positive. In this situation the centre of pressure is behind the centre of gravity, it becomes longitudinally unstable, causing it to tumble forward. The rotation rate and the number of rotations is unknown, but it is expected to be few due to the low altitude.

The centre section was found upside down with few indications on the ground of horizontal movement having struck the ground in a nearly horizontal attitude, with a large descent angle. This is a consequence of the forward rotation described above. moving in rearward direction.

A part of the fuselage just in front of door 3R was found under the aeroplane's keel beam structure and a part of the lower fuselage, just in front of the centre wing, was found just ahead of the main wreck. This is consistent with an upside down centre section moving in rearward direction when hitting the ground.

It is not possible to accurately determine the time between the start of the break-up and the impact with the ground. The wreckage distribution suggests that the forward part of the aeroplane is unlikely to have fallen at the same speed as the remainder of the aeroplane. Taking into account the descent speed and the path that the remainder of the aeroplane followed (see explanation on aerodynamic stability above), the centre and rear parts of the aeroplane were estimated to have taken about a minute and a half to reach the ground. Other lighter parts (e.g. cargo and baggage) will have taken longer to reach the ground.

Findings

The debris found near wreckage area 2 and wreckage area 3 is consistent with a rapid separation of the cockpit section and numerous smaller parts of the front section of the aircraft, that started at the last recorded aircraft location or slightly thereafter.

The centre and rear part of the fuselage remained, initially, intact, gliding aerodynamically and came to rest about 8.5 kilometres to the east. The centre section travelled the further than the rear part of the fuselage.

The time between the start of the break-up and the impact with the ground cannot be accurately determined. Taking into account the descent speed and the path that the remainder of the aeroplane followed, the centre and rear parts of the aeroplane were estimated to have taken between 1 – 1.5 minutes to reach the ground. Other, lighter parts, will have taken longer.

3.11.5 Passenger oxygen system

When the cabin of the aeroplane depressurised, the cabin altitude of 13.500 feet was exceeded, which normally deploys the passenger oxygen masks. However, no system data was found to confirm this, because it had not been stored in the equipment recovered and the recorder that had the capability to store such information was not recovered. FDR data shows that the cabin pressure altitude is recorded as being 4,800 feet during cruise up to the moment that the recording stopped at 13.20:03 (15.20:03 CET) (see Appendix K).

According to the manufacturer, when depressurisation occurs the deployment of the masks may take a few seconds. Since electrical power to the Cockpit Voice Recorder and Flight Data Recorder was lost almost instantly after the penetration by the high-energy objects, Electrical power to the solenoid was probably also lost immediately making it unlikely the passenger emergency oxygen masks were deployed. Nevertheless, the solenoid switches might have been moved into the unlocked position as a result of the forces on them during the accident or due to impact with the ground.

A visual examination of four generators recovered from the wreckage showed that the metal wires that normally initiate the production of oxygen had been pulled out and that the indicator stripe on the oxygen generators showed a black stripe indicator suggesting that they had been ‘fired’, producing oxygen, see below figure 65. Some masks may have deployed as a result of the aeroplane’s disintegration and all may have been exposed to strong winds or other dynamic forces during the fall of the aeroplane. Additionally, as it requires only a small force of only a few Newton (Federal Aviation Administration specification TSO-C64 refers) to remove the firing pin from the oxygen generator, it is conceivable that the oxygen generators were fired as a result of either the dynamic forces during the fall or from the impact with the ground.

4 CONCLUSIONS

The Dutch Safety Board determined the following conclusions in relation to the accident to flight MH17 on 17 July 2014.

4.1 Cause

The Dutch Safety Board determined the following main conclusions regarding the cause of the accident to flight MH17:

- On 17 July 2014, a Boeing 777-200 with registration 9M-MRD, operated by a licensed and qualified flight crew, was in cruise flight at flight level 330 close to the Ukrainian / Russian Federation border and under the control of Ukrainian Air Traffic Control.
- At 13.20:03 (15.20:03 CET) the structural integrity of the airworthy aeroplane was compromised and the flight crew were immediately incapacitated by the detonation of a 9M314-model warhead containing pre-formed fragments.
- The 9M314-model warhead carried by a 9M38-series missile was launched from a Buk, Buk-M1 or Buk-M1-2 surface-to-air missile system in an area south of Snizhne, Ukraine.
- The aeroplane consequently broke up in flight and fell to the ground near the town of Hrabove, Ukraine. All 298 occupants lost their lives.
- Other scenarios that could have led to the disintegration of the aeroplane were considered, analysed and excluded based on the evidence available.

4.2 Supporting conclusions

The Safety Board's investigation's main conclusion is supported by the following material.

1. *Moment of the in-flight break-up* The establishment of the moment of the in-flight break-up of the aeroplane is supported by the following findings:
   a. The Cockpit Voice Recorder and Flight Data Recorder stopped abruptly at 13.20:03 (15.20:03 CET) because the power supply was interrupted.
   b. The automatic Emergency Locator Transmitter activated within 2 seconds of the Cockpit Voice Recorder and Flight Data Recorder ceasing to record.
   c. The raw surveillance radar data from the Ukrainian Air Navigation Service Provider and the radar screen video replay from the Russian Federation's Air Navigation Service Provider showed that flight MH17

was in straight and level flight at FL330 until 13.20:03 (15.20:03 CET) as it crossed the eastern part of Ukraine.

d. The raw data from Ukrainian Air Navigation Service Provider further showed that flight MH17 was not transmitting any secondary surveillance data from 13.20:03 (15.20:03 CET) onwards.

e. The Russian Federation's Air Navigation Service Provider radar screen video replay of the combined primary and secondary radar data showed target tracks from the aeroplane from 13.20:03 (15.20:03 CET) onward which were the result of coasting and of falling debris.

2. *Sound peak* The Cockpit Voice Recorder recorded a 2.3 milliseconds sound peak that originated outside the aeroplane from a position above the left side of the cockpit, propagating from front to aft. The signal triangulation was consistent with the impact of a warhead detonating outside and to the left of the cockpit.

3. *No other aeroplanes* There was no evidence of other aircraft, civilian or military, in the direct vicinity of flight MH17. According to radar data only three other aeroplanes were in Dnipropetrovs'k Control Sector 4 at the time of the accident, all commercial air transport category aeroplanes. Two were flying eastbound one was flying westbound. All were under control of Dnipro Radar. At 13.20 (15.20 CET) the distance between the closest of these aeroplanes and flight MH17 was 33 km.

4. *High-energy object damage* The damage observed on the forward fuselage and cockpit area of the aeroplane indicates that there were multiple impacts from a large number of high-energy objects from outside the aeroplane. This caused sufficient structural damage to lead to an in-flight break-up. The pattern of damage observed to the forward fuselage and cockpit area of the aeroplane was not consistent with the damage that would be expected from any known failure mode of the aeroplane, its engines or systems.

5. *Fragments from one location* The aeroplane was struck by a large number of small objects with different shapes and sizes; cubic and in the form of a butterfly or bow-tie, moving at high velocity. The direction of both the penetrating and the non-penetrating fragments originated from a single location outside left and above the cockpit. The fragments caused damage to the left side of the cockpit, the left engine cowling lip ring and the left wing tip.

6. *Damage pattern* The location, shape and boundaries of the damage to the wreckage of flight MH17 and the number and density of hits on the wreckage was consistent with fragmentation spray pattern damage of pre-formed fragments from different shapes and sizes in a 9N314-model warhead carried on the 9M38-series of missiles and installed on the Buk, Buk-M1 or Buk-M1-2 surface to air missile system.

7. *Pre-formed fragments* High-energy objects found in the aeroplane and the bodies of the flight crew were mainly of unalloyed steel some of which showed evidence of having passed through the aeroplane's exterior surface and cockpit windows. Some of the objects showed traces of explosive residues. There were no high-energy objects found in the bodies of passengers. The objects found are consistent with the pre-formed fragments in the 9N314-model warhead carried on the 9M38-series of missiles as installed in the Buk, Buk-M1 of Buk-M1-2 ground to air missile system.

8. *Blast* Simulation of the blast after detonation of the 9N314-model warhead creates an area of very high pressure (shock wave) near the cockpit. The simulation showed that the blast causes structural damage to the aeroplane structure up to 35 metres from the point of detonation. This was consistent with the damage found on the aeroplane wreckage.

9. *Failure sequence* After the initial impact, the aeroplane broke up as follows:

a. There was an almost simultaneous separation of the cockpit from the forward part of the fuselage when the high-energy objects penetrated the cockpit. The cockpit from the forward part of the fuselage came to rest 2.3 kilometres from the last position recorded on the Flight Data Recorder.

b. The centre and rear part of the fuselage remained, initially, intact, gliding aerodynamically and came to rest about 8.5 kilometres to the east. The centre section travelled further than the rear part of the fuselage. This part came to rest upside down in two parts with the centre section beyond the empennage. The wreckage caught fire.

c. Some seats fell free of the fuselage, whilst others remained attached to the floor.

d. The time between the start of the break-up and the impact with the ground could not be accurately determined, but the centre and rear parts of the aeroplane were estimated to have taken about 1 – 1.5 minutes to reach the ground. Other, lighter parts, will have taken longer.

10. *Launch area* The missile was fired from within an area of about 250 km², that is approximately 15 km by 17 km. This area is located to the south of, and including, the village of Snizhne, Ukraine.

4.3 Excluding other causes

The Dutch Safety Board has investigated and analysed a number of different possible causes of the accident. The Safety Board excludes the following matters as having had a role in the accident to flight MH17.

1. *Crew* The flight crew members were properly licensed and qualified to conduct the flight. There is no evidence that the crew handled the aeroplane inappropriately nor were they under the influence of alcohol, drugs or medicine.

2. *Airworthiness and flight plan* The aeroplane was in an airworthy condition on departure from Amsterdam Airport Schiphol and there were no known technical malfunctions that could affect the safety of the flight. An Air Traffic Control flight plan had been filed and the flight crew had been provided with an operational flight plan, NOTAMs, loading and weather information.

3. *Loading and cargo* The mass and centre of gravity of the aeroplane were within authorised limits. There was no cargo classified as dangerous goods on board the aeroplane, nor was any evidence found of explosion with dangerous goods inside the aeroplane.

4. *Airspace* On 17 July 2014, airspace restrictions were in place for the eastern part of Ukraine and parts of the bordering airspace in the Russian Federation from ground level up to FL320. There were no restrictions for flight MH17 to fly in Dnipropetrovs'k Flight Information Region planned flight levels FL330 and FL350.

5. *Climb* The flight crew's decision not to accept the air traffic controller's request to climb from FL330 to FL350 was determined to be a normal operational consideration. Flying at the lower flight level had no influence on the ability of the surface to air missile to engage the aeroplane.

6. *Weather* The weather on the planned flight route showed the presence of thunderstorms moving north from the Black Sea. On request by the flight crew, the air traffic controller authorised flight MH17 to circumnavigate this weather. Flight MH17 did not deviate from the width of airway L980 by more than approximately 1.5 NM. In the last recorded position at 13.20:03 (15.20:03

CET), flight MH17 was within the width of airway L980. The weather had no influence on the accident to MH17.

7. *Pre-existing damage* There was no indication of a presence of pre-existing airframe damage, including fatigue or corrosion or inadequately performed repairs. There was no indication of engine failure.

8. *No warnings* Analysis of the Cockpit Voice Recorder and Flight Data Recorder confirmed the normal functioning of the aeroplane's systems prior to the accident. No warnings, failures or discrepancies were found in the data for the accident flight. No aural alerts or warnings of aircraft system malfunctions were heard on the Cockpit Voice Recorder. The communication between the flight crew members gave no indication of any malfunction or emergency prior to the occurrence. The engine parameters were consistent with normal operation during the flight. The recorded aircraft data showed no malfunctions, warnings, failures or discrepancies for the duration of the flight.

9. *Other weapons*
   a. *Air to air gunfire* The high-energy object damage was not caused by air to air gunfire because the number, the size and type of high-energy objects impact damage is not consistent with gunfire impact damage and the trajectories of the high-energy objects that struck the aeroplane are not parallel but converge to a single location close to, and above, the aeroplane.
   b. *Air to air missile* The high-energy object damage was not caused by an air to air missile because there was no military aircraft in the area of flight MH17 to launch such a missile. Air to air missile warheads do not have butterfly or bow-tie shaped fragments, and an infra-red guided missile would have caused damage to the aeroplane nearer the engines.
   c. It is extremely improbable that the aeroplane was struck by more than one weapon system simultaneously.

10. *Other scenarios* Other possible scenarios that could have led to the disintegration of the aeroplane were considered and analysed. These scenarios were an on-board fire or a fuel tank explosion, the detonation of an explosive device inside the aeroplane, lightning strike, and impact by a meteor or space debris re-entering the atmosphere. All of them were excluded based on the available evidence.