DUTCH
SAFETY BOARD

Two cases of wing fire

in Apex DR400 aeroplanes

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The Hague, May 2017

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Photo cover: Dutch Safety Board

Dutch Safety Board

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	Dutch Safety Board		
Chairman:	T.H.J. Joustra E.R. Muller M.B.A. van Asselt		
Secretary Director:	C.A.J.F. Verheij		
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		

NB: This report is published in the Dutch and English languages. If there is a difference in interpretation between the Dutch and English versions, the English text will prevail.

CONTENT

SUMMARY

On 8 July 2013 and 4 July 2014, respectively, two aeroplanes of the make and model Apex DR400/140B were seriously damaged by fire. In both cases, the fire started during taxi after landing, on the left-hand side of the aeroplanes, destroying the left-hand wing. Since the two fires seemed of a similar nature and both aeroplanes were operated by the same flying club, it was decided to combine the two investigations into the cause of these fires.

The investigation revealed that, in both cases, the heat that formed the source of the fires originated from the brake unit of the left-hand main landing gear. The brake disk had got hot as a result of friction between the brake disk and the brake pads. It remained unclear what caused this friction: neither technical nor operational causes could be ruled out.

The heat in the brake unit was so intense that it was able to start a fire in the wing construction. The wing construction of this type of aeroplane consists of wood, covered with polyester material. It was found that no fire-resistance certification requirements exist for wing covering materials. The combination of wood and non fire-resistant synthetic covering material enabled the rapid development of the fire.

In the course of the investigation, it was discovered that at least 21 similar occurrences with the same aeroplane type had been reported to France's aviation accident investigation bureau since 1988, the latest fire being in July 2016. All of these resulted in substantial damage to the wings, and some even in the loss of the entire aeroplane. The damage occurred on the left-hand side as well as on the right-hand side of the aeroplanes.

An on-board fire may create a dangerous situation, especially when the fire is detected after becoming airborne. While the Board acknowledges that the Apex DR400 meets all legal airworthiness requirements, it therefore considers it advisable to make this type of aeroplane less vulnerable to fire. That is the reason why the Dutch Safety Board issues the following recommendation to the European Aviation Safety Agency (EASA):

- Advise the manufacturer of the Apex DR400 to improve the aeroplane's brake unit, as to prevent overheating of the brake disk as a result of friction between the brake disk and brake pads.

1 FACTUAL INFORMATION

1.1 The accidents

1.1.1 Accident 1 - Apex DR400/140B, PH-SPZ, Rotterdam The Hague Airport, 8 July 2013

Photo: Dutch Safety Board

Identification number:	2013088
Classification:	Accident
Date, time[1] of occurrence:	8 July 2013, 17.17 hour
Location of occurrence:	Rotterdam The Hague Airport
Aeroplane registration:	PH-SPZ
Aeroplane model:	Apex DR400/140B[2]
Type of aeroplane:	Single engine piston
Type of flight:	Training flight
Phase of flight:	Taxiing after landing
Damage to aeroplane:	Serious
Cockpit Crew	One
Passengers:	None
Injuries:	None
Other damage:	None
Lighting conditions:	Daylight

1 All times in this report are local times (UTC+2 hours) unless otherwise specified.
2 PH-SPZ was originally an APEX DR400/140B, equipped with a 160hp Lycoming O-320-D2A engine. This engine was later replaced with a TAE 125-02-99 Centurion. A supplemental type certificate was issued by EASA on 17 July 2014.

On July 8th 2013, PH-SPZ made a flight from Midden-Zeeland Airport (EHMZ) to Rotterdam The Hague Airport (EHRD). After landing on runway 06, the pilot (who was the only occupant) was unable to vacate the runway at the first exit V3,[3] after which he continued to taxi to exit V2. During rollout, the pilot experienced unexpected deceleration and a leftward tendency of the aircraft. After vacating the runway at V2, the pilot taxied back via the taxiway. The pilot stated that by then, the problems had disappeared.

The air traffic controller stated he saw smoke appearing from the left-hand main landing gear from the taxiing aeroplane. He instructed the pilot to hold on the taxiway. However, when braking, the pilot experienced reduced braking action and a rightward tendency of the aeroplane. When the controller subsequently saw flames appearing, he hit the emergency alarm and urged the pilot to leave the aeroplane immediately. The pilot left the aeroplane. By this time, fire was coming from the left-hand wing. The fire department arrived on the scene to extinguish the fire, hereby halting the fire. The pilot was not injured. The fire damage to the aeroplane's left-hand wing was extensive.

Figure 1 shows the airport layout at the time of the accident, as well as PH-SPZ's track.

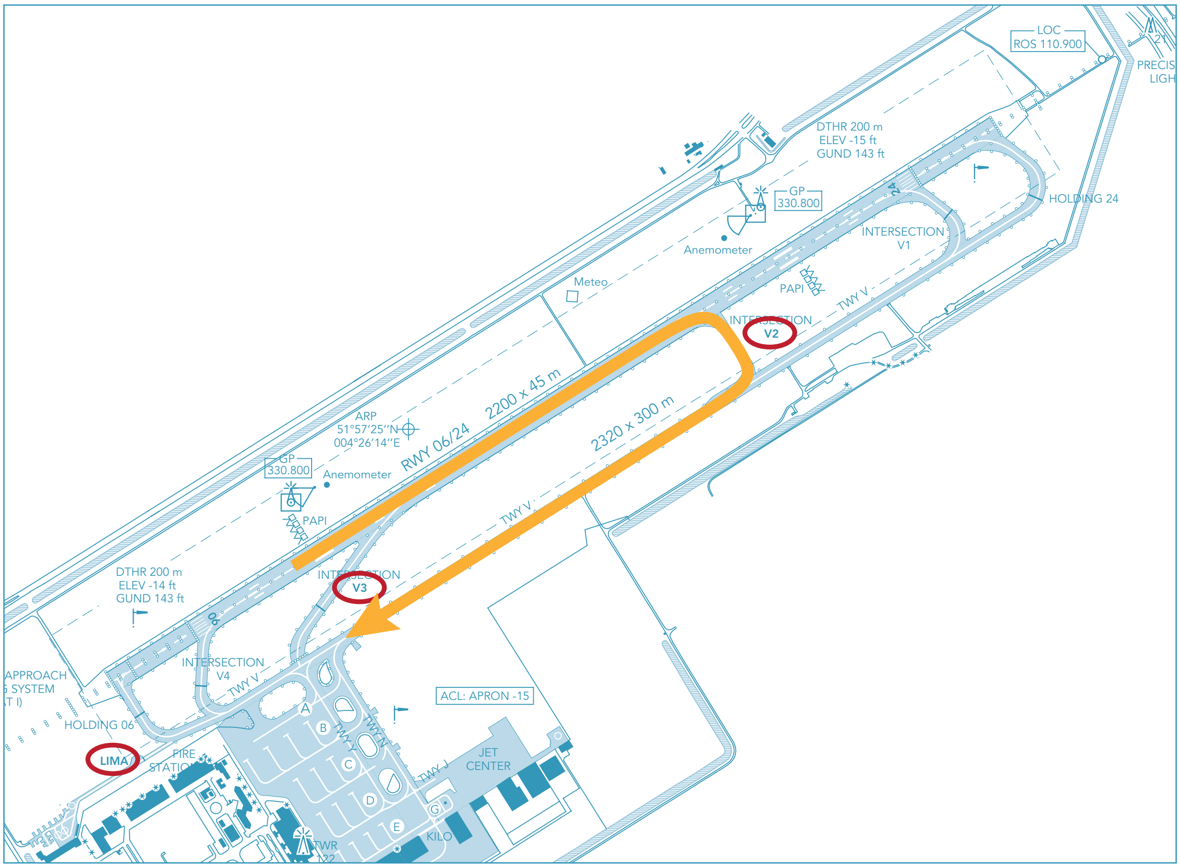

Figure 1: Rotterdam The Hague Airport ground chart with PH-SPZ's track. (Source: AIP The Netherlands / Dutch Safety Board)

3 Situation at the time of the event, runway exit designations have changed since.

1.1.2 Accident 2 - Apex DR400/140B, PH-HLR, Rotterdam The Hague Airport, 4 July 2014

Photo: Dutch Safety Board

Identification number:	2014070
Classification:	Accident
Date, time of occurrence:	4 July 2014, 12.02 hour
Location of occurrence:	Rotterdam The Hague Airport
Aeroplane registration:	PH-HLR
Aeroplane model:	Apex DR400/140B
Type of aeroplane:	Single engine piston
Type of flight:	Pleasure flight
Phase of flight:	Taxiing after landing
Damage to aeroplane:	Serious
Cockpit Crew	One
Passengers:	One
Injuries:	None
Other damage:	None
Lighting conditions:	Daylight

On July 4th, 2014, PH-HLR made a local flight from Rotterdam The Hague Airport (EHRD). The pilot landed on runway 24 and taxied from exit V3 towards point LIMA to park near the 'Vliegclub Rotterdam' clubhouse.

After parking the aeroplane, the pilot noticed that flames were starting to appear from out of the left wing. The pilot got out of the aeroplane in order to get help. An employee of the 'Vliegclub Rotterdam' arrived with a fire extinguisher to extinguish the fire.

At the same time the airport's fire department returned from an exercise elsewhere at the airport. The fire station is located near the flying club clubhouse, and on their way back the fire-fighters noticed the flames and smoke coming from the PH-HLR. Prior to the actual emergency notification, fire brigade vehicles were already present near the aeroplane. When they arrived they took over from the employee and extinguished the fire. The pilot and his passenger both left the aeroplane uninjured. The left wing of the aeroplane was damaged extensively by the fire.

Figure 2 shows the airport layout at the time of the accident, as well as PH-HLR's track.

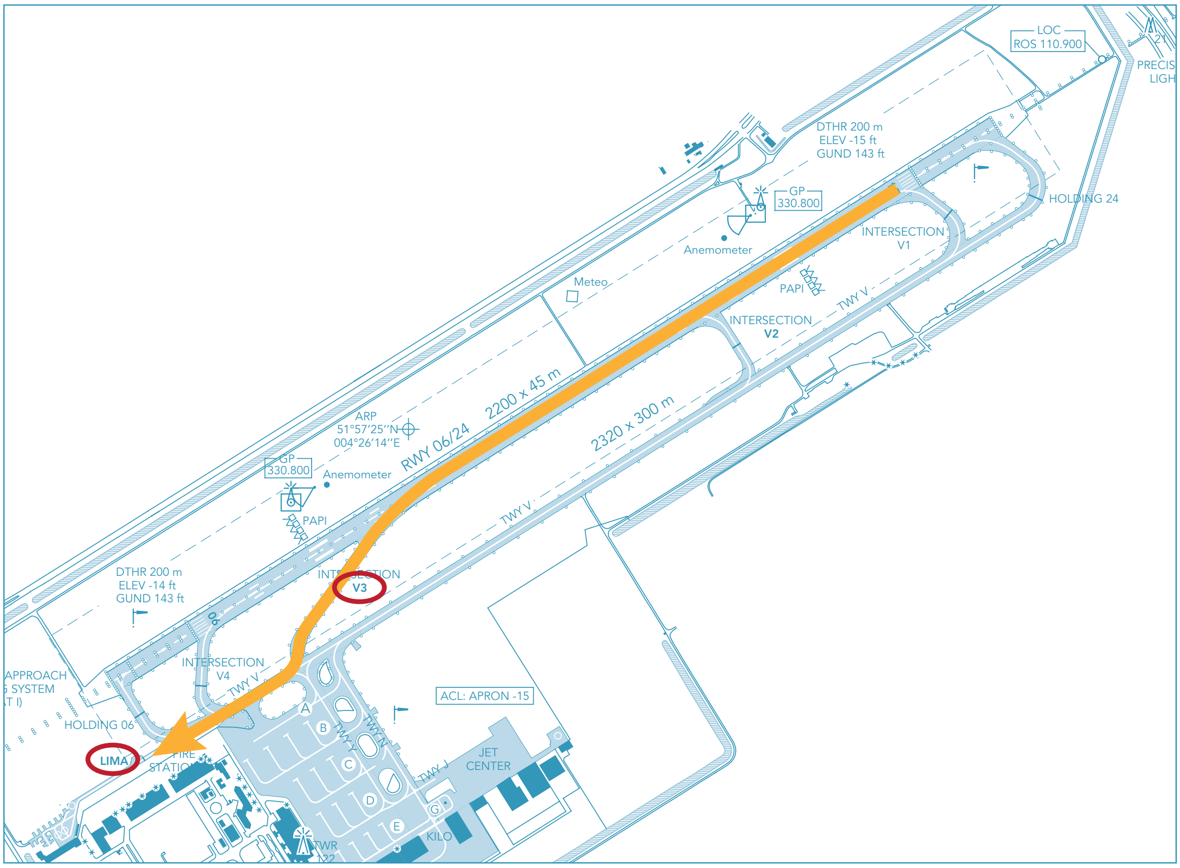

Figure 2: Rotterdam The Hague Airport ground chart with PH-HLR's track. (Source: AIP The Netherlands / Dutch Safety Board)

1.2 The Apex DR400 aeroplane

The Apex DR400 is a single-engine propeller fixed-wing aeroplane designed and built in France. The DR400 is a further development of the 1958 Jodel DR100 Ambassador two-seater and is essentially a larger, more powerful and sophisticated four-seater.

The original model of the Robin DR400/140B was type certified in August 1975 by the competent Airworthiness Authority, i.e. France's civil aviation authority DGAC *(Direction*

Générale de l'Aviation Civile). This certification was based on the airworthiness requirements laid down in amendment AIR2052 of June 6th, 1966. In 2003 the DGAC type certificate was transferred to an EASA type certificate, when EASA became the responsible authority for the certification of aircraft in the EU as a result of Commission Regulation (EC) No. 1702/2003.

The DR400's wing main spar is formed by a wooden box construction. While in 1958 the wing was covered with linen, in current generation DR400 aeroplanes the wooden wing structure is covered with a high-strength shrinkable polyester fabric painted with polyurethane paint. The DR400's hull design construction, too, is primarily made of wood and covered with this foil covering.

1.2.1 Landing gear and brake system

The aeroplane has a non-retractable tricycle landing gear, consisting of a left-hand and right-hand main gear and a steerable nose wheel. The main gear is attached to the wooden main wing spar. All the gear struts and wheels are covered by fairings, made of synthetic fibre (see figure 3).

Figure 3: DR400 landing gear strut and wheel fairings. (Photo: Dutch Safety Board)

Originally, Robin DR models were equipped with drum brakes, and a lever which activated the right and left-hand brakes simultaneously when pulled. Combined pulling and turning of this lever activated the parking brake. In 1980, this lever activation system was replaced by a system of toe-pedal braking, in which the left and right-hand drum brakes could be controlled independently. The parking brake system then is activated through a separate knob. From 1988 onwards, disc brakes replaced the drum brakes.

The current braking system consists roughly of the following parts: two brake pedals, two brake cylinders, a parking brake, brake lines, and one brake unit per wheel. The brake unit of each wheel consists of a brake disc and a cylinder assembly (i.e. one piston with two brake pads on either side of the brake disc), see figures 4 and 5.

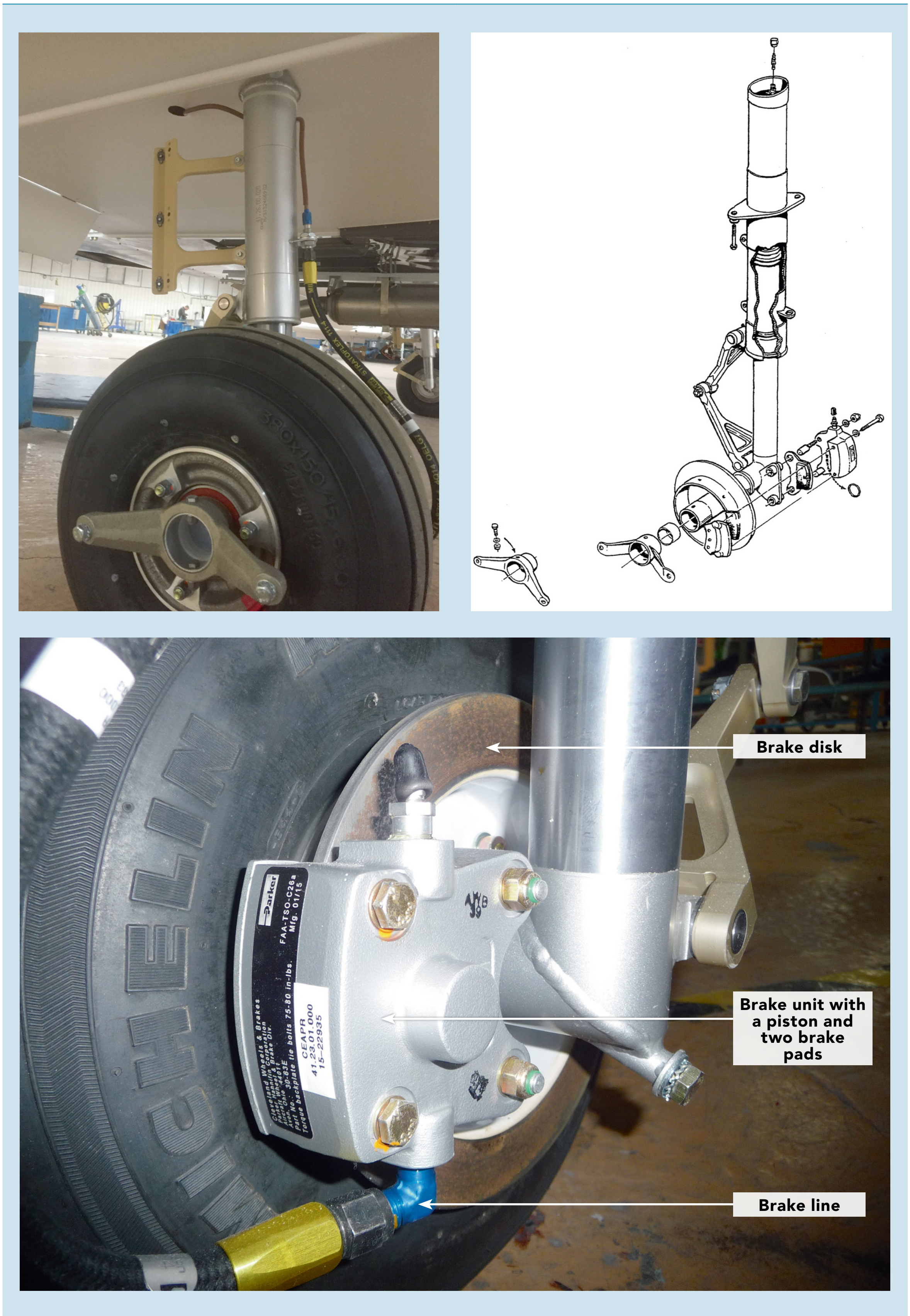

Figure 4: DR400 brake unit, schematically and as seen from either side of the wheel during aeroplane construction. (Source: Dutch Safety Board and Apex DR400 Aircraft Maintenance Manual)

By pressing the brake pedal (left, right or both), mechanical movement is applied to the brake cylinder. The cylinder in turn provides hydraulic pressure to the hydraulic oil which runs through a pipe and valve system to the parking brake unit. If the parking brake is not set, the hydraulic oil flows through the brake system to the cylinder assembly. The two brake pads located on each side of the brake disc will press onto the disc itself, resulting in braking action. The brake pads are pushed onto the brake disc by a piston which is sealed by an O-ring seal.

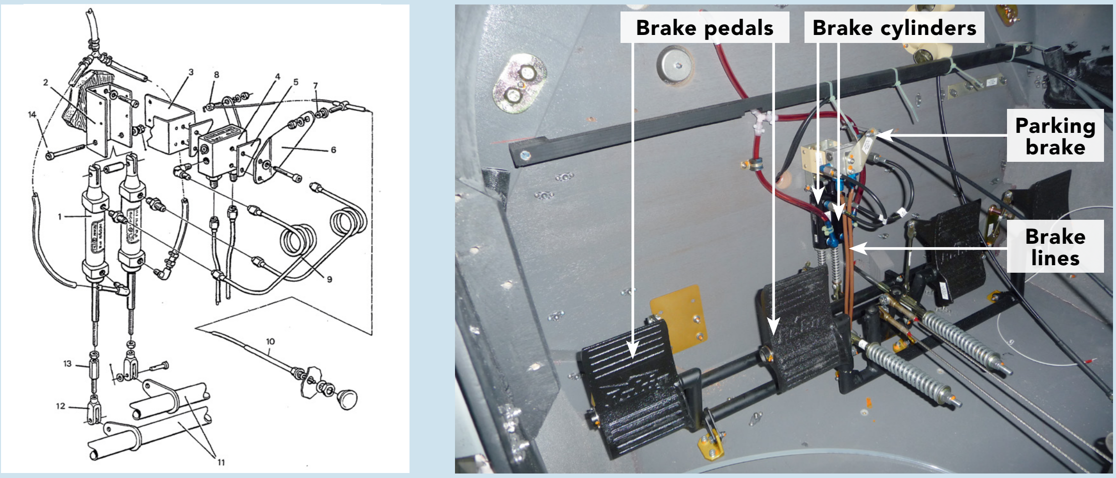

Figure 5: The DR400 brake system during aeroplane construction. (Source: Dutch Safety Board and Apex DR400 Aircraft Maintenance Manual)

In addition to normal braking, the aeroplane has a parking brake operated by a pull-out knob located under the dashboard. When the brake pedals are pressed and the knob is pulled, the brake pads are locked into position by preventing the hydraulic fluid from flowing back. The brakes are locked and thus the parking brake is set (see figure 5).

The aeroplanes involved in both accidents were DR400/140B models. According to the aeroplane manufacturer, this type is equipped with the current braking system which meets all legal requirements (see also table 2).

1.3 Damage

1.3.1 PH-SPZ

Following the accident, a technical investigation was performed on the PH-SPZ. The technical investigation's main focus was to determine the condition of the brake system and its components. During the technical investigation, the general state of components and the degree of damage were determined.

The left-hand wing was burnt to a large extent: the skin and frame behind the main spar, including the aileron, were largely consumed by fire (see figure 6). The aluminium left-hand flap was damaged by fire.

Figure 6: The PH-SPZ left-hand wing damage. (Photo: Dutch Safety Board)

The left-hand main gear was severely damaged by fire (see figure 7). The cylinder of the left-hand main gear was fully compressed. The left-hand main gear strut fairing was almost completely consumed by fire. Only some fibreglass remained. The right side of the tyre of the left-hand main gear was damaged by heat and/or fire. Some aluminium parts of the left-hand main gear had melted, other metal parts on the left-hand wing were damaged by fire. The left-hand flexible brake line was burnt and showed leaks.

Figure 7: The destroyed left-hand main gear and strut fairing from PH-SPZ, seen from front (left picture) and from aft (right picture). (Photos: Dutch Safety Board)

1.3.2 PH-HLR

A similar technical investigation was performed on PH-HLR. The top part of the left-hand wheel fairing showed extensive heat damage whereby the individual composite matrix fibres were visible. The damage was located just above the brake connection bracket. The rest of the wheel fairing was partially blackened by heat, but the composite matrix fibres were still intact (see figure 8).

Figure 8: PH-HLR side view of left-hand wheel fairing and gear strut fairing, damaged by heat. (Photo: Dutch Safety Board)

After being removed, the top part of the left-hand wheel fairing, above the disc brake, proved to be damaged extensively (i.e. matrix visible). On the inside of the wheel fairing several green blades of grass and dirt were found.

The brake fluid reservoir was found to be empty. A functional test on the brake system revealed a leak in the brake line, just below the left-hand main gear strut connection. The brake line was heavily damaged by fire, but no other damage or leaks were found.

Part of the inboard side of the left-hand tyre showed a semi-circular pyrolytic imprint which corresponded to the outline of the brake disc. About one-third of the tyre showed pyrolytic damage exceeding the contour of the brake disc (see figure 9).

The brake disc surface was found to be scratched but disc thickness was within specifications. The two brake pads were found intact. Both brake cylinder assemblies were intact (i.e. not broken). The piston including the O-ring seal was intact.

Figure 9: PH-HLR left wheel with damaged tyre and brake disc. (Photo: Dutch Safety Board)

The strut fairing was damaged by heat and fire. Within the fairing, two burned pieces of material were found. Inspection of the right-hand fairing revealed that inner lining material and a piece of leather were located here. This material provided protection against chafing of the gear strut fairing against the connecting lug on the strut (see figure 10).

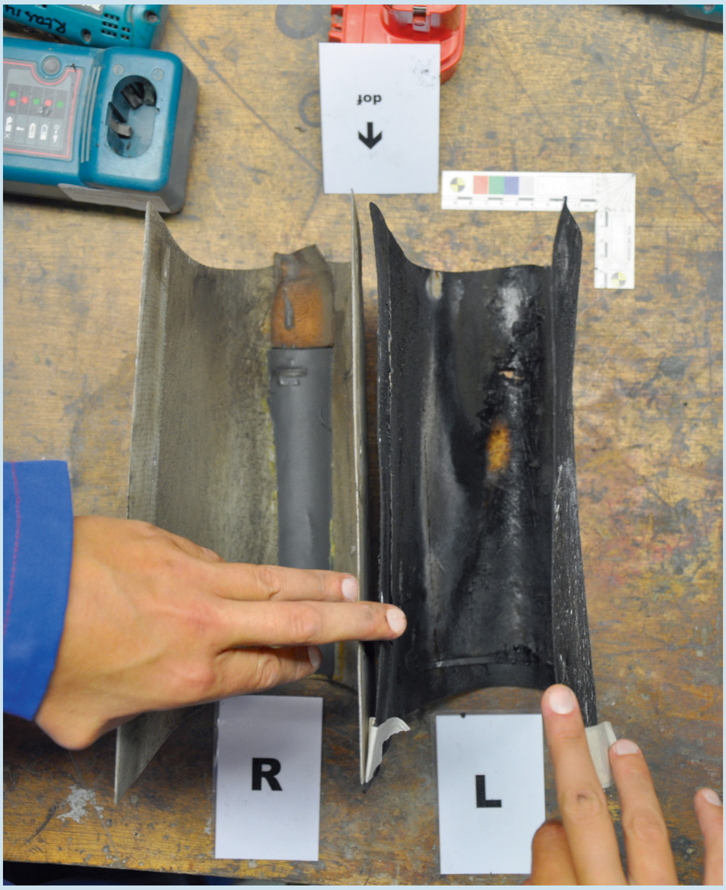

Figure 10: Inside view of left and right strut fairings. (Photo: Dutch Safety Board)

An electrical wire was found running along the forward main spar of the left-hand wing to the left-hand wing tip light. This wire was not damaged and showed no signs of any electrical arcing. No bearing damage or indication of heat was found on the wheel axis when the left-hand wheel was removed.

After disassembling the *right-hand* wheel fairing, the underside of the right-hand wing showed a distinctive, dark coloured mark. This mark extended towards the aft side of the aeroplane (see figure 11). Even though this mark first appeared to be a burn mark, it soon became clear that it was dirt and the structure underneath proved undamaged.

Figure 11: PH-HLR side-view of right-hand gear strut with both fairings removed, showing the dark coloured mark on the wing covering. (Photo: Dutch Safety Board)

1.4 Engine data - FADEC

Both accident aeroplanes were equipped with TAE 125-02-99 Centurion engines, with the engine and propeller being electronically controlled by a Full Authority Digital Engine Control (FADEC) unit. The FADEC consists of two redundant components, FADEC-A and FADEC-B. The engine is normally controlled by FADEC-A, with FADEC-B as its back-up. The FADEC has a fault and data storage capability which can be used to diagnose engine-related failures. For maintenance purposes, the data can be downloaded after a flight and subsequently analyzed for faults.

The FADEC data from the PH-SPZ and PH-HLR were downloaded after the events and analysed by the Dutch Safety Board. Figure 12 shows the selected load (i.e. throttle position) data of both aeroplanes plotted against time (in seconds) just after the moment of touchdown (T=0). The graphs show the two previous landings of each aeroplane depicted in green and blue, and the accident landing of each aeroplane in red. It shows that, in both accident flights, selected load during taxiing was significantly higher than in the last flights before the accident.

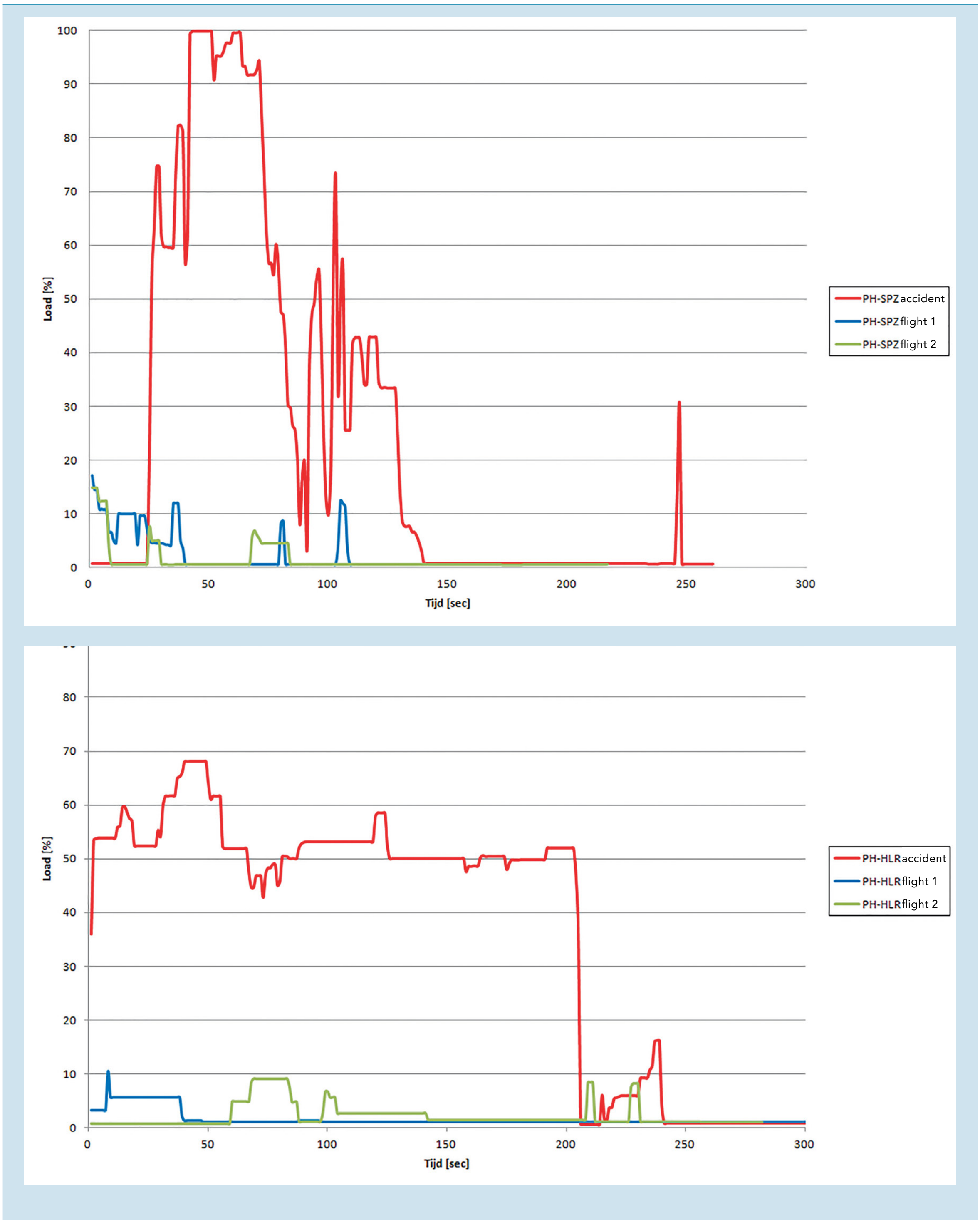

Figure 12: Data from both accident aeroplanes (top: PH-SPZ; bottom: PH-HLR) as recorded on the aeroplanes' FADECs. Time=0 indicates touchdown. (Source: Dutch Safety Board)

1.5 Aeroplane maintenance and condition

According to records received, both accident aeroplanes held valid certificates of airworthiness. According to maintenance records, maintenance had been performed on PH-SPZ's right-hand main gear on June 13th, 2013. During this maintenance, the right-hand fairing (damaged) and hydraulic brake cylinder (unserviceable) were both temporarily replaced with spare parts from another aeroplane. Final installation of new parts was deferred until next maintenance. It was found there were no deferred maintenance action items on PH-HLR at the time of the accident flight.

The Fault Finding paragraph in the Brake System chapter of the DR400 maintenance manual states that permanent rubbing of the pads on the brake disc may be caused by a defective or binding brake unit piston seal or by an incorrect pedal position c.q. feet applying pressure. No reference to maintenance activities related to these faults was found in the documentation or logs for either aeroplane.

2 INVESTIGATION AND ANALYSIS

2.1 The accidents

In both cases the FADEC engine data showed that more power was selected for taxiing after landing during the accident flights than during previous flights. In combination with the fact that no abnormally high taxiing speeds were reported, this suggests that one or both main wheels experienced such a drag that more engine power was necessary to achieve taxiing speed.

The Dutch Safety Board concludes that the most plausible explanation for this drag would be the brake pads continuously rubbing against the brake disc, heating it up due to friction. Both fires started on the left-hand main gear, indicating that in these accidents it was the left-hand brake unit that heated up to very high temperatures. The Board subsequently investigated the two possible causes mentioned in the DR400 maintenance manual for brake pads continuously rubbing against the brake disc during taxiing: technical brake system failure and brake activation by the pilot.

a. *Technical brake system failure*
   Before each flight, any pilot is required to conduct a walk-around inspection. This walk around inspection is a normal routine and part of the flight preparation for security, safety, and operational reasons. Only when wear or damage is suspected will the wheel fairing be opened to gain access to the brake and wheel. The DR400 manual states that the (right-hand and left-hand) main landing gear must be checked, with a focus on the condition of the fairing attachment, shock absorber and tyre inflation. The design of the wheel and strut fairings makes more detailed pre-flight visual inspection difficult. Apart from a check on possible leakage, brake condition is not part of the pilot walk-around inspection. A defective brake system resulting in rubbing brake pads, can only be noticed when the aeroplane is moved by hand or when a rightward or leftward tendency is experienced during taxiing. In both accidents there were no indications that this was the case.

   As a result of a technical failure in the brake system, permanent rubbing of the brake pads on the brake disc may occur. Depending on the force of rubbing, the result may range from light friction to a jammed wheel. In the case of jamming, the wheel is unable to rotate, which would likely leave a skid mark behind the aeroplane and result in a flat spot on the tyre. In both events investigated by the Dutch Safety Board, neither a skid mark on the runway nor a flat spot on the left-hand tyre were found.

   The maintenance manual states that permanent rubbing of the brake pads on the brake disc may be caused by a defective or binding piston seal (O-ring). In the PH-HLR case, the O-ring was found intact: an inspection of the hydraulic system and seal did not reveal any faults in the system. Furthermore, the hydraulic brake system was checked: normal hydraulic braking was achieved during the technical investigation, but any rubbing of the brakes after releasing the brakes, could not be replicated during the test. The bearings of the left-hand side were found to be in normal condition and no flat spot on the tyre was found. Therefore it was concluded that PH-HLR's left-hand wheel was able to turn normally at the time of the accident, even though technical brake failure could not be ruled out.

In the PH-SPZ case, according to his statement, the pilot noted a leftward inclination of the aeroplane upon touchdown. However, he was able to maintain control. This suggests that the left-hand brake was slightly, albeit not fully, jammed, and is an indication that the wheel was able to rotate to some degree. During taxiing the brake problems disappeared, but when the pilot applied the brakes after the controller called that he saw flames, he experienced reduced braking action. The aeroplane also showed a rightward tendency. This is an indication that parts of the brake unit were already damaged by fire or heat, resulting in a leakage of the braking fluid. Damage to the PH-SPZ was so severe that the state of the O-ring could not be determined.

b. *Brake activation by the pilot*
Unintentional brake activation during taxiing, resulting in a hot brake disc, may be caused by either a not fully released parking brake or by a phenomenon known as 'brake riding'.

A parking brake that remains partly activated during taxiing will result in unintentional braking action, as the brake pads remain pressed onto the brake disc. It could not be determined in either accident that this situation occurred during the accident flights.

The DR400 maintenance documentation states that permanent rubbing on the brake disc by the brake pads can be caused by unintentional application of brake pressure as a result of an incorrect feet position on the pedals. This phenomenon is known as 'brake riding'. During taxiing, the pilot's feet must be positioned on the lower end of the pedals to steer the nose wheel. Only during braking, the feet must be moved to the upper side of the pedals, see figure 13.

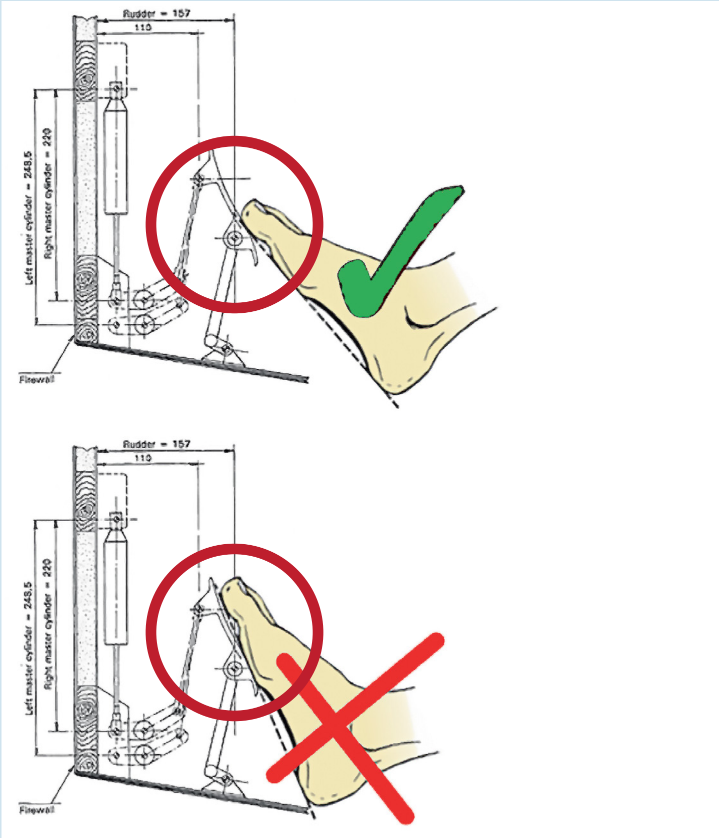

Figure 13: Correct and incorrect positioning of the feet on the pedals. (Source: Vliegclub Rotterdam, circles by Dutch Safety Board)

Although the aeroplane is equipped with adjustable front seats, the cockpit design may be considered to be tight for some users. Note that the average pilot's height has significantly increased since the time in which the aeroplane was designed. The average 30 year-old French man's height in 1960 (around the time of the first design) was approximately 170 cm.[4] In contrast, the occupants of the accident aeroplanes were 184 (PH-SPZ), and 186/179 cm (PH-HLR), respectively. Because of the limited space, the pilot's feet might possibly push the brake pedals.

Furthermore the pedals of the combined nose wheel steering/brake system are comparatively small. Moreover, contrary to the drawing in figure 13, the pedals in the DR400 are placed in a steep angle, see figure 5. These three factors may lead to feet being misplaced, c.q. inadvertent braking. Brake riding could therefore not be ruled out in either of the two accidents.

Following the second accident, the flying club published a newsletter drawing attention to foot placement in the cockpit. This newsletter also included the drawing of figure 13. Also, the flying club's instructors were advised to pay special attention to their students' feet positioning during flying lessons in the DR400. Finally, club members were reminded to monitor their taxi power settings.

4 Data from University of Tuebingen, as retrieved from https://ourworldindata.org/human-height/ on 30 January 2017.

Note that a form of *intentional*, but inappropriate, braking occurs when high taxi speed as a result of high power settings is compensated by the pilot through braking rather than through power reduction. The pilots of neither of the two accident flights reported having applied excessive braking, and the Dutch Safety Board did not have reason not to doubt these statements. In the paragraph on engine data, it was shown that in both accidents, taxi power settings were significantly higher than those during two previous flights. In spite of this, the taxiing speeds of the accident aeroplanes were normal, at times even low in the PH-SPZ case. This indicates that some sort of resistance had to be overcome, which may be an indication that rubbing of the brakes was so significant, that in both case much higher power settings were necessary to achieve an acceptable taxi speed.

The need to apply relatively high power to achieve a desired taxi speed may indicate a brake problem. This may have an operational and/or technical reason. Before continuing taxiing, the pilot should ensure that the brake pedals are not accidentally pressed. If high power remains necessary, there may be a technical reason. In that case, taxiing has to be aborted.

2.2 Fire

The fire triangle in figure 14 illustrates that three elements need to be present for any fire to ignite: oxygen, fuel, and a heat or ignition source. In the accidents investigated, these three elements all proved to be present, and in this paragraph it is analysed which aeroplane materials or operational circumstances served as / contributed to one of these elements. Together with an analysis of the damage described in the previous chapter, this analysis will be used to identify the most likely sequence of events with regard to the origin of the fires and the way the primary fire developed into a fire destroying the aeroplanes' wing and main landing gear.

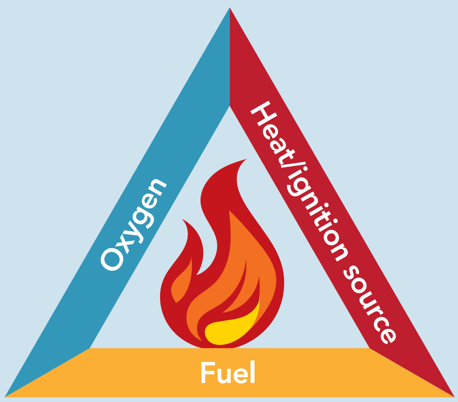

Figure 14: The fire triangle.

2.2.1 Oxygen

The accidents investigated by the Dutch Safety Board both took place while taxiing in open air. It is likely that the thus created flow of air provided a constant supply of oxygen to the location where the fires originated. A hole in the wing cover fabric, through which the hydraulic brake line runs from the brake unit into the wing, provides an open connection between open air and the inside of the wing. Since the fairings are not sealed to the aircraft frame, oxygen is also present there.

2.2.2 Fuel

The DR400 has of a number of components which are potential fuel sources for a fire as observed in the two investigated accidents. Table 1 shows the state these materials were found to be in after the PH-HLR and PH-SPZ fires, respectively.

Component	Flammable material	Damage in PH-HLR	Damage in PH-SPZ
Wing construction	Wood	Mostly destroyed	Mostly destroyed
Wing covering material	Polyester	Mostly destroyed	Mostly destroyed
Strut/wheel fairings	Polyester + resin	Heat damage	Destroyed
Foreign material inside wheel fairing	Various	Grass present[5]	Unknown (fairing destroyed)
Brake fluid	Oil	Unknown	Unknown
Grease	Oil	Unknown	Unknown
Tyre	Rubber	Pyrolytic damage	Pyrolytic damage
Fuel tank	Aeroplane fuel	Intact	Intact

Table 1: State of flammable aeroplane components after the fires in PH-HLR and PH-SPZ.

Compared to PH-SPZ, in the PH-HLR case more evidence remained available as the fire was extinguished at an earlier stage. In contrast to the wing (which was severely damaged) both the PH-HLR strut fairings and wheel fairings remained relatively intact. This suggests that the wing structure and wing covering material were more prone to being damaged by fire than these fairings, and/or that the fire originated at the wing and later spread into the strut fairings and wheel fairings.

2.2.3 Heat or ignition source

Although in both cases investigated by the Dutch Safety Board the left-hand wing structure was heavily damaged by fire, the technical investigation revealed no (electrical) ignition and/or heat sources on the wing itself. In both accidents, more taxi power (RPM/LOAD) was selected compared to previous flights. This suggested that friction had to be overcome during taxiing. This friction could have caused the combination of brake disc and brake pads to heat up.

5 Grass inside a wheel fairing was also identified as the fuel source in a DR400 fire of 3 March 1998. After the PH-HLR fire, the wheel fairings all other DR400 aeroplanes of the affected flying club (8 in total) were removed. None of them contained any grass on the inside.

The pyrolytic damage that was found on the left-hand tyre of PH-HLR, and which had the same circumference as the brake disc, clearly shows that the left-hand brake disc had become hot enough to damage the wheel's rubber. In the PH-SPZ case, the right-hand side of the left-hand tyre also showed marks indicating high temperatures in the proximity of the brake assembly. Given this evidence it is concluded that in both cases the brake disc had become so hot that the rubber of the tyre suffered pyrolytic damage corresponding with the outline of the brake disc.

2.2.4 Causes of a hot brake unit

When the original model of the Robin DR400/140B was type certified by the DGAC in 1975, the requirements of amendment AIR2052 applied. With regard to the brakes, AIR2052 stated:

"there must be brakes that are adequate to:

a. *Prevent the airplane from rolling on a paved runway with takeoff power on the critical engine; and*
b. *Provide adequate speed control during taxiing without excessive pilot loads".*

Following Commission Regulation (EC) No. 1702/2003, the DGAC type certificate was transferred to an EASA type certificate in 2003. As its original certified design stems from before 2003, the DR400/140B model's brake system was not subject to European Aviation Safety Agency (EASA) certification requirements. The latter would be based on *EASA Certification Specifications (CS) 23 - Normal, Utility, Aerobatic and Commuter Aeroplanes*. Section 23.735 thereof contains the formula in table 2, used to calculate the energy that each brake of this type of aeroplane needs to be able to dissipate during landing.

$$KE = \frac{0{,}5 \times M \times V^2}{N}$$

KE	=	Kinetic energy per wheel (Joules);
M	=	Mass at design landing weight (kg);
V	=	Aeroplane speed in m/s. V must be not less than VSO, the power off stalling speed of the aeroplane at sea level, at the design landing weight, and in the landing configuration;
N	=	Number of main wheels with brakes

Table 2: The energy that brakes need to dissipate on landing (Source: EASA CS 23 (2003), section 23.735)

Calculations by the manufacturer show that the brake system used in the DR400 meets EASA requirements (even though they are not formally applicable[6]). This makes it unlikely that overheating of the brake unit occurred while being in normal use during landing.

6 Please note that, in contrast, any design modification to the aeroplane's brake system made after 2003 would need to comply with the EASA formula.

2.3 Sequence of events

The observed damage patterns and the available fire elements (as described in paragraph 2.2) were analysed with a specialized fire investigator of the Dutch Safety Board, in order to determine the most likely sequence of events in the PH-SPZ and PH-HLR accidents.

The damage analysis showed that the fires had not started as a result of radiation (from the brakes to the polyester wheel fairing) or convection (within the strut and wheel fairings). Rather, a scenario was identified in which:

1. *Friction leads to heated brake disc*
   Figure 9 showed two distinct patterns of pyrolytic damage to PH-HLR's left-hand tyre. The circular shape congruent with the brake disc, shows that friction resulted in a brake disc that heated up to very high temperatures, which radiated onto the rubber tyre nearby.[7] The cause of this friction remains as yet unknown, as neither a technical cause nor any design aspects leading to unintentional pilot braking could be ruled out in the investigation.

   Along with the heating-up of the brake disc, there was significant heat transport to the brake pads and other metal parts of the brake unit, as a result of thermal conduction.

2. *Heat transport from brake unit towards wing through strut*
   The metal from the DR400 strut is a very good thermal conductor, and an effective medium for heat transport from the brake units upward towards the wing of the aeroplane. It is well possible that grease and/or oil on the strut or on the fluid lines or oil in the shock absorber (which is located inside the strut) heated up whereas the strut and wheel fairings reduce the possibilities for cooling substantially, thus leading to heat retention. Therefore, shortly after the brakes heating up (without fire) the entire strut became very hot as well, all the way up to its connection with the wing.

3. *Fire ignites at connection of strut and wing construction*
   As a result of the heat, the polyester wing covering and the wood of the wing construction started releasing gases, an endothermic process known as *pyrolysis*. Heat can serve as an ignition source when in simultaneous contact with sufficient amounts of both oxygen and fuel. Oxygen must be considered to be present throughout the aeroplane's construction, while the wooden wing structure with its polyester covering formed an abundant source of fuel. Therefore, the initial heat was able to initiate an ignition process at the point where the strut and the wooden main spar of the wing are connected (See figure 15). In addition to this, it could not be ruled out that grease and oil played a conducive role in the development of the fire.

7 The tyre of PH-SPZ was damaged to such a degree that identification of similar patterns was not possible.

Figure 15: The wing-strut connection plate (marked in red), seen with and without fairing, during construction. (Photos: Dutch Safety Board)

4. *Fire spreads through the wing construction*
   The fire was able to spread throughout the wing of the aeroplane, with the wooden wing construction and synthetic fibre of the covering material serving as fuel. Depending on the amount of time until the moment the fire is extinguished, the damage may involve part of the wing, the whole wing, or even (as the hull is essentially built from the same materials) the entire aeroplane.[8]

5. *Combustion gases spread downward into the strut and wheel fairings*
   The part of the PH-HLR tyre showing the larger damage pattern (shown on the right-hand side of figure 9) was damaged through a different mechanism than friction from the brake disc. This pyrolysis damage was not caused by radiation from hot metal parts, but by hot combustion gases inside the wheel and strut fairings. This part of the tyre was in an upward position after the aeroplane had come to a stop.

   The gear strut fairing, acting as a chimney, caused hot combustion gases, and eventually fire, from the burning parts of the aeroplane to flow down from the wing towards the wheel. This gas flow caused the typical damage pattern to the PH-HLR left-hand wheel fairing (see figure 8). The blackened fire damage line marks the boundary of the hot gas that filled the upper part of the fairing. Note the step-wise pattern in line with the gear strut, indicating that hot gases were pushed down into the wheel fairing from the burning part of the aeroplane above (i.e. the wing), not the other way around. The fairing does not show any sign of radiation from the hot wheel axis, as the distance from the axis to the fairing is too large.

   The burn damage observed on the PH-SPZ left-hand gear strut and left-hand strut fairing hence was the result of the fire spreading downward. Fire spreads slowly in

8 For example, the fire in the accident in France of July 2016 destroyed most of the aeroplane.

downward directions, which explains why at the time of extinguishing the fire in the strut fairing had not developed to the same extent as the wing fire.

It is the opinion of the Dutch Safety Board that the above sequence of events offers the most plausible explanation for the observed damage patterns. However it cannot completely be excluded that the fire in fact started in or near the heated brake unit. In that case the fire went upwards and ignited the wing covering and wooden wing construction.

The Dutch Safety Board is of the opinion that the fires most likely started at the aeroplanes' wing structure. This would have provided the fuel which, in addition to the heat rising up from the brakes along the strut and omnipresent oxygen, provides the final element necessary to start a fire. It could not be ruled out that grease and oil played a conducive role in the development of the fire.

2.4 Specifications of the wing covering material

Tests on the PH-HLR wing and hull covering material by the Dutch Safety Board showed that this synthetic material starts degrading from around 180 degrees Celsius, and is destroyed at higher temperatures. Heat and/or fire coming from the main spar inside the wing may therefore (under certain conditions) also affect the wing covering material, in that it could lose its physical properties and/or catch fire as well.

Like in many similar occurrences (see paragraph 2.5), both the PH-SPZ and PH-HLR fires were only detected (either by ATC or, at a later stage, by the pilot) once fire and/or smoke started to appear from the wing. This late moment of detection reduces the occupants' time to escape from the aeroplane (when on the ground), or perform an emergency landing.

This suggests that it is especially important that the wing covering material has specified fire-resistant properties. One way to achieve this is through certification of the covering material. However, it was found that no fire resistance certification requirements exist for wing covering materials. The only requirements for such materials are in terms of thread use and traction resistance. It was found the aeroplane manufacturer uses a synthetic material (Diatex 2000EV3) which meets these requirements and has been certified for the use on this type of aeroplane.[9]

9 LBA-RS-25-03/93-1 and No. II-A 61

2.5 Similar occurrences

Since 1988, 21 occurrences have been investigated by France's aviation accident investigation bureau (BEA), whereby Apex DR400 or similar aeroplanes suffered a fire resulting in various degrees of damage to the aeroplane. An overview of these is provided in table 3.

Date	Registration	Serial number	Build date	Type of brake activation	Gear fire started	Flight Phase	Model if not DR400	POB	Prob cause	Wheel fairings
13-2-1988	F-GCUR	273	December 1980	Toe pedals	Left	Departure	Aiglon	2	Unknown	Unknown
23-5-1989	F-BRFQ	371	April 1969	Central	Unknown	Departure	DR340	4	Long taxiing	Yes
27-9-1989	D-EEGT	1061	December 1975	Central	Right	Arrival		2	Unknown	Unknown
31-1-1992	F-GAXO	153	December 1978	Unknown	Right	Departure	R2160	1	Mechanical	Yes
15-6-1992	D-EIKR	1839	June 1988	Central	Left	Departure		1	Long taxiing	Unknown
6-6-1993	F-GCAB	233	June 1979	Toe pedals	Right	Arrival	Aiglon	2	Maintenance	Unknown
29-7-1997	OO-VMS	1124	May 1976	Central	Left	Arrival		3	Tyre burst	Unknown
3-3-1998	F-GEID	1677	January 1985	Central	Left	Departure		3	Dry grass in fairings	Yes
10-10-1999	F-BRCY	353	February 1969	Central	Left	Departure	DR340	4	Residual braking	Yes
3-2-2000	F-GTZE	342	December 1999	Toe pedals	Left	Departure	HR200	2	Maintenance	Yes
21-3-2000	F-BXRB	1063	July 1975	Central	Left	Departure		1	Maintenance	Yes
13-6-2000	F-BVDJ	910	March 1974	Central	Left	Departure		4	Long taxiing	Unknown
3-6-2001	F-GORT	2299	January 1996	Toe pedals	Left	Departure		4	Unknown	Unknown
1-3-2004	F-GBVC	1387	February 1979	Central	Left	Departure		3	Residual braking	Yes
31-8-2005	F-GCIG	1453	December 1979	Central	Left	Departure		4	Maintenance	Unknown
13-6-2009	F-GEIF	1690	April 1985	Central	Right	Departure		4	Unknown	Yes
20-3-2011	F-BRTK	408	August 1969	Central	Left	Departure	DR315	1	Residual braking	Yes
11-5-2012	F-BXET	1024	April 1975	Central	Right	Departure		1	Residual braking	Unknown
8-7-2012	F-GGJU	1822	April 1988	Central	Left	Departure		4	Long taxiing	Yes
3-7-2015	F-GAHH	1177	December 1976	Central	Left	Departure		1	Long taxiing	Yes
July 2016	G-GBUV	1376	1978	Central	Left	Departure		2	Unknown	Yes

Table 3: Overview of main landing gear and wing fires involving Apex DR400 or similar aeroplanes. (Source: BEA)

It should be noted that the fires in these cases were observed on both the left-hand and right-hand side of the aeroplane, with both central and toe-pedal brakes, and after landing as well as before (and occasionally even after) take-off. The investigation did not reveal why (like those in PH-HLR and PH-SPZ) most fires started on the left-hand side. The Dutch Safety Board considers this a coincidence.

No supporting evidence to substantiate the cause of these fires is presented here. However, the Dutch Safety Board received some additional information from BEA on their findings, confirming that in various cases the brakes had become overheated due to a constant rubbing of the brake discs. Explanations for this rubbing ranged from continuous (unintentional) braking by the pilot, to a mechanical defect.

From these French accidents, the Dutch Safety Board concludes that overheating of a main gear brake unit can indeed result in the loss of a wing following a scenario as presented in paragraph 2.3 for the two Dutch accidents.

In conversations with the Dutch Safety Board, users and maintenance organisations recognised the risks mentioned above. They proposed the following improvements regarding the DR400:

- Design and implement a more robust brake unit and rim.
- Design and implement a parking brake sensor and warning system.
- Design and implement a brake sensor indicating braking pressure.
- Re-design the nose wheel steering/brake pedals, in terms of size and position.

3 CONCLUSIONS

At the time of the accidents, both PH-SPZ and PH-HLR had been maintained in accordance with the requirements and held valid airworthiness certificates.

Engine data showed that in both accidents significantly more power had to be selected to reach normal taxi speed after landing than during previous flights. Therefore, it was determined that friction between the brake pads and brake disc was present. This friction caused the brake disc to be heated up to very high temperatures.

The analyses suggested the fires first ignited in the wing, as a result of heat conduction from the hot brake unit through the metal strut. The fires likely started at the point where the strut is connected to the wood and polyester of the wing structure, which served as fuel. Oil and grease on the strut may have added to the development of the fire. From the burning wing, fire and hot combustion gases spread downwards into the strut and wheel fairings. It can not ruled out completely that the fire started near the brake unit.

As no skid marks or flat spot of the landing wheel tyres were found in either accident, a blocked wheel is unlikely to have caused the friction in the brake disc. A more likely cause is continuous braking, causing the brake disc to heat up. However, the cause of this continuous braking could not be established.

No fire resistance certification requirements exist for wing covering materials. The only requirements for such materials are in terms of thread use and traction resistance.

During the investigation it appeared that since 1988, DR400, or similar type aeroplanes have been involved in at least 23 wing fires resulting in either loss of the wing or of the entire aeroplane. The Board is of the opinion that this number is high, even when taking into account the significant number of flights made with this type of aeroplane (approximately 1 million landings per year with the current fleet of 2.500 aeroplanes, according to the manufacturer[10]). Although a definitive cause of these fires could generally not be established, it is clear to the Safety Board that DR400 type aeroplanes are prone to fires due to the used materials. The design of the main gear strut, including the brake unit and fairing, plays a crucial role in the developing of these fires.

10 Source: article in French magazine *Info-Pilote* of February 2013.

4 RECOMMENDATIONS

Although the Apex DR400 aeroplane meets all legal airworthiness requirements, it is advisable to make the aeroplane less vulnerable to fire caused by a heated brake unit. That is the reason why the Dutch Safety Board makes the following recommendation to the European Aviation Safety Agency (EASA):

- Advise the manufacturer of the Apex DR400 to improve the aeroplane's brake unit, as to prevent overheating of the brake disk as a result of friction between the brake disk and brake pads.

DUTCH
SAFETY BOARD

Visiting Address
Anna van Saksenlaan 50
2593 HT The Hague
T +31(0)70 333 70 00
F +31(0)70 333 70 77

Postal Address
PO Box 95404
2509 CK The Hague

www.safetyboard.nl