# Final Report

# BOEING B777-200, REGISTRATION 9V-SQK

# TOW TUG FIRE

# 29 NOVEMBER 2017

AIB/AAI/CAS.155

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

11 March 2020

***The Transport Safety Investigation Bureau of Singapore***

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## GLOSSARY OF ABBREVIATIONS

| | | |
|---|---|---|
| ARFF | : | Airport rescue and firefighting service |
| AGLCMS | : | Airfield Ground Lighting Control and Monitoring system |
| AOC | : | Apron Operations Centre |
| ATC | : | Air Traffic Control |
| CCTV | : | Closed circuit television |
| CT | : | Certified Technician |
| DO2 | : | Duty Officer at Fire Station 2 |
| DT | : | Domestic tender |
| ECU | : | Engine Control Unit |
| FS1 | : | Fire Station 1 |
| FS2 | : | Fire Station 2 |
| FT | : | Foam tender |
| LMSP | : | Line maintenance service provider |
| LT | : | Local time |
| MCO | : | Maintenance Control Office |
| TCU | : | Transmission Control Unit |
| WRO | : | Watch Room Operator |
| WSFS | : | West Satellite Fire Station |

## SYNOPSIS

On 29 November 2017, a B777 aircraft was being towed by a tow tug along Taxiway South Cross 1 at Singapore Changi Airport when the tow tug caught fire at about 0402LT.

The tow tug was damaged by the fire and the aircraft suffered heat damage to its nose gear and forward fuselage area.

The fire was put out by the airport's rescue and firefighting service. No one was injured in the occurrence.

The Transport Safety Investigation Bureau classified this occurrence as an incident.

## AIRCRAFT DETAILS

| | | |
|---|---|---|
| Aircraft type | : | B777-200 |
| Operator | : | Singapore Airlines |
| Registration | : | 9V-SQK |
| Engine details | : | 2 x Rolls-Royce Trent 800 |
| Date and time of occurrence | : | 29 November 2017, 0402LT |
| Location of occurrence | : | Changi Airport, Singapore |
| Type of flight | : | Aircraft on maintenance tow |
| Persons onboard | : | 1 |

## 1 FACTUAL INFORMATION

All times used in this report are Singapore times. Singapore local time (LT) is eight hours ahead of Coordinated Universal Time (UTC).

### 1.1 Sequence of events

#### 1.1.1 Towing of aircraft

1.1.1.1 A tow tug from a Line Maintenance Service Provider (LMSP) and numbered as Unit 90[1] was assigned to tow a B777 aircraft from bay 400 to bay A19 in Singapore Changi Airport. The towing party comprised a tow tug driver, a headset man and a certifying technician (CT). The headset man and the tow tug driver sat in the driver's cabin of the tow tug and the CT positioned himself in the aircraft's cockpit.

1.1.1.2 Towing an aircraft at Changi Airport required coordination of three entities. The towing party would communicate its request to the aerodrome operator's Apron Control, who in turn would coordinate with Control Tower of Changi Airport's Air Traffic Control (ATC). As per this procedure, the towing party informed Apron Control that they were ready to move the aircraft and Apron Control informed Control Tower of the towing party's request and obtained the Control Tower's clearance. Apron Control forwarded Control Tower's clearance to the towing party at 0350LT. The tow route comprised Taxiways A3, Taxiway EP, South Cross 1 (SC1) and Taxiway U3 (see **Figure 1**).

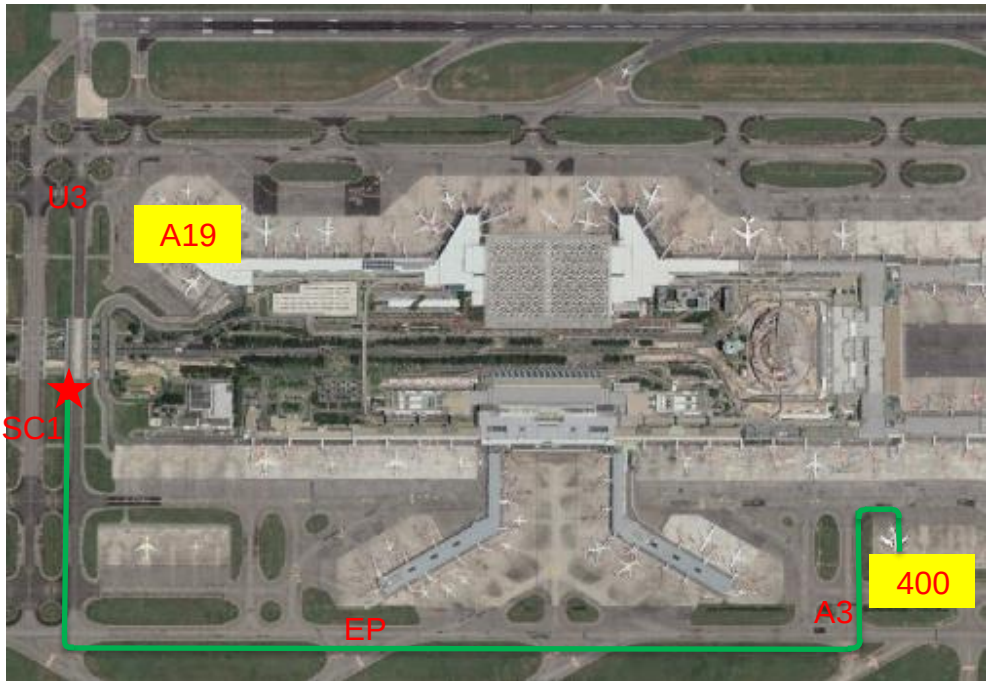


Figure 1. Tow route of the aircraft

[1] The LMSP had five other tow tugs from the same tow tug manufacturer, numbered as Units 01, 91, 97, 98 and 99.

1.1.1.3 At about 0401LT, the towing party was approaching a taxiway bridge (marked ★ in **Figure 1**) on SC1. When the towing party reached the bridge, the headset man and the driver felt vibrations. Then the engine stopped and they looked back and noticed a fire at the area of the engine which was located directly behind the driver's cabin[2]. The driver and headset man quickly evacuated the driver's cabin.

1.1.1.4 The headset man alerted the CT about the fire and asked the CT to set the park brakes of the aircraft[3]. The CT set the park brakes and informed Apron Control of the fire through the aircraft radio at about 0402LT. He asked Apron Control to alert the airport rescue and firefighting service (ARFF)[4]. Apron Control informed Control Tower about the fire. Control Tower then alerted the ARFF Watch Room in Fire Station 2 (FS2) of the smoke[5] from a tow tug on SC1. Apron Control also called the ARFF later to inform about the fire.

1.1.1.5 In the meantime, the tow tug driver used the 2 kg ABC dry powder fire extinguisher onboard the tow tug to fight the fire. He used up all the fire extinguishing agent of the 2 kg fire extinguisher but still could not extinguish the fire. He then called his supervisor to inform about the fire and that he could not extinguish the fire. He did not call the ARFF as he was aware that the headset man had informed the CT about the fire and he assumed that the CT would inform the necessary parties.

1.1.1.6 Around that time, on being informed by the headset man that the fire had worsened, the CT decided to leave the aircraft for his safety**.** He informed Apron Control that he would be leaving the aircraft. He then shut down the aircraft's power by switching off the auxiliary power unit (APU) and the battery. After obtaining ground clearance from the headset man, he deployed the slide raft at the door 4 left and evacuated the aircraft.

1.1.1.7 The first ARFF vehicle that arrived at the scene of the fire, at about 0413LT, was a domestic tender[6] (DT) from West Satellite Fire Station (WSFS). The DT managed to control the spread of the fire. A foam tender (FT1) from WSFS arrived at about 0420LT and extinguished the fire with foam. Another foam tender (FT2) from FS2 arrived after FT1 had extinguished the fire.

1.1.2 Actions and events relating to Apron Control, Control Tower and ARFF

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[2] According to the tow tug driver, there had been no abnormal indication on the instrument panel in the driver's cabin.

[3] The towing parties are required to comply with the Aerodrome Operator's Ground Operations Safety Manual (GOSM). The GOSM prescribed, among others, that the tow tug driver should inform the member of the towing party in the cockpit of the aircraft about the fire and that the tow tug driver should try to fight the fire, whereas the member of the towing party in the cockpit should inform the ARFF and Apron Control.

[4] The headset man also called his company's Maintenance Control Office (MCO) to inform about the fire.

[5] The Control Tower could only see smoke in the direction of SC1.

[6] Domestic tenders were used for fighting non-aircraft related fires, e.g. building or installation fire, vehicle fires, ground equipment fires. Domestic tenders carried only water.

| Time | Actions/events relating to Apron Control | Actions/events relating to Control Tower | Actions/events relating to ARFF |
|---|---|---|---|
| 0402:04LT | The CT informed the towing coordinator in Apron Control of the tow tug fire via aircraft radio using the towing frequency 121.9MHz. The CT asked Apron Control to alert the ARFF. | | |
| 0402:45LT | Another aircraft towing party that was towing an aircraft on South Cross 2 (SC2), a taxiway parallel to SC1, saw the fire and alerted Apron Control with the message "*witness fire onboard aircraft in front of me fire flame ah air tug*[7] *there's a fire*"[8]. | | |
| 0403:06LT | The towing coordinator informed Control Tower of the tow tug fire and its location[9]. | Control Tower told Apron Control it saw smoke in the direction of the indicated location. However, it did not see the fire as it did not have line of sight to the fire. | |
| 0403:26LT | The aircraft towing party on SC2 reported further to Apron Control "*fire onboard the aircraft in front me major fire*"[10]. | | |
| 0403:35LT | | Control Tower alerted the ARFF Watch Room in FS2[11] of smoke from a tow tug on SC1 and asked the ARFF to check out the situation. | After the call from Control Tower to the Watch Room in FS2 had ended, an unknown caller called the Watch Room in FS2 to inform of a tow tug fire. |
| 0404:04LT | The CT informed Apron Control that he would be leaving the aircraft. He shut down | | |

[7] The term "air tug" refers to a tow tug.

[8] This message was obtained from the recording of the towing frequency.

[9] According to the towing coordinator in Apron Control, he called the ARFF but the line was engaged. He left it to the Duty Manager of Apron Control (who had overheard the radio communications between the towing coordinator and the CT) to follow up and he himself went back to his normal tasks.

[10] This message was obtained from the recording of the towing frequency.

[11] Control Tower did not call the ARFF emergency hotline but called instead the fire station that it believed was closest to the fire scene.

| | | | |
|---|---|---|---|
| | the aircraft's power by shutting down the APU and the battery. | | |
| 0404:22LT | The Duty Manager of Apron Control used his mobile phone to call the ARFF emergency hotline (65412525) to inform the ARFF Watch Room Operator (WRO) in Fire Station 1 (FS1) of the tow tug fire on SC1[12]. | | The WRO asked the Duty Manager of Apron Control to check whether there was an aircraft being towed by the tow tug. |
| 0405:17LT | | Control Tower called ARFF Watch Room in FS2 to check if the ARFF vehicles had been sent as they could see smoke from the direction of the scene of fire. | ARFF Watch Room in FS2 replied that they were sending out the vehicles. |
| 0405:23LT | | | The WRO sounded fire alarm to alert WSFS. |
| 0405:32LT | | | The WRO ordered WSFS to despatch a DT[13] to the scene of fire. |
| 0406:40LT | The aircraft towing party on SC2 overheard the communications between the CT and Apron Control, and informed Apron Control that the power of the incident aircraft would be turned off and there would be no more communications from the incident aircraft. | | Apron Control replied that they had already informed the ARFF about the fire. |
| About 0408LT | | | The WRO was updated by the Duty Manager of Apron Control that an aircraft was on tow by the tow tug on fire. At 0408:27LT, he ordered WSFS to despatch a foam tender (FT1) to the scene of fire. |
| About 0413LT | | | The DT arrived at the scene of the fire. |

[12] The Duty Manager of Apron Control could not recall if he had indicated to the ARFF that an aircraft was on tow.

[13] The ARFF's procedures were that foam tenders would be used for fighting aircraft-related fire and domestic tenders for non-aircraft related fire. The WRO classified the occurrence as a non-aircraft related fire pending a reply from the Duty Manager of Apron Control as to whether there was an aircraft being towed by the tow tug.

| | | | |
|---|---|---|---|
| 0413:58LT | | | The DT informed the WRO that firefighting was in progress. |
| 0417:11LT | | | Duty Officer from FS2 (DO2) deployed a foam tender (FT2) to the scene of fire after the crew of the DT had requested for more support to fight the fire. |
| 0420:23LT | | | FT1 arrived at the scene of fire and put out the fire within a minute. . |
| About 0422LT | | | FT2 arrived at the scene of the fire[14]. |

1.2 Injuries to persons

1.2.1 The CT who was in the aircraft sustained some scratches when evacuating via the slide raft.

1.3 Damage to aircraft

1.3.1 The following components of the aircraft sustained heat damage (see **Figure 2**):

- Radome
- Nose landing gear and tyres and nose landing gear doors
- Hydraulic and electrical components inside the nose landing gear wheel well
- Some fuselage skin panels and supporting structure between the radome bulkhead and aft edge of Door 1 and below the cockpit floorboard
- Panels and several electrical components in the Main Equipment Compartment (MEC)

[14] FT2 arrived at the rear of the aircraft at 0419:31LT. However, it could not get to the front of the aircraft using SC1 as the aircraft wings were blocking the way. It also did not wish to skirt around the aircraft on the grass area to avoid the risk of getting itself stuck on soft ground. So it made a detour to reach the front of the aircraft.

Figure 2: Damage to aircraft structure and nose landing gear

1.4 Damage to tow tug

1.4.1 The tow tug was destroyed (see **Figures 3** to **5**).

Figure 3: Damage to the driver's cabin of the tow tug

Figure 4: Damage to the right side of the tow tug

Figure 5: Damage to the left side of the tow tug

1.5 Personnel information

1.5.1 The members of the towing party were assigned to the towing operation by the LMSP. They had been trained by the LMSP.

1.6 Tow tug information

1.6.1 General

1.6.1.1 The tow tug involved in the incident was a diesel-powered Kalmar Towbarless 190 (TBL190) model.

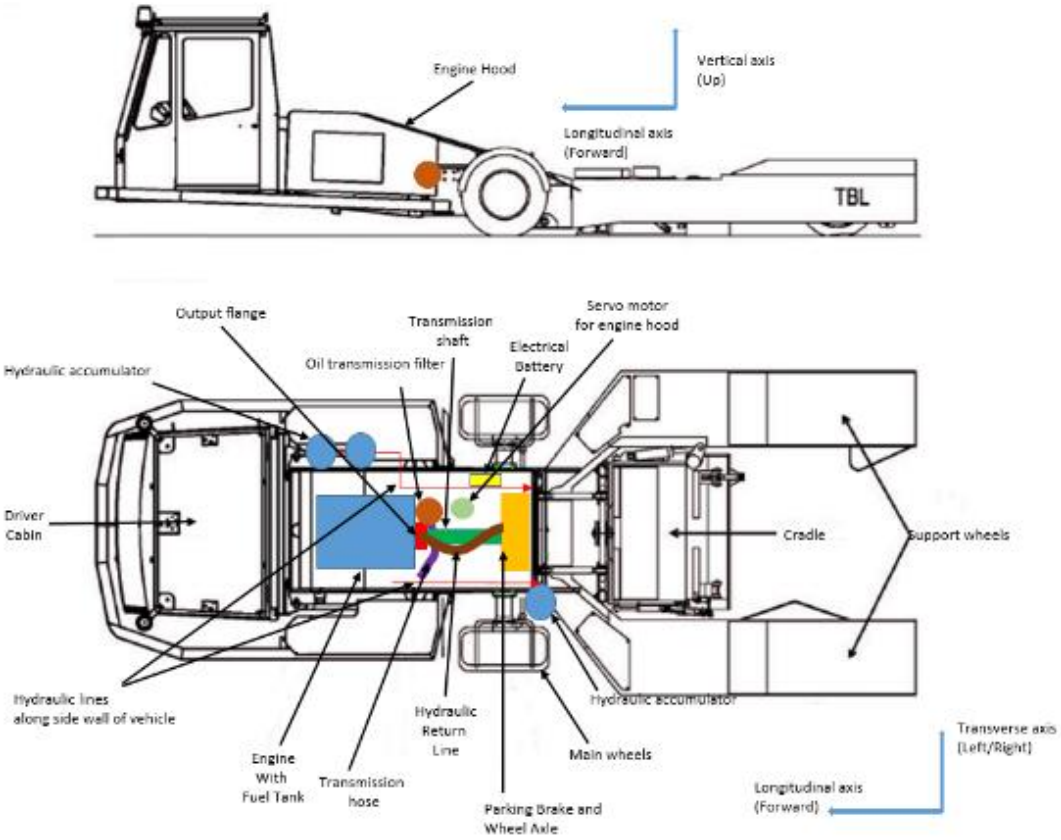


Figure 6: Tow tug schematic

1.6.1.2 The weight of the aircraft was about 138,418 kg and the general gradient of SC1 at the vehicular bridge was less than 1°. They were within the tow tug's capabilities.

1.6.2 Transmission shaft assembly

1.6.2.1 The tow tug's engine gearbox drove the front wheel axle system via a transmission shaft assembly. For the purpose of this investigation report, the transmission shaft assembly is termed as comprising four elements, viz. a fixed yoke, a splined yoke and two universal joints (see **Figure 7**).

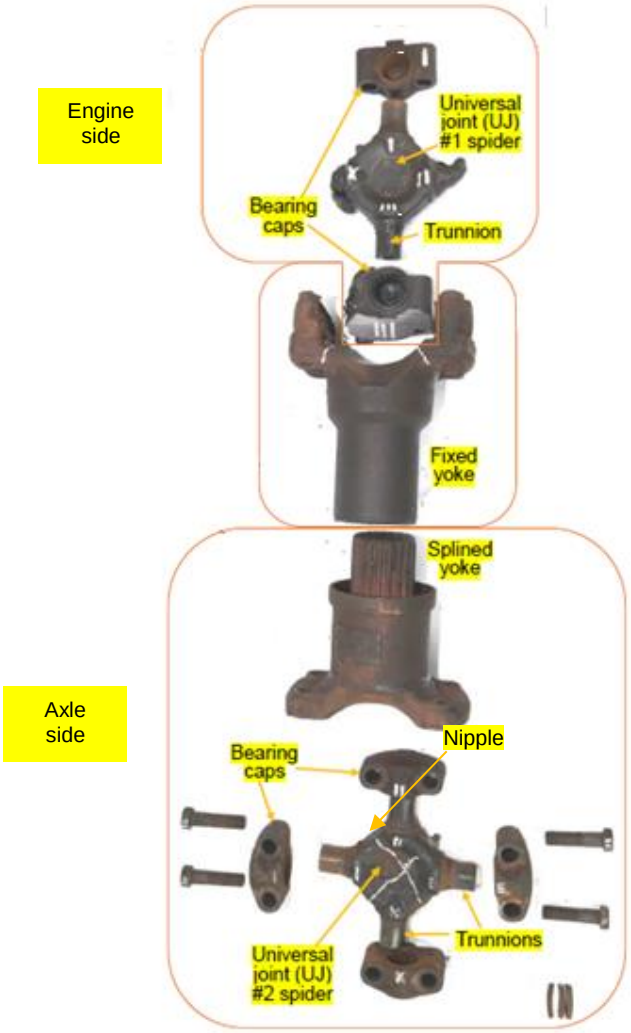


Figure 7: Tranmission shaft assembly

1.6.2.2 The fixed yoke was connected to the engine transmission (the "engine side") by one of the two universal joints. The splined yoke was connected to the front axle input flange (the "axle side") by the other universal joint (see **Figure 8**). Each universal joint comprised four bearing caps (with needle bearings) and a spider (with four trunnions). The LMSP's practice of

lubricating the transmission shaft assembly involved injecting grease into the nipple of each universal joint spider until the grease flowed out from the trunnions of the universal joint spider into the bearing caps.

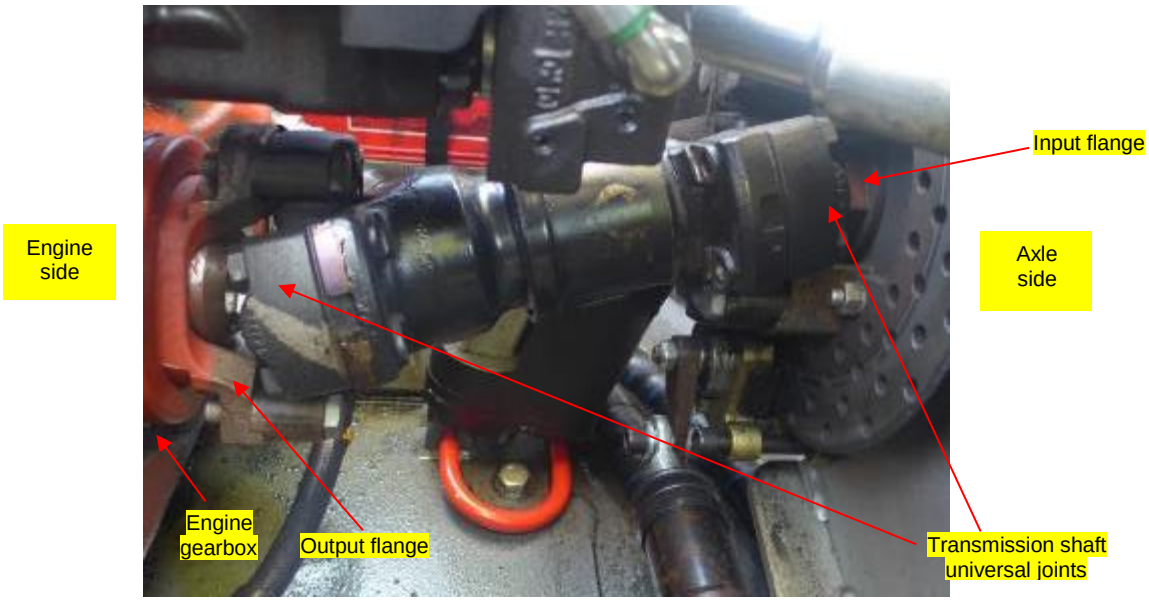


Figure 8: Transmission shaft assembly in situ

1.6.3 Engine transmission output flange

1.6.3.1 The engine transmission output flange (including its screen sheet) was held onto the output shaft of the engine transmission by a retainer plate and two bolts that were screwed into threaded holes at the end of the transmission output shaft (see **Figure 9**).

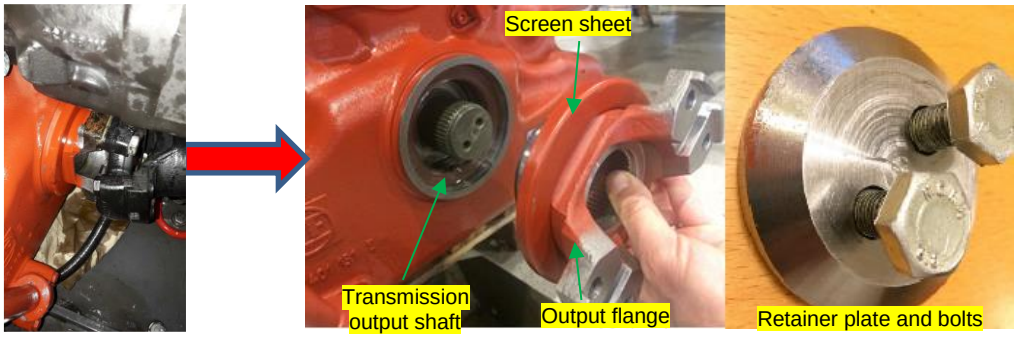


Figure 9: Retainer plate holding output flange (illustration picture only)

1.6.4 Tow tug maintenance

1.6.4.1 Based on the tow tug manufacturer's operating manual, the LMSP developed a 500 hourly servicing programme for the tow tug. The scheduling of the 500 hourly servicing was based on the cumulative operating hour data displayed on the tow tug's dashboard[15].

[15] The tow tug had a Transmission Control Unit (TCU) that also recorded cumulative operating hours. However, the LMSP did not have access to the TCU data.

1.6.4.2 The tow tug entered service with the LMSP on 18 January 2016. It had operated for 22 months by the time of the occurrence. According to the LMSP's maintenance records, the LMSP had performed, since the day the tow tug entered service, 14 instances of 500 hourly servicing on the tow tug. The maintenance records showed that the transmission shaft assembly was greased at each of these servicing. The last 500 hourly servicing prior to the occurrence was performed on 20 October 2017 when the tow tug had clocked 7,012 operating hours as displayed on the dashboard[16].

1.6.5 Maintenance pertaining to transmission shaft assembly

1.6.5.1 The tow tug manufacturer's operating manual indicated the maintenance requirements for transmission shaft (or "prop-shaft" in the tow tug manufacturer's parlance) as follows (see **Figure 10**):

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Brakes; function, chamber attachment, linings | K | | K-J | | K-J | K-J |
| Parking brake, Function, Adjustment | | K | K-J | K | K-J | K-J |
| Prop-shaft; attachment, lubrication | | K-S | K-S | K-S | K-S | K-S |

Figure 10: Maintenance requirements[17] of the transmission shaft assembly in the tow tug manufacturer's operating manual

1.6.5.2 The LMSP's 500 hourly servicing programme also provided for the lubrication of the transmission shaft assembly.

1.6.6 Maintenance support by tow tug manufacturer

1.6.6.1 The tow tug manufacturer did not have a local maintenance facility to provide maintenance servicing of tow tugs. It trained LMSP's maintenance personnel to perform tow tug maintenance. It also appointed a local company to be its agent who would provide technical service and after-sales support to the LMSP.

1.6.6.2 Following the occurrence, the tow tug manufacturer assisted the LMSP to carry out thorough inspection of the LMSP's five other TBL 190s[18] (Units 01,

[16] The tow tug operating hours as clocked on the dashboard at the time of the occurrence were unknown since the tow tug's dashboard was destroyed by the fire. However, the tow tug was noted from the dashboard to have operated 7,448 hours when it went into the workshop for an ad hoc servicing on 26 November 2017 (three days before the occurrence). These additional 436 hours were consistent with an estimated daily usage of about 12 hours. By extrapolation, the operating hours at the time of the occurrence three days later could be estimated to be about 7,500 hours. Separately, the Transmission Control Unit (TCU) recovered from the tow tug wreckage contained data that showed a cumulative 7,726 operating hours, some 230 hours more than the estimated 7,500 hours. It is not known how this discrepancy between the TCU clock data and the dashboard clock data came about.

[17] Legend: A = Daily, B = 500 hours or 2 times/year, C = 1000 hours or 1 time/year, D = 1500 hours, E = 2000 hours, K = check, S = lubricate, Prop-shaft = transmission shaft assembly

[18] According to the tow tug manufacturer, it deemed it had no more warranty obligation vis-à-vis the LMSP in respect of the tow tugs as the LMSP had never submitted any maintenance service reports.

91, 97, 98 and 99) in the LMSP's maintenance workshop during the period December 2017 to January 2018.

1.6.6.3 The tow tug manufacturer shared with the investigation team in February 2018, in the course of the latter's investigation, its reports on its observations from this assistance mission for the LMSP as regards the tow tugs it had inspected:

(a) Fresh grease used by the LMSP being blue in colour and as the grease of the transmission shaft assemblies of two tow tugs (Units 97 and 99) was found to be black, the tow tug manufacturer concluded that the transmission shaft assemblies had not been re-greased since the tow tugs entered service in May 2017[19]. As for the other three tow tugs (Units 01, 91 and 98), the tow tug manufacturers could not draw any conclusion as the grease was blue, suggesting that the transmission shaft assemblies had been re-greased recently.
(b) The engine gearboxes were overfilled with transmission oil and transmission oil was exuding through the transmission breather.
(c) The tow tugs operated with various leaks in the hydraulic system.
(d) Axle hubs were not adequately filled with oil.
(e) Sliding points of the cradle were not greased since the tow tugs entered service.
(f) Hinges of doors, panels, and covers were not greased.
(g) Various areas of the tow tugs were found with dirty oily rags left in the chassis.

1.6.6.4 The investigation team was unable to gather evidence to ascertain the tow tug manufacturer's observations. The investigation team did have an opportunity to come across two of the five tow tugs (Units 98 and 99) in service at the airside on 8 December 2017 and observed that there was grease on the prop-shafts but did not observe any spilt/leaked oil, dirt or oily rags at the bottom of the engine compartment of the tow tug.

1.6.6.5 The LMSP, on its part, carried out tests which were witnessed by the investigation team and which showed that fresh grease in the transmission shaft assembly of a tow tug could start to turn dark after as soon as three

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The submission of the service reports was a condition of the tow tug manufacturer for the warranty to remain valid, as indicated in the service report form contained in the tow tug manufacturer's operating manual. However, the LMSP indicated it was not aware of this condition. It had been using its own maintenance report form to document its tow tug maintenance activities. The tow tug manufacturer told the investigation team it had reminded the LMSP to submit service reports on several occasions prior to the occurrence. However, the LMSP told the investigation team that it had never received any reminder from the tow tug manufacturer. The LMSP also told the investigation team that it had from time to time emailed to the tow tug manufacturer about servicing issues and the tow tug manufacturer responded to those emails.

[19] The LMSP did not agree with the observation and carried out a test by injecting fresh grease into the transmission shaft assembly of tow tug Unit 01 and inspected the grease condition after seven days of operation. The grease started to turn dark. The test was repeated and yielded the same result. The test was then conducted on tow tug Unit 99 and the grease was inspected after three days. It yielded the same result.

days of operation[20].

1.7 Meteorological information/aerodrome conditions

1.7.1 There was no precipitation at the time of the occurrence. The wind was about 2 to 7 knots varying from a direction of 270° to 320°[21].

1.8 Recorded data

1.8.1 The following recordings were useful for establishing the sequence of events:

(a) Video footage from the aerodrome operator's closed circuit television (CCTV) cameras facing the taxiway
(b) ATC radio transmission recordings
(c) Recordings of the Airfield Ground Lighting Control and Monitoring System (AGLCMS)
(d) Recordings from the telematics system (which had been installed in the tow tug by a third party)
(e) Recorded data from the Transmission Control Unit (TCU)
(f) Recordings of the communications between:
    (1) ARFF watch rooms and Control Tower; and
    (2) Apron Control and Control Tower

1.8.2 The occurrence tow tug's Engine Control Unit (ECU) was destroyed by fire and no data could be retrieved from it.

1.9 Tow tug wreckage information

1.9.1 Parking brake

1.9.1.1 There was no evidence of seizure of the parking brake at the wheel axle location[22].

1.9.2 Engine compartment

1.9.2.1 **Figure 11** shows the damage to engine components under the engine hood. The transmission oil filter, made of steel, had the underside of its casing punctured (see **Figure 12**), resulting in oil leakage from the casing.

[20] The fresh grease in the transmission shaft assembly of tow tugs Unit 01 and 99 started to turn dark after seven and three days of operation respectively.
[21] The fire was blown towards the nose of the aircraft on tow.
[22] Seized brake could be a source of heat for ignition.

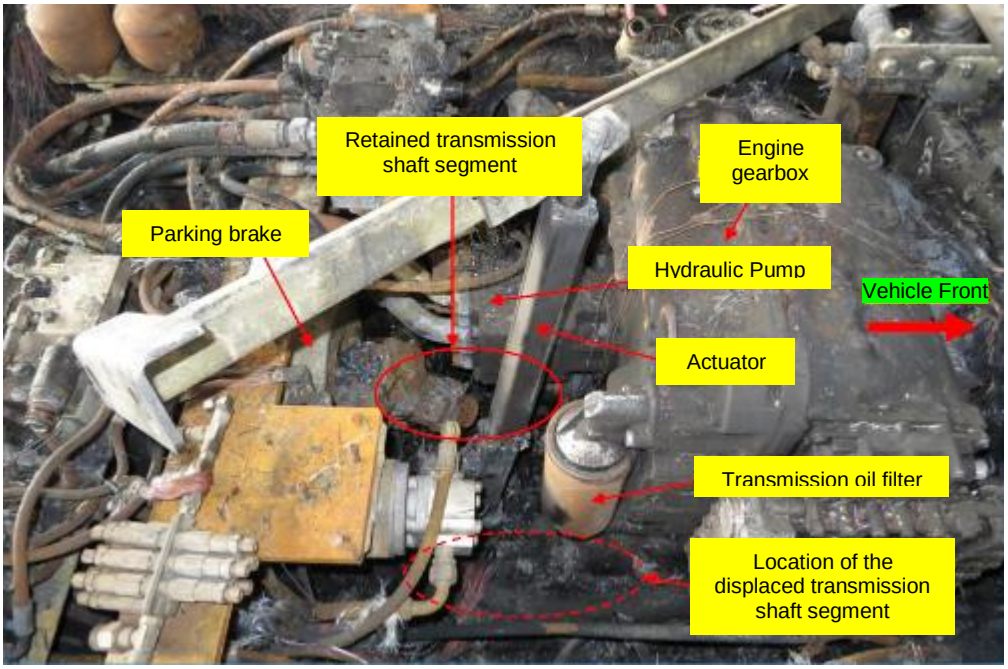


Figure 11: Damage to components under the engine hood

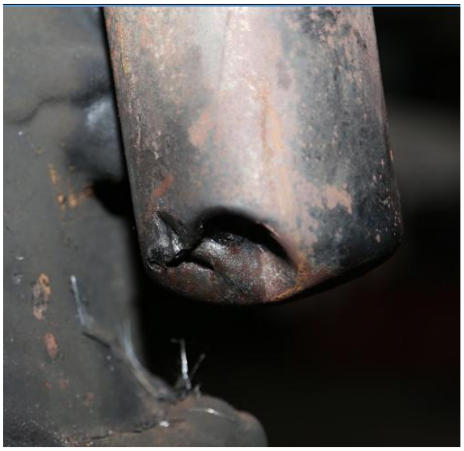

Figure 12: Puncture on the underside of the transmission oil filter casing

1.9.2.2 The hydraulic oil tank was almost empty. Some hydraulic hoses had been burnt off.

1.9.2.3 There was evidence of transmission oil loss.

1.9.3 Transmission shaft assembly

1.9.3.1 The fixed yoke segment of the transmission shaft assembly was separated from the splined yoke (see **Figure 13**).


Figure 13: Fixed yoke segment of the transmission shaft assembly (left photo showing the component after cleaned-up)

1.9.3.2 The spider of the universal joint at the engine side connecting the fixed yoke and the transmission output flange was still in place but one of the two pairs of trunnions of the spider was deformed (see **Figure 14**).

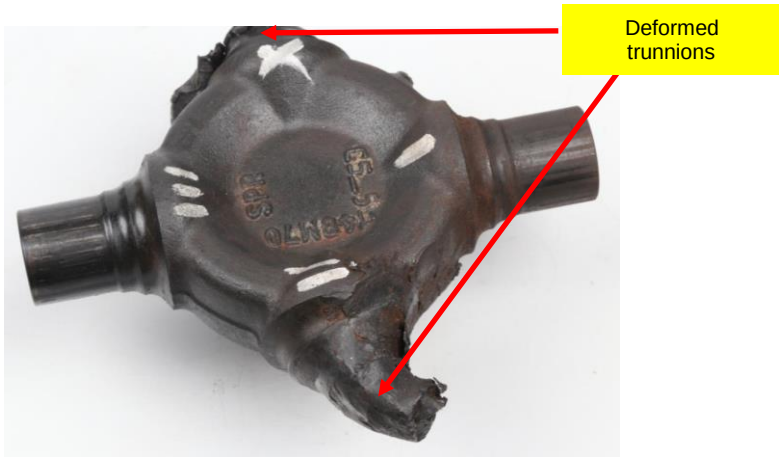


Figure 14: Damaged spider of the universal joint connected to the output flange

1.9.3.3 The needle bearings in the corresponding pair of bearing caps on the fixed yoke were missing. The two retainer plate bolts were found to be loose from the threaded holes of the output shaft (see **Figures 15 and 16**). As a result, the retainer plate was not fully secured against the output flange.


Figure 15: Output shaft of the engine gear box (output flange removed for clarity)

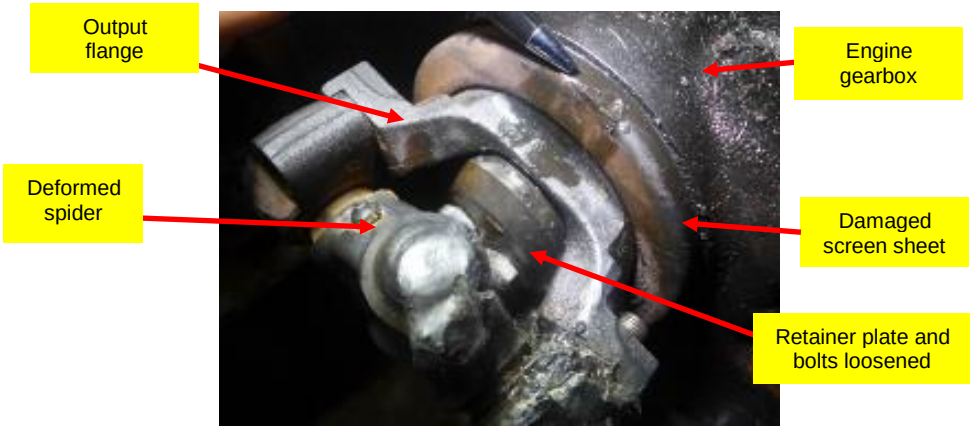

Figure 16: Deformed spider of universal joint

1.9.3.4 The other pair of trunnions on the spider of the universal joint at the engine side connecting the output flange was not damaged (see **Figure 17**). No abnormalities were found on the corresponding pair of bearing caps and the needle bearings inside. Grease was found on these bearings[23] and within the grease channels in the universal joint spider.

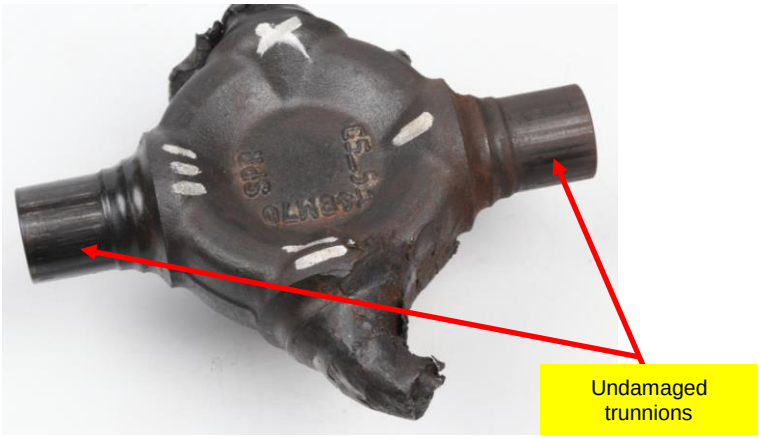

Figure 17: Undamaged trunnions

1.9.3.5 The burnt state of the grease in the universal joint spider at the engine side as well as the axle side was such that it is not possible to estimate the amount of grease in the universal joint spider before the fire.

1.9.3.6 On 14 August 2017, when operating TBL190 tow tug Unit 01, the driver noticed a leak from the vehicle on the tarmac but he did not notice any abnormal vibrations. Unit 01 had by then operated 1,137 hours. Subsequently, the LMSP found damages to the output flange and retainer plate (see **Figure 18**) of the engine gearbox and there was a leak of transmission oil from the gearbox. The two retainer bolts were also found loosened[24]. The occurrence was reported to the tow tug manufacturer,

[23] The four bearing caps with their needle bearings and the universal joint spider at the axle side were found to have only little grease residue on them after the fire incident but there was no abnormal wear on their corresponding pairs of trunnions.

[24] One of the two retainer bolts had loosened, and the other bolt had loosened off and was found on the bottom of the engine compartment. Units 91, 97, 98 and 99 had operated for 6,889, 2,663, 2,579 and

through its local agent. The damaged output flange, retainer plate and bolts, and associated seals were replaced by the LMSP as recommended by the tow tug manufacturer. The tow tug manufacturer mentioned to the investigation team that it was not aware of any case of bolt loosening prior to this 14 August 2017 case that occurred to the LMSP.

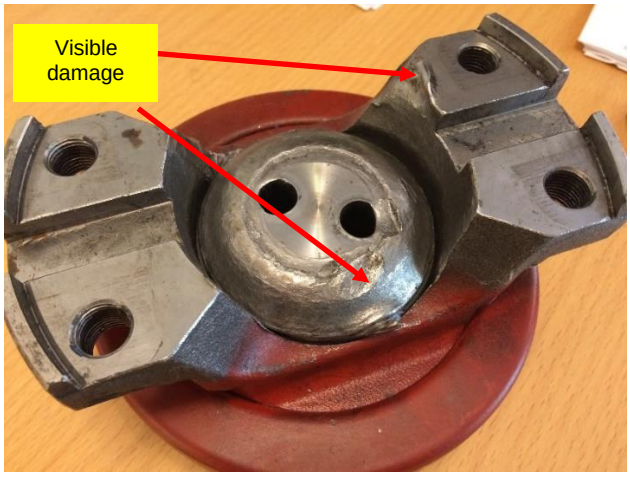


Figure 18: Damage on output flange and retainer plate

1.10 Medical and pathological information

1.10.1 The tow tug driver underwent medical examinations and toxicological tests after the occurrence. There was no evidence of any medical or toxicological factors that could have affected his performance.

1.11 Fire

1.11.1 Fire extinguisher for tow tugs

1.11.1.1 Airside vehicles, including tow tugs, operated under an airfield vehicle permit (AVP) issued by the aerodrome operator. For the issuance of AVP, the aerodrome operator required all vehicles to have at least a 1 kg fire extinguisher of fire rating 13A/B or equivalent[25]. The occurrence tow tug had a 2 kg ABC dry powder fire extinguisher of fire rating 13A/55B[26]. This met the aerodrome operator's requirement.

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2,682 hours respectively as of 29 November 2017 and had not encountered any similar looseness.

[25] The letter code A (or B or C) in the fire rating denotes the type of fire that the extinguisher is to be used for:

- Class A extinguishers are for fire involving ordinary combustibles such as wood, paper or textiles;
- Class B extinguishers are for fire involving flammable liquids such as petrol, diesel or oils; and
- Class C extinguishers are for fires involving flammable gases.

The number (e.g. 13) in the fire rating is a code for the size of fire that the extinguisher is able to put out. An extinguisher with a bigger size code can put out fire of a bigger size.

[26] Size code 13 for type A fire and size code 55 for type B fire.

1.11.2 Notification to ARFF

1.11.2.1 The aerodrome had an ARFF emergency hotline (65412525) to centralise all fire calls. The aerodrome operator had been promoting awareness of the ARFF emergency hotline to the airside workers by the following means:

(a) Briefing airside workers on the airside fire emergency procedure when they were attending the mandatory airside safety briefings, before issuing them with airport passes for access to the airside or renewing their airport passes;
(b) Issuing vehicle decals[27] and Airside Driving Theory Handbooks to airside drivers; and
(c) Distributing emergency contact cards.

1.11.2.2 At the time of the occurrence, the aerodrome operator was in the midst of developing a mobile application which was eventually introduced to the airside community in December 2017.

1.11.2.3 The aerodrome regulator interviewed 10 airside workers[28], selected on a random basis, on 29 December 2017, i.e. one month after the occurrence, to assess the effectiveness of the aerodrome operator's promotional efforts. Only one of the 10 workers was found to be aware of the need to call the ARFF hotline (i.e. 65412525) in the event of a fire.

1.11.3 Fire response plan

1.11.3.1 The ARFF intended that all fire calls should be made via the ARFF emergency hotline to the Watch Room in FS1, manned by the WRO. The WRO could, for an initial response, decide on which fire station's (FS1, FS2 or WSFS) personnel to activate and what kinds of ARFF assets to deploy.

1.11.3.2 However, if the Watch Room in FS2 received a fire call directly, it could also, for an initial response, decide on which fire station's (FS1, FS2 or WSFS) personnel to activate and what kinds of ARFF assets to deploy.

1.12 Tests and research

1.12.1 Further metallurgical examinations and tests arranged by the investigation team revealed the following:

(a) The head of the hexagonal bolts securing the fixed yoke to the bearing cap (see **Figure 19**) was hexagonal in shape and zinc-coated.

[27] One such decal was pasted on the side of the fire extinguisher of the occurrence tow tug used by the tow tug driver.

[28] The 10 airside workers comprised tow tug drivers, equipment drivers and internal shuttle drivers. They were asked on what to do and what the number to call in an emergency or in the case of a fire.


Figure 19: Hexagonal bolt heads on the fixed yoke of the cleaned-up transmission shaft assembly

(b) The puncture on the casing of the transmission oil filter had an indentation that appeared to be hexagonal in shape (see **Figure 20**).

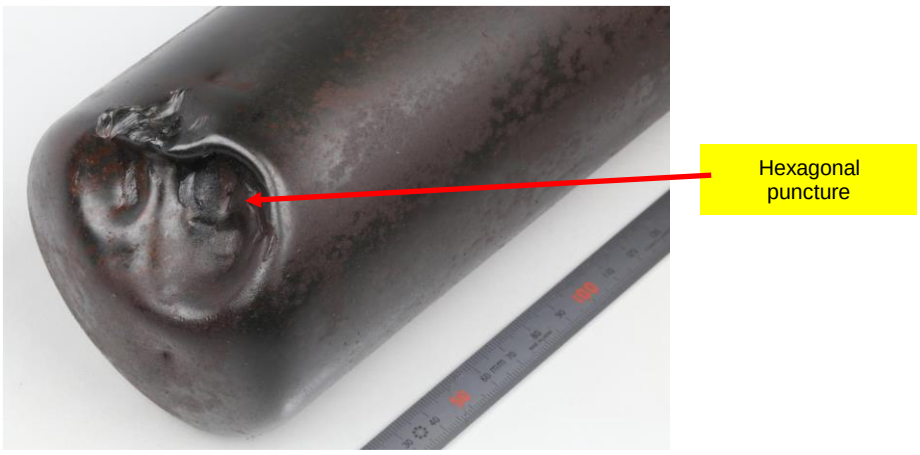


Figure 20: Hexagonal shaped puncture on the transmission oil filter casing

(c) There was evidence of zinc material transfer, on the hexagonal shaped puncture, from the head of a hexagonal bolt securing the fixed yoke to the bearing cap. This suggested that the fixed yoke had hit the casing.
(d) The transmission oil filter operated at a high pressure of 20 bars. Thus, a puncture of the casing could result in the spraying out of the pressurised oil through the punctured area.
(e) The temperature of the fixed yoke was well above the flash point of the transmission oil[29] when the transmission oil from the transmission oil filter was sprayed over it.
(f) The pair of damaged trunnions of the universal joint spider at the engine

[29] Microscopic examination of the bearing caps on the fixed yoke and the output flange revealed evidence that the fixed yoke and its universal joint had been subjected to severe temperature excursion (short term overheating) and high load/stress. There was evidence of recrystallisation in some parts of the microstructure of the fixed yoke. This suggested that the fixed yoke metal had been subjected to a temperature higher than its recrystallisation temperature (around 500-700°C), which was well above the flash point of the transmission oil. However, the temperature of the fixed yoke metal did not reach its melting point (greater than 1300°C).

side failed due to short term frictional heating[30].

1.12.2 The metallurgical examination did not find any evidence of melting of the transmission shaft assembly i.e. the transmission shaft metal had not reached its melting point.

[30] Microscopic examination of the deformed trunnions did not show any microscopic abnormalities or features that could be associated with long term overheating.

## 2 ANALYSIS

The investigation looked into the following:

(a) Cause of fire and failure of transmission shaft assembly
(b) Loose output flange retainer plate bolts
(c) Maintenance of the tow tug
(d) Fire extinguishers for airside vehicles
(e) Fire notification to ARFF

### 2.1 Cause of fire and failure of transmission shaft assembly

2.1.1 The tow tug manufacturer has suggested the following as regards the failure of the transmission shaft assembly and fire development sequence:

(a) The transmission shaft assembly experienced frictional heating at the needle bearings due to a lack of lubrication.
(b) The overheated transmission shaft assembly produced sparks as a result of the grinding of the shaft material and started to melt.
(c) The sparks came into contact with oily rags and/or fluid[31] at the bottom of the engine compartment of the tow tug and initiated a fire.
(d) The tow tug continued to move with the transmission shaft assembly melting, and this created vibration and caused the transmission output flange retainer plate and bolts to come slightly loose.
(e) Finally, the fire burnt through the wires connected to the ECU which caused the engine to stop and the transmission shaft assembly broke away.

2.1.2 The investigation team suggested, on the basis of the results of the metallurgical examinations and tests, that the fire could have developed as follows:

(a) The disintegration of the needle bearings of the universal joint at the engine side of the transmission shaft assembly resulted in metal-to-metal rubbing of the bearing caps and trunnions. The rubbing caused the deformation of the bearing caps and trunnions under short-term frictional heating, resulting in the liberation of the fixed yoke (which could have a temperature of 500-700°C or higher) and engine stoppage[32].
(b) The liberated fixed yoke flung and hit the transmission oil filter casing, which was punctured as a result.
(c) The transmission oil sprayed out from the transmission oil filter casing

[31] When the tow tug manufacturer helped the LMSP inspect the LMSP's remaining tow tugs in the maintenance workshop (see paragraph 1.6.6.2), it observed that tow tug Units 97 and 99, while in the workshop, had spilt oil, dirt and oily rags at the bottom of the engine compartment of the tow tugs. The tow tug manufacturer concluded that there was spilt oil, dirt and oily rags at the bottom of the engine compartment of tow tug Unit 90 at the time of the tow tug fire.

[32] The investigation team believed that once the transmission shaft assembly had failed, there would have been no more torque loading of the engine's gear box. The engine rotational speed would have increased as a consequence. The ECU would have then sensed the increased engine rotational speed and an engine protection feature to prevent an overspeed of the engine could have stopped the engine to prevent any damage.

onto the hot surfaces of the fixed yoke and the remnants of the transmission shaft assembly, resulting in fire ignition.

(d) This fire caused the hydraulic system's feeding hose to be burnt off and hydraulic oil started to feed the fire[33].

2.1.3 The ECU data could have thrown light on the cause of fire and failure of transmission shaft assembly. As the ECU was destroyed by fire, no ECU data was available. The investigation team was unable to determine the cause of fire and the failure of transmission shaft assembly.

2.1.4 Nevertheless, the investigation team had doubts about the tow tug manufacturer's fire development hypothesis in paragraph 2.1.1 in view of the following:

(a) It could not be established that, at the time of the occurrence, there was spilt oil, dirt and oily rags at the bottom of the engine compartment of the tow tug (see paragraph 1.6.6.4).

(b) The likelihood of sparks generated from frictional forces to start a fire was low[34].

2.1.5 Also, the tow tug manufacturer opined that the transmission shaft assembly experienced frictional heating at the needle bearings due to a lack of lubrication and the frictional heating caused the transmission shaft assembly to melt. However, basing on the results of the metallurgical examination, the investigation team could not agree with the tow tug manufacturer's view, in consideration of the following:

(a) There is no evidence that there was a lack of lubrication of the engine side of the transmission shaft assembly[35].

(b) There is no evidence that the temperature of the transmission shaft metal reached its melting point.

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[33] Even after the engine had stopped, the hydraulic system would still have been pressurised from the hydraulic accumulators and the hydraulic fluid would still have been flowing out of the burnt hydraulic hoses to feed the fire.

[34] This was in view of the following:

- The heat energy of the sparks emitting from the grinding of the shaft material was not as high as that of a piece of red hot glowing solid metal. The sparks generated from the shaft material, which was of low amount and mass, would not stay hot for long, and would extinguish quickly. Thus, the sparks were unlikely to be able to ignite the oily rags and/or fluid, if any, at the bottom of the engine compartment.
- In view that the relatively high flash points of the transmission oil (greater than 200°C) and hydraulic oil (greater than 177°C), the spilt fluid at the bottom of the engine compartment, if any, was unlikely to produce vapour to support ignition when coming into contact with the sparks. The atomised oil from a high pressure (20 bars) oil transmission filter casing that was punctured, was more likely to produce vapour to support ignition.

[35] As mentioned in 1.9.3.5, the burnt state of the grease in the universal joint spider at the engine side as well as the axle side was such that it was not possible to estimate the amount of grease in the universal joint spiders before the fire. The investigation team was inclined to believe that the damaged universal joint of the transmission shaft assembly was greased, judging by the presence of grease in the undamaged trunnions and its associated needle bearings of the failed universal joint spider and given that the two damaged and the two undamaged trunnions were greased via the same nipple on the universal joint spider.

2.2 Loose output flange retainer plate bolts

2.2.1 The tow tug manufacturer's operating manual indicated that the transmission shaft assembly and its "attachment" should be "checked" and "lubricated" every 500 hourly. In the course of the investigation, the tow tug manufacturer explained to the investigation team that "attachment" was referring to "not only the prop-shaft (i.e. the transmission shaft assembly) but also to all the included parts and screws for the entire system, including the transmission output flange and the front axle input flange". The operating manual did not include details of how the "attachment" should be "checked" and "lubricated", e.g. visual inspection only or inspection requiring special tools (such as torque wrench). The lack of details would leave room for different interpretation by maintenance organisations of the scope of inspections.

2.2.2 The LMSP developed its 500 hourly servicing programme based on the level of detail within the tow tug manufacturer's operating manual. The servicing programme provided for the visual inspection and the lubricating of the transmission shaft assembly, but did not provide for detailed inspections of the transmission output flange, retainer plate and bolts, and front axle input flange, including the checking for looseness of transmission output flange and retainer plate and bolts, as they were not specified in the tow tug manufacturer's operating manual.

2.2.3 While there was no evidence that the looseness of retainer plate and bolts was associated with the failure of transmission shaft assembly, the investigation team believed that it would be desirable for the tow tug manufacturer's operating manual to be improved by incorporating detailed inspection requirements for the transmission output flange, retainer plate and bolts, and front axle input flange, including the checking for looseness of these components. This would provide clarity to tow tug users on the maintenance requirements. If bolt looseness cannot be easily detected visually, it would be essential to have a proper joint design for securing the transmission output flange.

2.3 Maintenance of the tow tug

2.3.1 As mentioned in paragraph 1.6.6.3, the tow tug manufacturer had shared its observations with the investigation team about the LMSP's maintenance of the tow tugs, but the investigation team was unable to gather evidence to ascertain the tow tug manufacturer's observations. It was difficult for the investigation team to conclude as to whether maintenance of the tow tugs was a factor in the occurrence.

2.4 Fire extinguishers for airside vehicles

2.4.1 The tow tug had a 2 kg dry powder fire extinguisher of rating 13A/55B which met the aerodrome operator's requirements. However, this tow tug fire

showed that a 2 kg ABC dry powder fire extinguisher was not adequate.

2.4.2 There appears to be a need for the aerodrome operator to review the fire extinguisher requirements for airside vehicles.

2.5 Fire notification to ARFF

2.5.1 The aerodrome had an ARFF fire emergency hotline (65412525) to call for the reporting of a fire. Airport personnel were required to report any fire directly to the ARFF. In this way, the ARFF on receiving the call would have an opportunity to verify directly with the reporter about the details of the fire and promptly despatch the appropriate firefighting assets to the correct location to attend to the fire.

2.5.2 In this incident, there were delays in alerting the ARFF or responding to the fire alert:

(a) The headset man informed the CT about the fire and then the CT relayed this information to Apron Control. Thereafter, the tow tug driver called his supervisor and the headset man called the LMSP's Maintenance Control Office for fire assistance. Neither of them called the ARFF directly.
(b) The CT informed Apron Control of the tow tug fire at 0402:04LT. Apron Control, which had been alerted, did not call the ARFF immediately. Instead, it called Control Tower.
(c) Control Tower did not call the ARFF emergency hotline but chose to call FS2 which Control Tower believed was closest to the scene of the tow tug fire. This was not in line with ARFF's plan to have all fire calls to ARFF emergency hotline[36].
(d) Between 0402:04LT and 0403:35LT, there was a considerable amount of time taken by Apron Control and Control Tower to establish the location of the occurrence and to ascertain whether there was a fire or there was only smoke, instead of alerting the ARFF immediately. The investigation team opined that Apron Control and Control Tower should have alerted the ARFF immediately even if only smoke was observed.
(e) Apron Control was aware that an aircraft was being towed by the tow tug from bay 400 to bay A19 as it was involved in arranging for towing clearance from Control Tower. Yet, when asked by the WRO to check whether there was an aircraft being towed by the tow tug, Apron Control somehow needed some three minutes to provide a reply to the WRO.
(f) While awaiting a reply from the Duty Manager of Apron Control as to whether there was an aircraft being towed by the tow tug, the WRO despatched a DT to the scene of fire. The investigation team felt that the WRO could have assumed a worst case situation, i.e. that the fire had involved an aircraft, and despatched at least a FT.
(g) The Watch Room in FS2 received the fire alert from Control Tower

[36] All fire calls via ARFF emergency hotline were received by the Watch Room in FS1.

before the Watch Room in FS1 received from the Duty Manager of Apron Control, but the Watch Room in FS2 did not immediately activate WSFS. Instead, it spent time taking a call from an unknown caller who reported the same fire. The investigation team felt that the Watch Room in FS2 should have put the unknown caller on hold and activated the WSFS immediately.

2.5.3 The airport community should review the fire reporting system to ensure that fire occurrences are reported to the ARFF and relevant information provided to the ARFF as soon as possible. In particular, personnel working in the airport should be constantly reminded to call the ARFF directly whenever they first noticed a fire and to provide relevant information to the ARFF so that the latter could deploy the firefighting assets promptly and effectively.

## 3 CONCLUSIONS

*From the information gathered, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.*

3.1 The causes of the fire and failure of the transmission shaft assembly could not be conclusively determined.

3.2 The output flange retainer plate bolts of the transmission shaft assembly were found loosened.

3.3 The tow tug manufacturer's operating manual did not provide sufficient details for the maintenance of the transmission shaft assembly and output flange connections. The LMSP, who based its tow tug maintenance programme on the tow tug manufacturer's operating manual, also did not have any detailed maintenance procedure for the transmission shaft assembly and output flange connections.

3.4 The fire safety requirements for airside vehicles would need reviewing and updating.

3.5 There was room for improvement for the airport community to alert the ARFF of fire occurrences and provide relevant information to the ARFF as soon as possible.

## 4 SAFETY ACTIONS

*During the course of the investigation and through discussions with the investigation team, the following safety actions were initiated by the line maintenance service provider (LMSP), and the aerodrome operator (including its ARFF).*

### 4.1 Engineering measures

4.1.1 Immediately after the occurrence on 29 November 2017, the aerodrome operator required the LMSP to ensure the operational safety of the tow tugs. Subsequently, the LMSP requested the tow tug manufacturer to carry out a thorough inspection of its five other TBL 190s (Units 01, 91, 97, 98 and 99) during the period December 2017 to January 2018. The inspection included the following:

(a) Replacing all the transmission shaft assemblies with new ones and lubricating them.
(b) Rechecking the alignment[37] of the transmission and output flange assemblies of each TBL 190 tow tug if necessary.
(c) Re-installation of all the retainer plate bolts with the torqueing performed in two phases: a first round of torqueing to 39 Nm and without application of thread locker (a kind of grease that, when hardened, could resist loosening of the bolts) and a second round of torqueing at 53 Nm. (Previously, torqueing was done to 47 Nm with thread locker.)

4.1.2 To assure the operational safety of the tow tugs, as required by the aerodrome operator, the LMSP also implemented a new mandatory inspection of the tow tug transmission shaft assembly and output flange connections every seven days until the cause of the fire is determined. One of the tasks during this periodic inspection is to ensure proper lubrication of the transmission shaft assembly[38] with the introduction of an enhanced lubrication procedure. These inspection requirements were also included into the 500 hourly preventive maintenance schedule.

4.1.3 The tow tug manufacturer designed an automatic fire detection and extinguishing system, which will be offered as an option for installation by its clients.

[37] Such realignment was done at factory level. The tow tug manufacturer had brought along its factory calibration tools to the LMSP for the realignment.

[38] The lubrication action would be considered satisfactory only if excess grease has exuded from all the four lubricant channels from the spider of a universal joint.

4.2 Safety management measures

4.2.1 The LMSP:

- Shared the occurrence with vehicle maintenance staff to highlight the importance of proper tow tug maintenance.
- Required its maintenance staff to sign against each task pertaining to lubrication on the task sheet, instead of ticking off these tasks when they were completed, with a view to establishing a higher degree of accountability.
- Required all its tow tug drivers to undergo fire extinguisher training.
- Required all its operational staff to be briefed on the airside fire emergency procedures through fire safety courses and safety briefing.
- Displayed ARFF emergency hotline (65412525) decals on prominent external surfaces of all motorised equipment to serve as a constant reminder.
- Revised the fire reporting procedures to report a fire directly to ARFF fire emergency hotline.

4.2.2 The aerodrome operator revised the fire reporting procedures for its Apron Control Staff to first contact the ARFF through the fire emergency number in event of an air side fire occurrence.

4.3 Firefighting capability measures

4.3.1 Following the tow tug fire, the aerodrome operator reviewed the fire extinguisher requirements for tow tugs with reference to standards developed by the National Fire Prevention Association (NFPA)[39]. As an interim measure pending the review, the aerodrome operator required two 6 kg dry powder fire extinguishers of rating 34A/233B[40] to be installed on the TBL 190 tow tugs. The LMSP installed the fire extinguishers as required.

4.3.2 The aerodrome operator completed its review of the fire extinguisher requirements in August 2018. It now requires tow tugs to have at least one fire extinguisher of a rating not less than 21B and of a minimum capacity not less than 6.8 kg. This new fire extinguisher requirement was implemented on 1 January 2019.

4.3.3 The aerodrome operator also conducted a one-time random inspection on the tow tugs operating within the airport and found that the inspected tow tugs were meeting the new requirements.

[39] Reference NFPA Manual 410. The NFPA is an international non-profit organisation that develops codes and standards for building, processing, design, service and installation around the world to minimise the risk and effects of fire. The NPFA is a premier resource for fire data analysis and research, and conducts investigations of fire incidents of technical interest.

[40] Size code 34 for type A fire and size code 233 for type B fire.

4.4 Fire response measures

4.4.1 The ARFF introduced the following measures to improve ARFF crew awareness and response to emergency calls:

- The Watch Room Operator (WRO) will make a public address announcement to all fire stations for all types of incidents to have all ARFF assets on standby for response.
- A water tender and a foam tender will be deployed together for any fire emergency calls involving aircraft ground handling vehicles.

4.5 Promotion of awareness of the ARFF fire emergency hotline

4.5.1 In response to a survey finding of the aerodrome regulator that many airside workers might not be aware of the ARFF emergency hotline (see paragraph 1.11.2.3), the aerodrome operator enhanced its promotion of awareness of the ARFF emergency hotline by the following:

- Revised the airside safety briefing materials to place more emphasis on the need to call the ARFF upon the sighting of smoke or fire in the airside.
- Revised the Airfield Driving Permit (ADP) application form to include the ARFF emergency hotline and a declaration by ADP applicants that they are aware of the hotline.
- Made it mandatory for airside vehicles to display a decal containing the ARFF emergency hotline.

## 5 SAFETY RECOMMENDATIONS

*A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.*

It is recommended that:

5.1 The tow tug manufacturer review the design for securing the transmission output flange in the TBL190 tow tugs. [TSIB Recommendation RA-2020-001]

5.2 The tow tug manufacturer provide more detailed inspection requirements in the TBL190 tow tug operating manual to ensure appropriate maintenance for its tow tugs. [TSIB Recommendation RA-2020-002]

5.3 Control Tower review its incident reporting procedure pertaining to airside fire occurrences. [TSIB Recommendation RA-2020-003]

5.4 The aerodrome operator review the fire reporting system so that information is made available to the ARFF quickly for a prompt response. [TSIB Recommendation RA-2020-004]