FINAL REPORT

BOEING B777-200ER, REGISTRATION 9V-SVC

AIR TURNBACK DUE TO FUEL DISCREPANCY

16 APRIL 2014

AIB/AAI/CAS.103

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

12 June 2018

The Transport Safety Investigation Bureau

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CONTENTS

GLOSSARY

AMSP	:	Aircraft maintenance service provider
CAAS	:	Civil Aviation Authority of Singapore
CT	:	Certifying Technician
EICAS	:	Engine Indicating and Crew Alerting System
ER	:	Extended range
FMC	:	Flight Management Computer
FQIS	:	Fuel Quantity Indicating System
FQPU	:	Fuel Quantity Processing Unit
IRP	:	Integrated refuel panel
LT	:	Lead Technician
PSM	:	Program switch module
RDO	:	Refuelling dispenser operator

SYNOPSIS

On 16 April 2014, while flying from Singapore to Johannesburg, the flight crew of a Boeing B777-200ER was prompted with a “FUEL DISAGREE” aircraft system message one hour into the flight. The flight crew carried out the necessary checks and noticed that, at that point in the flight, the fuel quantity onboard as calculated by the Flight Management Computer (FMC) based on the quantity of the fuel that had burnt off during the flight was less than the fuel quantity as measured by the aircraft’s fuel quantity indicating system (FQIS), and the difference between these two quantities was increasing. After consulting the airline’s maintenance centre, the flight crew decided to return to Singapore. The aircraft landed in Singapore without incident.

After landing, the fuel quantity remaining in the aircraft’s fuel tanks was measured. Subsequent calculation showed that the aircraft had departed with some 127 tonnes of fuel, instead of 86 tonnes as displayed to the flight crew by the FQIS. There was no injury to any person nor damage to the aircraft. The flight crew also did not encounter any flight handling difficulty.

The occurrence was classified as an incident.

AIRCRAFT DETAILS

Aircraft type	:	Boeing 777-200ER
Operator	:	Singapore Airlines
Aircraft registration	:	9V-SVC
Date and time of incident	:	16 April 2014, 0642 hours Singapore time
Location of occurrence	:	En-route from Singapore to Johannesburg
Type of flight	:	Scheduled passenger flight
Persons on board	:	264

1 FACTUAL INFORMATION

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

1.1 History of the flight

1.1.1 The incident aircraft was scheduled to depart at 0130 hours. The refuelling dispenser had arrived at 0013 hours to refuel the aircraft. A Certifying Technician (CT)[1] and a Lead Technician (LT) from an aircraft maintenance service provider (AMSP) oversaw the refuelling of the aircraft by the refuelling dispenser operator (RDO). The CT communicated with the flight crew through a headset. The LT positioned himself under the aircraft wing to monitor the aircraft's integrated refuel panel (IRP)[2] for the fuel quantity that was to be uploaded onto the aircraft.

1.1.2 The flight crew initially instructed the RDO, through the CT, to fuel the aircraft to a total fuel quantity of 82 tonnes. The flight crew later gave an instruction for a final total fuel quantity of 86 tonnes[3].

1.1.3 The RDO carried out the fuelling as instructed. The LT instructed the RDO to stop the refuelling operation when the LT read from the IRP that the aircraft's total fuel quantity had reached 86 tonnes. The LT then informed the CT, and the CT informed the flight crew accordingly. The flight crew confirmed to the CT that the figure tallied with the cockpit fuel indication.

1.1.4 Based on the refuelling dispenser's fuel flow counter, the RDO presented to the LT a receipt for 121.5 tonnes of fuel uplifted to the aircraft. Noticing the abnormally high fuel quantity stated on the RDO's fuel receipt, the LT confirmed from the IRP that the final total fuel quantity was 86 tonnes. He informed the CT of the fuel quantity discrepancy between the IRP and RDO figures.

1.1.5 The RDO showed the CT that the fuel quantity of 121.5 tonnes delivered by the dispenser as measured by the fuel flow counter (i.e. the amount of fuel transferred through the hose) was the same as that measured by the refuelling dispenser's start/end quantity totaliser gauge (i.e. the amount of fuel transferred out of the dispenser). The CT then queried if the fuel flow counter had been reset to zero prior to the refuelling operation. The RDO was uncertain at that

[1] The CT would sign off on the fuel receipt presented by the refuelling dispenser operator after verifying that the refuelling work had been done correctly.

[2] The IRP panel was a console under the left wing that allowed an aircraft refueller to control refuelling/defuelling operation. It also displayed the total fuel quantity in the aircraft's fuel tanks.

[3] It was a normal practice for the flight crew to provide a provisional (initial) total fuel quantity and confirmed at a later stage the final total fuel quantity.

time if he had reset the fuel flow counter but accepted CT's suggestion that the fuel flow counter might not have been reset[4].

1.1.6 The CT had earlier noted from the cockpit fuel quantity indicator before the refuelling operation that there was about 5.5 tonnes of fuel in the aircraft remaining from the previous flight[5]. The uplift of 121.5 tonnes of fuel would make a total of about 127 tonnes. This would mean 41 tonnes above the target figure of 86 tonnes.

1.1.7 The CT informed the flight crew about the fuel discrepancy and that there would be a delay to departure. He then consulted his supervisor and was advised to perform a manual fuel quantity check for the aircraft's fuel tanks using fuel measuring sticks[6]. (Such fuel measuring sticks were known commonly as "magnasticks". More details on magnastick check in paragraph 1.6.)

1.1.8 The CT delegated the magnastick check to the LT[7]. The CT assumed that the main wing tanks were full and asked the LT to perform the magnastick check for only the aircraft's centre fuel tank. Accordingly, the LT performed the check on two magnasticks located on the left and right sides of the centre fuel tank[8]. From the LT's readings and his assumption about the fullness of the main wing tanks, the CT arrived at a final fuel quantity of 86.001 tonnes (see paragraphs 1.6.3 and 1.6.4). Thus, the flight crew considered that the fuel quantity figure from the refuelling dispenser was inaccurate and accepted the CT's figure which tallied with the IRP figure and cockpit fuel indication of 86 tonnes.

1.1.9 The aircraft took off at 0200 hours. About one hour into the flight, the Engine Indicating and Crew Alerting System (EICAS)[9] warning message "FUEL DISAGREE" appeared[10]. The flight crew carried out the necessary checks and

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[4] The RDO later told the investigation team that the dispenser hose mechanism actually would not allow fuel delivery if the fuel flow counter was not first reset.

[5] For ensuring that refuelling was performed correctly, the CT was required to record the following amounts in a fuel log:

- Remaining fuel from the previous flight,
- Fuel uplifted during the refuelling operation; and
- Total of the above.

[6] The aircraft's fuelling manual would allow a maximum discrepancy of 1.786 tonnes before magnastick check was required. The discrepancy limit (in tonnes) can be calculated from the formula "0.005X +1.356", where X is the fuel uplift in tonnes. With X equals 86 tonnes, the discrepancy limit is 1.786 tonnes. The discrepancy of 41 tonnes in this case well exceeded the limit.

[7] The CT was required to perform the reading of the magnastick himself (see paragraph 1.7.2).

[8] These two magnasticks were the left and right No.1 magnasticks of the centre fuel tank (see paragraph 1.6.4). According to the LT, he had checked the magnastick decals before readings were taken to ensure that he was using the correct magnasticks.

[9] The EICAS is an integrated system used in Boeing aircraft to provide the flight crew with readings of aircraft systems as well as warnings and annunciations.

[10] During a flight, the Flight Management Computer (FMC) of the aircraft works out a "CALCULATED fuel" by subtracting the quantity of fuel burnt off by the engines from a baseline fuel quantity figure (TOTALIZER fuel as measured by the Fuel Quantity Indicating System (FQIS) before a flight). This CALCULATED fuel quantity would normally tally with the TOTALIZER fuel during the flight.

deemed the situation to be safe at that time. The flight crew monitored the situation, and they noticed that the CALCULATED fuel quantity remaining as computed by the Flight Management Computer (FMC) based on the quantity of the fuel that had burnt off during the flight was less than the fuel quantity remaining indicated by the aircraft's fuel quantity indicating system (FQIS) (see paragraph 2.4). It was expected that the FMC's calculated fuel figure should match the FQIS' measured fuel figure. The flight crew also noticed that the difference between the FMC and FQIS figures was increasing.

1.1.10 The flight crew reported the situation to the airline's maintenance centre and, after some discussion, decided to return to Singapore. The aircraft landed in Singapore without incident.

1.1.11 After landing, the aircraft's fuel quantity remaining was manually measured by magnasticks by another team of ground crew and their computations confirmed that the aircraft had departed with some 127 tonnes of fuel.

1.1.12 The flight did not result in injury to any person or damage to aircraft. The flight crew did not encounter any flight handling difficulty.

1.2 Personnel information

Certifying Technician	Male
Age	36
Experience in current capacity	4.5 years

Lead Technician	Male
Age	37
Experience in current capacity	5 years

Refuelling dispenser operator	Male
Age	63
Experience in current capacity	40 years

1.3 Fuel tank arrangement

1.3.1 Both the Boeing 777-200 and 777-200ER (the specific variant of the incident aircraft for Extended Range operation) models had left and right wing tanks and a centre tank. The left and right wing tanks of both models had approximately similar capacity[11]. However, the centre tank of Boeing 777-200 was much smaller than that of Boeing 777-200ER because the former included a large dry bay (see **Figure 1**) and the difference was about 40.5 tonnes.

[11] The difference in capacity was about 0.767 tonne per tank.

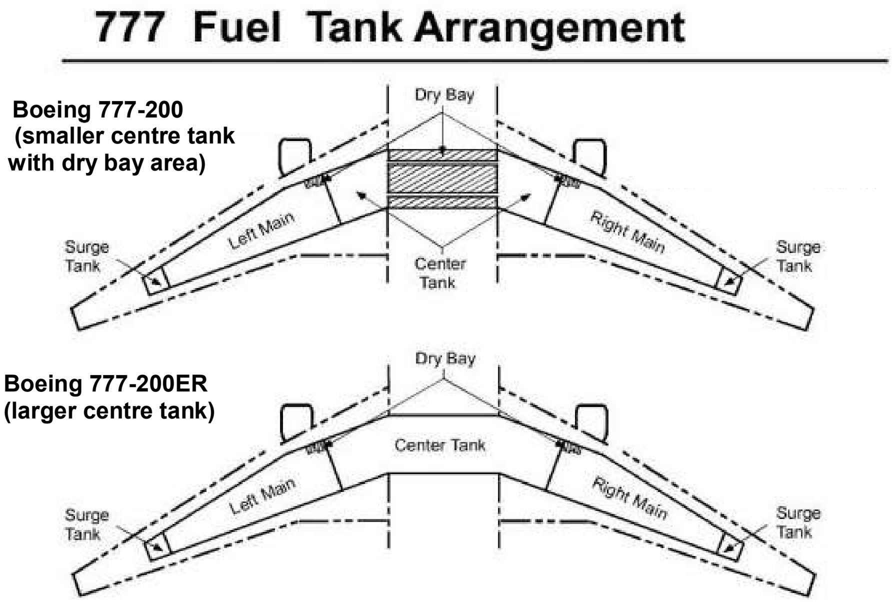


Figure 1. Differences in centre fuel tank arrangement between Boeing 777-200 and Boeing 777-200ER

1.3.2 The fuel capacity (in tonnes) of the various tanks were as follows (assuming specific gravity of fuel to be 0.780 kg/litre):

(In tonnes)	Boeing 777-200	Boeing 777-200ER
Center tank	36.612	77.063
Left tank	27.460	28.227
Right tank	27.460	28.227

1.4 Fuel Quantity Indication System

1.4.1 The aircraft's fuel quantity indicating system (FQIS) computed the total fuel quantity in the aircraft's fuel tanks by way of a system of sensors in the fuel tanks (e.g. densitometers, water detectors, fuel temperature sensors) and sent the computed total fuel quantity figure to both the IRP and the cockpit for display. Fuel tank sensors' input and computation were handled by the FQIS' Fuel Quantity Processing Unit (FQPU).

1.4.2 The bigger centre tank on the Boeing 777-200ER entailed an additional eight fuel sensors in the centre tank as compared to the Boeing 777-200. There was no difference between the two models in the fuel sensors arrangement for the wing tanks.

1.4.3 The aircraft was installed with a program switch module (PSM) (see **Figure 2**) consisting of pin switches that could be preset[12]. The PSM pin switch pattern for the Boeing 777-200ER was different from that for the Boeing 777-200 and allowed the FQPU to accept the inputs from the eight additional sensors on the Boeing 777-200ER centre fuel tank. In other words, the PSM made the FQPU "know" which aircraft model it was dealing with so that the FQPU would get inputs from the correct sensors and compute the fuel quantity accordingly.

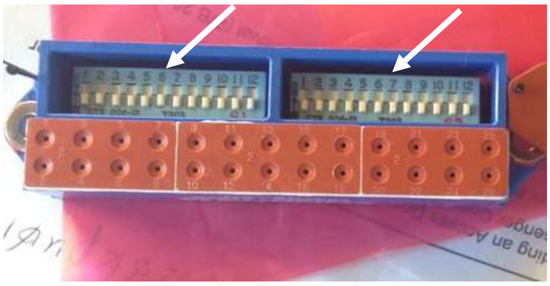


Figure 2: Program switch module with two sections of pin switches (white arrows)

1.4.4 A review of the FQPU data by the aircraft manufacturer after the incident showed that the FQPU was operating in the Boeing 777-200 mode, instead of the Boeing 777-200ER mode. Thus, the inputs from the eight extra centre fuel tank sensors on the Boeing 777-200ER model were not taken into account and the FQIS was under-reading the fuel quantity, registering only 86 tonnes when the actual fuel quantity was some 127 tonnes.

1.4.5 However, when the PSM was inspected after the incident, it was found that the PSM had the correct pin switch pattern for a Boeing B777-200ER. The FQIS had also been operating normally prior to this incident flight and there was no recent maintenance work done to the FQIS or PSM.

1.4.6 The aircraft manufacturer carried out a detailed inspection of the PSM. Its key findings were as follows:

(a) The seals of the connection wire grommets were distorted with damage. The aircraft manufacturer suspected the damage had arisen from the PSM not having been seated squarely in its receptacle during installation but was unable to comment on how the damage could have occurred.
(b) Some of the PSM's soldering junctions had incomplete solder fillings and did not conform to the aircraft manufacturer's standards.

[12] According to the aircraft manufacturer, the switch pattern, once set during aircraft manufacturing, would not need to be changed. The PSM related maintenance procedure is limited to checking for correct pin switch pattern. If the pattern is correct, there is no further action needed. If the pattern is incorrect, the pattern has to be reset to the correct one.

(c) The switches showed signs of wear from multiple movement, including some witness marks of physical contact on the switch housing and possible ink marks on two of the switches which the aircraft manufacturer believed to be consistent with the use of a pen to move the switches.
(d) The PSM showed much more wear than other modules returned from service.

1.4.7 Notwithstanding these findings, the aircraft manufacturer's testing of the PSM in question could not identify any electrical or mechanical fault. The aircraft manufacturer indicated that it had received reports of FQIS faults in the past where the problems were identified to be with the FQPU, the PSM or poor connection between components. However, it did not identify any such problem on the FQIS components on this incident aircraft.

1.5 Refuelling dispenser and refuelling operation

1.5.1 The refuelling dispenser's fuel flow counter and start/end quantity totaliser gauge were calibrated once every 6 months. They were last calibrated five months before the incident. Following the incident, they were subject to a calibration check and were found to be satisfactory.

1.5.2 Both the RDO and LT noted that the refuelling operation had taken longer than usual.

1.5.3 Both the CT and LT mentioned to the investigation team that they needed to complete their refuelling operation before the aircraft's planned departure time of 0130 hours and that they were on a tight schedule. The refuelling was completed at 0129 hours. However, the aircraft departed at 0200 hours, owing to delay in resolving the fuel quantity discrepancy.

1.6 Magnastick check

1.6.1 Each of the aircraft's fuel tanks had magnasticks installed. The magnasticks were used for physical measurement of fuel quantity when the fuel quantity shown by the FQIS was in doubt or when there was a high discrepancy between the uplifted fuel figures from the dispenser and the aircraft indications. The magnastick checks were considered final and would supersede the FQIS and refuelling dispenser readings.

1.6.2 Each magnastick was housed in a vertical cylinder in the fuel tank area. The cylinder was surrounded by a magnetic fuel float that could slide up or down the cylinder commensurate with the fuel level in the tank. When used, the magnastick, which had a magnetic armature at its top, would reach an equilibrium position in the cylinder owing to the magnetic force exerted by the fuel float on the armature. At this equilibrium position, the lower part of the magnastick would protrude outside the lower surface of the aircraft's body or wing (see **Figure 3**) and the reading on the scale on the magnastick could be correlated to a fuel quantity figure.

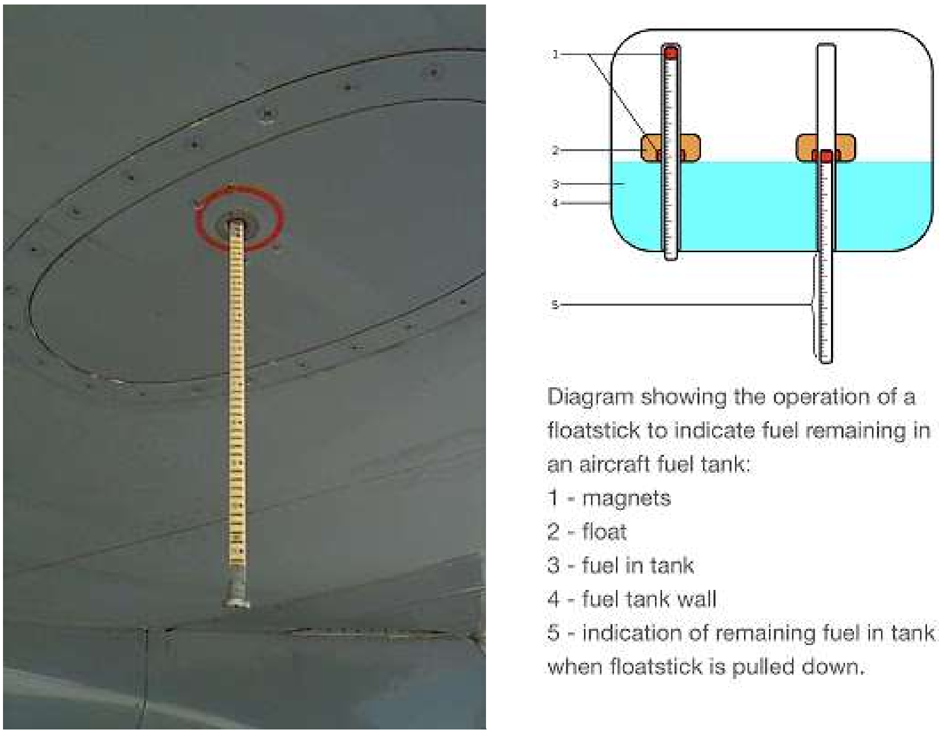


Figure 3. Example of magnastick in fuel tank

1.6.3 There were 16 magnasticks installed on the aircraft, six in each main wing tank and four in the centre tank. For each left and right side of the aircraft, the magnasticks were numbered No.1 and No.2 for the centre tank and No.3 to No.8 for the main wing tank, from inboard to outboard (see **Figure 4**).

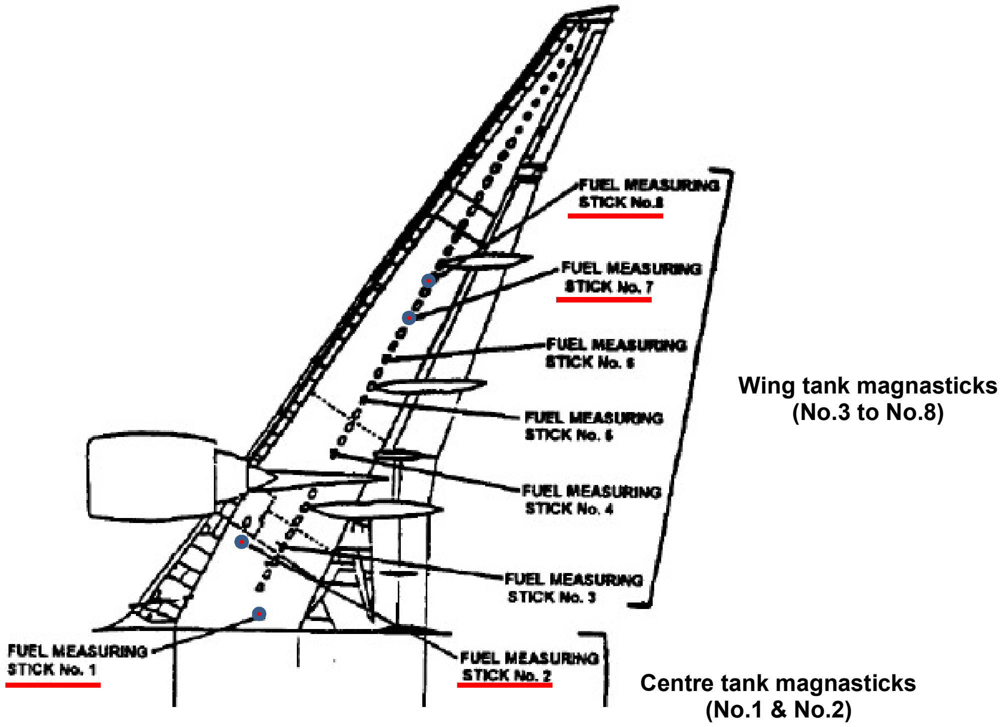


Figure 4. Magnastick locations on the B777 (magnasticks underlined in red were required to be read)

1.6.4 The magnastick check for this incident flight would require the maintenance personnel to take magnastick readings from the left and right No.1 magnasticks of the centre fuel tank (and also from the left and right No.2 magnasticks[13] when fuel load was high[14]) and the No.7 and No.8 magnasticks of the left and right main wing tanks. However, the CT had assumed that the two main wing tanks were full, with 28.227 tonnes each, and directed the LT to take (without any explanation to the LT) the left and right No.1 magnastick readings from the centre tank. The CT made this assumption on the basis that the refuelling system was programmed to always fill the left and right main wing tanks full before the centre fuel tank was filled. Thus, the LT only took readings from the left and right No.1 magnasticks of the centre fuel tank. Both the left and right

[13] Centre fuel tank quantity was measured using the left and right No.1 and No.2 magnasticks of the centre fuel tank. The No.1 magnasticks were located at the lower part of the centre fuel tank while the No.2 magnasticks were located at the higher part of the centre fuel tank. At low fuel quantity in the centre fuel tank, readings could be obtained from the left and right No.1 magnasticks. For higher fuel quantity in the centre fuel tank, as in this overfuelled incident, the No.1 magnasticks could not be used and the No.2 magnasticks would have to be used. This is because the cylinder housing of the No.1 magnastick would be totally submerged in the fuel and the magnastick armature and fuel float components of the magnasticks would be at their topmost position and the magnasticks would only protrude slightly outside the lower surface of the aircraft. This small protrusion of the magnasticks would not provide a reading and the next step is to perform a check on No.2 magnasticks.

[14] For the occurrence aircraft, when the centre tank fuel quantity exceeded 51.747 tonnes, the No.2 magnasticks would have to be used.

No.1 magnasticks gave the same reading. The maintenance crew deduced from the fuelling manual that the reading corresponded to a centre fuel tank quantity of 29.547 tonnes.

1.6.5 The total fuel quantity as computed by the CT was as follows (using specific gravity of fuel to be 0.780 kg/litre):

Magnastick Location	Magnastick readings (taken from the aircraft fuel record)	Fuel quantity computed based on the magnastick reading (tonnes)
Centre tank (L & R No.1 magnasticks) (Both magnasticks gave the same readings)	28.5 units	29.547
Main wing tank (Left) assumed	12.2 units	28.227
Main wing tank (Right) assumed	12.2 units	28.227
Total		86.001

1.6.6 After the air turnback, the aircraft's remaining fuel quantity was manually measured by magnasticks by another team of ground crew. The measured fuel quantity remaining in tanks were as follows:

Magnastick Location	Fuel quantity measured by magnasticks (tonnes)
Centre tank (L & R)	9.0
Main wing tank (Left)	19.2
Main wing tank (Right)	19.4
Total	47.6

The ground crew's computations confirmed that the aircraft had departed with 126.9 tonnes of fuel[15]. This correlated well with the figure of 127 tonnes derived from adding the fuel dispenser uplifted fuel of 121.5 tonnes to the 5.5 tonnes of fuel on board the aircraft before refuelling commenced.

1.7 Qualifications for performing a magnastick check

1.7.1 According to training records, the CT and LT had undergone aircraft refuelling training, provided by their AMSP, in 2010 and 2008 respectively. The training covered the theory of aircraft refuelling operations on various aircraft types including a topic on magnastick check theory. The training also included a field trip to at least one aircraft type (non-specific). The CT said that he could not recall the details of the magnastick check lesson and that the field trip to the aircraft did not have a practical session on the conduct of magnastick check.

[15] Adding the 47.6 tonnes of remaining fuel to the 79.3 tonnes of fuel used by the engines during flight (obtained from FMC), the fuel quantity at the start of the flight was calculated to be 126.9 tonnes.

1.7.2 The CT was a holder of a Limited Maintenance Authorisation (Category A) issued by the Civil Aviation Authority of Singapore (CAAS). As such, he could perform specific maintenance tasks (including some component changes) and routine checks during departure and transit. The CT was required to perform magnastick check himself. According to the CT, he had certified the magnastick check on two occasions (including the one on the incident aircraft) but the magnastick check, on both occasions, was done by others and he did not perform the magnastick check himself.

1.7.3 The LT said that he had performed magnastick check only twice, once on the incident aircraft and once under supervision on a B747. The LT told the investigation team that he encountered some difficulties while performing the magnastick check on the incident aircraft (e.g. some flexing of the stick, difficulty in moving the stick) but that he eventually managed to get the magnastick to engage the magnetic float and obtain a reading[16].

1.8 Fuel disagreement on Flight Management Computer

1.8.1 The Flight Management Computer (FMC) would provide the flight crew with an avenue for determining fuel quantity on board while in flight, by cross-checking with the FQIS on the fuel quantity remaining in flight. The FMC would automatically compute a "calculated fuel" figure by subtracting the fuel quantity consumed by the engines from the FQIS measured fuel quantity before flight (i.e. the fuel in tank quantity as measured by the FQIS and its sensors before the engines were started, 86 tonnes in this case) which would be used as the base reference. Essentially, the FMC "calculated fuel" was the fuel remaining in tank after usage by the engines.

1.8.2 This FMC "calculated fuel" was displayed real-time to the flight crew, who could compare it with the real-time "measured fuel" displayed by the FQIS or Totalizer, both fuel figures being displayed side by side (see **Figure 5**). The FMC "calculated fuel" should match the FQIS "measured fuel". However, in this incident flight, the flight crew was alerted by the EICAS warning of "FUEL DISAGREE". They also noticed, on checking further, that the FMC "calculated fuel" was lower than the FQIS "measured fuel" and the difference between these two figures was increasing.

[16] As mentioned in Footnote 13 in 1.6.4, it was not quite possible to obtain readings from the left and right No.1 magnasticks when the fuel load was high. The investigation team was not able to establish a reason for the LT being able to obtain readings, although one hypothesis is that the LT had actually used, correctly, the left and right No.2 magnasticks of the centre fuel tank but used, incorrectly, the No. 1 magnastick conversion table. However, as mentioned in Footnote 8 in paragraph 1.1.8, the LT was sure that he used No.1 magnasticks.

Figure 5. FMC displaying the discrepancy between “measured fuel” remaining (i.e. totalizer) and “calculated fuel” remaining (i.e. calculated)

1.9 **Duplicate inspection on critical system**

1.9.1 The CAAS has a requirement for duplicate inspections for maintenance work which, if not completed correctly, could affect the safety of an aircraft. A duplicate inspection is defined as an inspection first made and certified by one qualified person and then repeated independently and certified by a second qualified person. Duplicate inspections shall be made and certified by persons approved or authorised to undertake work on the particular critical system.

1.9.2 At the time of the occurrence, the CAAS did not have a specific requirement for duplicate inspection for magnastick check. Also, neither the AMSP nor the airline operator concerned had such a requirement.

2 ANALYSIS

2.1 Overfuelling

2.1.1 The fuel discrepancy was a result of the under-reading of the total fuel quantity by the FQIS. The under-reading was due to the centre tank's eight fuel tank sensors not being taken into account in FQPU's computation despite the correct setting of the PSM. The under-reading resulted in the overfuel of 41 tonnes of fuel. The aircraft manufacturer explained that the reason the eight centre fuel tank sensors were not taken into account by the FQPU was a fault in the PSM. While the aircraft manufacturer mentioned past reports of faults due to poor connections between FQIS components (e.g. FQPU, PSM and other wiring connections), it did not identify such problems on this incident aircraft. Neither the aircraft manufacturer nor the investigation team was able to establish the nature of the fault in the PSM.

2.1.2 The aircraft manufacturer had found that, while the PSM switches were correctly set for B777-200ER, they showed signs of wear from multiple movement, along with ink marks which it believed to be consistent with the use of a pen to move the switches. The degree of wear was also higher than on other PSMs that were returned to the aircraft manufacturer from service. In the opinion of the aircraft manufacturer, such wear had the potential to cause a fault in the FQPU and might cause it to default to the B777-200 mode. There had been no recent maintenance work done to the FQIS or PSM prior to the occurrence, but the investigation team understands that aircraft maintenance personnel may at times need to reset the PSM switch pattern in the course of troubleshooting the fuel quantity indication system. Such troubleshooting practice could probably explain the ink marks and wear. However, it cannot be established whether the wear had affected the FQPU and caused it to default to the B777-200 mode.

2.1.3 The only indication of a potential fuel quantity discrepancy was from the abnormally high fuel quantity uplifted from the RDO (as reflected on the RDO's fuel receipt), which prompted the taking of the magnastick readings.

2.1.4 The FQIS of the incident aircraft could not detect or alert the CT, the LT or the flight crew to the existing incorrect aircraft model (B777-200) referenced by the FQIS mode. It would be desirable to have an aircraft safety system that could detect or alert the flight crew or maintenance crew when there was a mismatch between the aircraft model referenced by the FQIS and the actual aircraft model.

2.2 Training on magnastick check

2.2.1 The CT and LT had limited practical experience in performing the magnastick check. The magnastick readings taken for the incident flight were likely not correct. As such, the CT, the LT or the flight crew were not alerted to the overfuel condition. If the overfuel condition had been detected through correct magnastick check, the overfuel condition, and perhaps later the erroneous FQIS fuel quantity reading, would have been detected.

2.2.2 Practical training, initial and recurrent, on magnastick check must be made available to the technicians who need to perform this function. This is to ensure that they have the relevant experience and confidence in performing the task as well as the knowledge to compute the fuel quantity using the relevant refuelling manual.

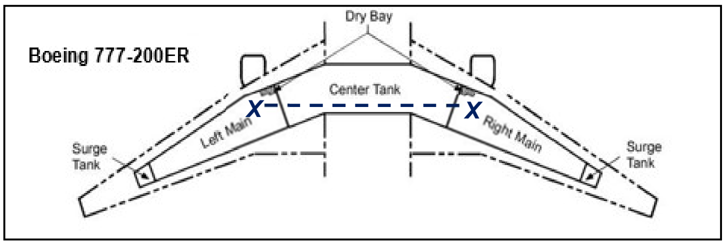
2.3 Duplicate Inspection on magnastick check

2.3.1 The correct amount of fuel to be uplifted has a significant impact to the safety of a flight. Too much fuel being uplifted may result in some operational issues in controlling the aircraft such as take-off speed and take-off runway; additional fuel burned due to heavier aircraft; etc. Too little fuel being uplifted, if undetected, could result in fuel starvation in flight.

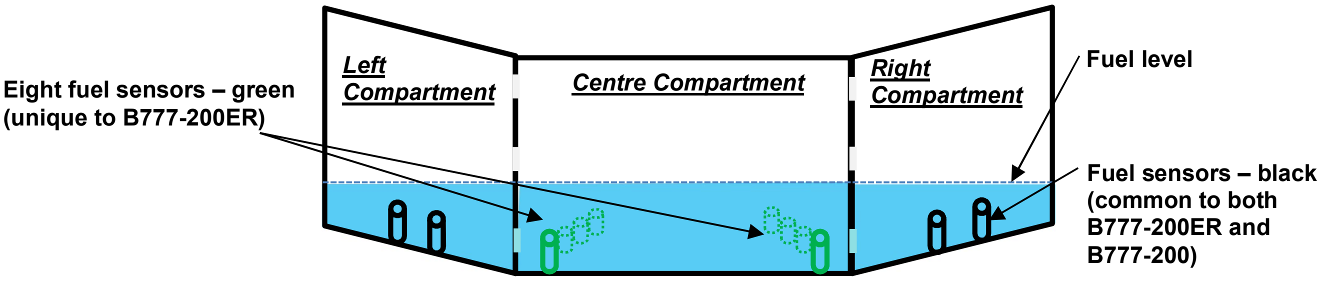
2.3.2 In this occurrence, the magnastick readings were grossly inaccurate but it was fortuitous that the aircraft had been fuelled with much more fuel than it needed. Had the magnastick reading errors been in the other way, the aircraft could have ended up in a fuel starvation situation in flight. It may be prudent to have another qualified person to conduct an independent magnastick check to verify the actual total fuel quantity in fuel tanks whenever a magnastick check of fuel quantity is required. In other words, it may be desirable to require duplicate inspection in respect of magnastick check.

2.4 Fuel disagreement in flight

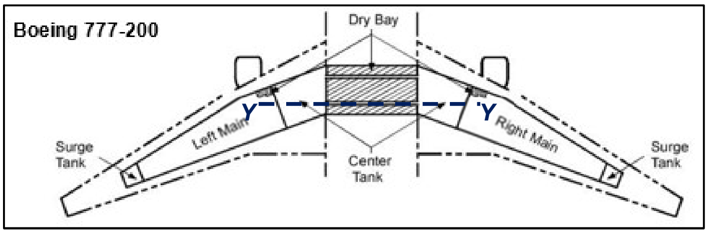
2.4.1 Due to the incorrect aircraft model referenced by the FQIS which resulted in the eight centre fuel tank sensors not being recognised by the FQPU, the FQIS was under-reading the actual overfuelled state of the centre tank. The actual fuel uplifted to the centre tank for this incident flight was about 70.546 tonnes, much more than the intended 29.547 tonnes (i.e. about 41 tonnes overfuelled). This under-reading meant that the 70.546 tonnes of actual fuel in the centre tank was represented by 29.547 tonnes on the FQIS cockpit indication (i.e. more actual fuel would have to be expended before the FQIS cockpit indication records a change). Thus, the FQIS “measured fuel” quantity appeared to be decreasing at a slower rate (see **Figure 6** for details of the under-reading).



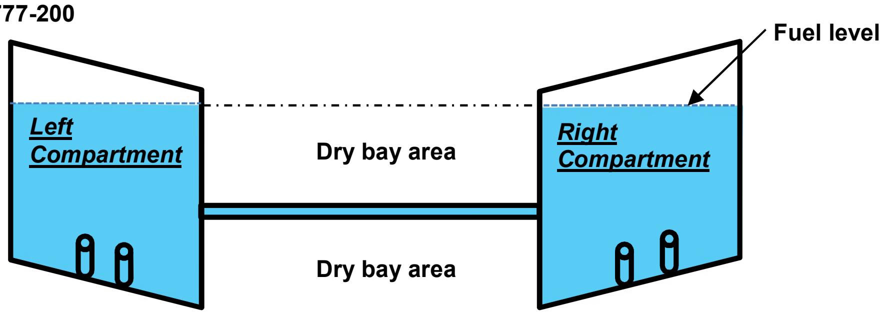
1) B777-200ER



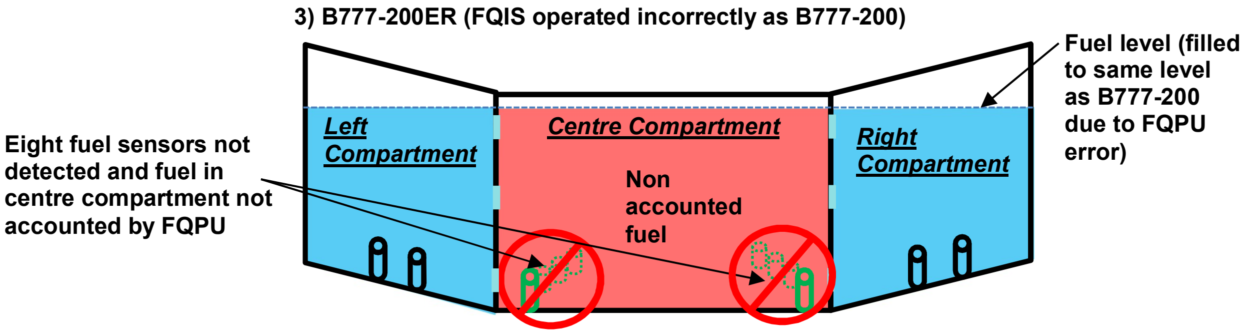
Cross section X – X of simplified B777-200ER centre fuel tank.
The centre fuel tank of the B777-200ER comprised three (left, centre and right) compartments. When the FQIS was operating correctly, the fuel level shown schematically above corresponded to the amount of fuel in the centre fuel tank needed for the incident flight (i.e. 29.547 tonnes). The fuel sensors detected the fuel level in the left, centre and right compartments of the centre fuel tank and sent that information to the FQPU which computed the total fuel quantity in the centre fuel tank (which displayed that figure on the IRP and cockpit indicators).



2) B777-200



Cross section Y – Y of simplified B777-200 centre fuel tank (note the smaller fuel tank and the dry bay area in place of a centre compartment).
In the smaller B777-200 centre fuel tank, the same 29.547 tonnes of fuel in the centre fuel tank would be stored mostly in the left and right compartments of the centre fuel tank.



Details of incident aircraft's B777-200ER centre fuel tank (which was operated as the B777-200 model).
With the malfunctioning PSM, the FQPU "thought" it had a B777-200 fuel tank configuration and received no input from the eight fuel sensors in the centre compartment. The fuel in the left and right compartments needed to reach the same high level as shown in the earlier diagram in order for the FQPU to "believe" it had 29.547 tonnes in the centre fuel tank. However, filling up the left and right compartments also filled up the area in the centre compartment that would have been dry bay volume in a B777-200. This resulted in overfuelling of 41 tonnes of fuel (in red).

Figure 6: Explanation of FQIS under-reading

2.4.2 Due to the measuring error of the FQIS, the FMC had taken the incorrect initial total fuel quantity (i.e. 86 tonnes) as its base reference figure. In addition, the overfuelled aircraft being actually heavier by 41 tonnes would incur higher inflight drag effect and this resulted in a higher fuel consumption rate. This correlates with the flight crew's account of higher fuel burn by the engines. Thus, the incorrect 86 tonnes base reference, coupled with the higher fuel burn by the engines, caused the FMC to reflect a faster than expected reduction of "calculated fuel" quantity remaining. When comparing the FQIS "measured fuel" quantity remaining with the FMC "calculated fuel" quantity remaining, a pattern of increasing fuel discrepancy between calculated and measured fuel remaining values was presented to the flight crew which prompted their return to Singapore.

3 CONCLUSIONS

3.1 The B777-200ER aircraft was overfuelled by about 41 tonnes before its departure from Singapore. The increasing discrepancy between calculated fuel quantity remaining and the measured fuel quantity remaining on the aircraft prompted the flight crew to return to Singapore.

3.2 The cause of the overfuel situation was that the B777-200ER aircraft was erroneously recognised as a B777-200 version by the FQIS owing to a fault in the PSM. This had resulted in the eight sensors within the mid-section of the centre fuel tank of the B777-200ER not being computed by the aircraft's FQIS and caused an under-reading of the fuel quantity. The nature of the fault in the PSM could not be established.

3.3 The discrepancy between actual fuel quantity uplifted to the aircraft by the refuelling dispenser and the fuel quantity indication on the aircraft prompted the maintenance crew to perform manual fuel quantity check using the magnasticks. The magnastick check performed by the maintenance crew did not discover the overfuel situation. It was likely that the maintenance crew did not perform the magnastick check correctly.

3.4 The CT and LT underwent training on refuelling operation which included theory on magnastick check. However, there were no practical session on magnastick check during their training on refuelling operation. In addition, magnastick check was not a commonly performed task in the course of their work.

3.5 There was no regulatory requirement on duplicate inspection, performed by qualified personnel, for magnastick check. Neither the AMSP nor the airline operator concerned had such a requirement.

3.6 Apart from the abnormally high fuel uplift receipt from the RDO which prompted the magnastick check, there was no indicator to provide an alert when incorrect aircraft model was referenced. It would be desirable to have an aircraft safety system that could detect or alert the flight crew or maintenance crew when there was a mismatch between the aircraft model referenced by the FQIS and the actual aircraft model.

4 SAFETY ACTIONS

During the course of the investigation and through discussions with the investigation team, the following safety actions were initiated by the aircraft operator, the aircraft maintenance service provider and the aircraft manufacturer.

4.1 Immediately after the incident, the aircraft operator had replaced the incident aircraft's FQIS components (e.g. the FQPU, the fuel tank sensors, the PSM and associated components).

4.2 Following the incident, the AMSP (employer of the CT and LT) implemented a one-time refuelling refresher training and competency assessments for various aircraft types for their personnel. Practical training on taking magnastick readings was also provided using a fuel tank simulator training tool.

4.3 The AMSP conducted a briefing for their personnel on lessons learnt from this incident, and also reminded them to consult their managers whenever they are not familiar with any task assigned.

4.4 The aircraft manufacturer upgraded subsequent versions of the FQPU to be able to detect and prevent incorrect program pins configuration.

4.5 The aircraft manufacturer reviewed two areas of potential safety concerns pertaining to overfuelling, raised by the FQIS referencing an incorrect aircraft model, namely, runway overrun in a rejected take-off scenario and insufficient climb capability. The aircraft manufacturer determined that the aircraft would have sufficient safety margin in both scenarios and did not consider that the scenarios presented a safety hazard.

4.6 In view of the actions in paragraphs 4.4 and 4.5, the aircraft manufacturer is of the view that it is not necessary to put in place an aircraft safety system that could detect or alert the flight crew or maintenance crew when there is a mismatch between the aircraft model referenced by the FQIS and the actual aircraft model.

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 aircraft maintenance service provider require the magnastick check to be performed by two qualified personnel independently.
[TSIB Recommendation RA-2018-012]

5.2 The civil aviation authority consider requiring the aircraft maintenance service providers to have magnastick checks performed by two qualified personnel independently. [TSIB Recommendation RA-2018-013]

5.3 The aircraft maintenance service provider consider the need for refresher training on magnastick check to be conducted for personnel at a suitable time interval. [TSIB Recommendation RA-2018-014]