Final Report

BOEING B737-700, REGISTRATION VP-CAM

DAMAGE TO APPROACH LIGHTS DURING TAKE-OFF AT SELETAR AIRPORT

16 NOVEMBER 2017

AIB/AAI/CAS.154

Transport Safety Investigation Bureau
Ministry of Transport
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The Transport Safety Investigation Bureau of Singapore

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GLOSSARY OF ABBREVIATIONS

ATC	Air Traffic Control
AT	Assumed Temperature
CDU	Control Display Unit
CVR	Cockpit Voice Recorder
FDR	Flight Data Recorder
FMC	Flight Management Computer
FMS	Flight Management System
OAT	Outside Air Temperature
OPT	Onboard Performance Tool
PIC	Pilot-in-Command
PEI	Primary Engine Indications
PM	Pilot Monitoring

SYNOPSIS

On 16 November 2017, a Boeing B737-700 departed from Seletar Airport, Singapore for Beijing, China. It took off on Runway 03 with a thrust setting which was significantly below that required for the conditions of the day. The tower controller noticed that the aircraft lifted off close to the end of the runway and climbed slowly.

The flight crew was informed by Air Traffic Control of the possibility of runway approach lights having being damaged by the aircraft. They checked the aircraft and determined that all systems were operating normally. They elected to continue their flight to Beijing. The flight continued to Beijing without further incident.

A runway inspection revealed damage to 10 approach lights at the end of Runway 03.

After the aircraft had landed in Beijing, the two tyres on the left main landing gear were found damaged with cuts and gouges. There was no injury to any person.

The Transport Safety Investigation Bureau classified this occurrence as a serious incident.

AIRCRAFT DETAILS

Aircraft type	:	Boeing Business Jet B737-700
Operator	:	MyJet Asia
Aircraft registration	:	VP-CAM
Numbers and type of engines	:	2 x CFM56-7B27/3B3
Engine hours/cycles since new	:	1219 hours 01 minute each / 337 cycles each
Engine hours/cycles since last shop visit	:	Not applicable (First shop visit not due yet)
Date and time of incident	:	16 November 2017, 0908 hours
Location of occurrence	:	Seletar Airport, Singapore
Type of flight	:	Non-scheduled
Persons on board	:	4

1 FACTUAL INFORMATION

All times used in this report are Singapore Local Time (LT) unless otherwise stated. Singapore Local Time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

1.1.1 On 16 November 2017, the flight crew of a Boeing B737-700 parked in Singapore Seletar Airport boarded the aircraft at about 0830LT to prepare for a flight to Beijing, China. The flight crew comprised a Captain on the left seat who was the Pilot-in-Command (PIC) and Pilot Flying (PF) and another Captain on the right seat who was the Pilot Monitoring (PM). The flight also carried two cabin crew members.

1.1.2 The take-off weight of the aircraft was 67,106 kg, which was within the take-off weight limit. The aircraft had 24,050 kg of fuel, which was 5,856 kg more than the 18,194 kg needed for the flight to Beijing[1].

1.1.3 As part of the flight preparation, the flight crew needed to determine the V-speeds (comprising V_1, V_R and V_2)[2] for the take-off (TO) as well as the engine N_1[3] power setting. The PIC and PM each had an Electronic Flight Bag with a software known as the Onboard Performance Tool (OPT) for performing calculations of the V-speeds and N_1 setting. Only if the OPT calculations by the PF and PM produced the same results would the flight crew proceed to use the Flight Management Computer (FMC) to calculate the V-speeds and take-off power setting N_1.

1.1.4 The flight crew entered the following data into their OPTs to calculate the V-speeds and take-off power setting N_1:

Aircraft take-off weight	67,106 kg

[1] The practice of carrying of more fuel than what is required is called tankering fuel. The tankering of fuel is an accepted practice. The tankering fuel quantity is limited by an aircraft's maximum take-off weight and take-off performance.

[2] V_1 (decision speed): The speed defining a decision point on an aircraft's take-off at which, should an engine fail, the pilot can elect to abandon the take-off or continue. The pilot should abandon the take-off if the engine fails before this speed and should continue the take-off if the engine fails after this speed.

V_R (rotation speed): The speed at which the nose of an aircraft should be lifted to attain the take-off attitude.

V_2 (take-off safety speed): The minimum speed after take-off that would allow an aircraft to meet climb-out requirements after lift-off following one engine failure.

(The above explanations were adapted from "An Illustrated Dictionary of Aviation" published by McGraw-Hill.)

[3] N_1 is the engine fan or low pressure compressor speed, expressed in % of the engine's rated power.

Runway	03 (assumed)[4]
Thrust setting for take-off	TO
Flap setting for take-off	5°
OAT (Outside Air Temperature)	26°C[5]

The OPTs produced the same results: V_1 129 knots, V_R 134 knots, V_2 142 knots and N_1 102.1%.

1.1.5 The flight crew then proceeded to enter data into the FMC via the Control Display Unit (CDU) in accordance with the operator's standard operating procedures. Anticipating that they would be using Runway 03, the flight crew input Runway 03 into the FMC. For the Performance Initialisation page of the FMC, the flight crew entered the following data for the calculations of the V-speeds[6] and take-off power setting N_1:

Zero Aircraft Weight	43,186 kg
Aircraft take-off weight	67,106 kg
Thrust setting for take-off	TO
Flap setting for take-off	5°
OAT	26°C[7]

The flight crew accepted the FMC figures of V-speeds and N_1 setting[8] and they proceeded with their flight preparation. However, they could not remember the FMC figures of V-speeds and take-off power setting N_1[9].

1.1.6 At 0854LT, Air Traffic Control (ATC) cleared the aircraft for pushback. ATC also provided the latest weather information, including the OAT (which was 29°C).

1.1.7 With a new OAT of 29°C, the flight crew used their OPTs to recalculate the V-speeds and N_1 setting and obtained the following: V_1 129 knots, V_R 134 knots, V_2 142 knots and N_1 102.5%. They noted that the V-speeds were the same as the previous OPT figures[10] and N_1 had changed by +0.4%.

1.1.8 ATC assigned Runway 03 for the take-off. The PM checked that Runway 03

[4] At this stage, the runway to be used by the flight crew had not yet been assigned by Air Traffic Control.
[5] OAT as provided by the airport's Automated Terminal Information System (ATIS).
[6] According to the operator, the policy was to always use the FMC calculated V-speeds.
[7] The flight crew chose to enter the OAT figure of 26°C, as provided by ATIS (see paragraph 1.1.4 and Footnote 4), even though the FMC showed an OAT of 30°C, as obtained from the aircraft's external temperature sensor, as they believed that ATIS' OAT figure was more accurate.
[8] Data from the aircraft's flight data recorder showed the following: V_1 138 knots, V_R 139 knots, V_2 142 knots and N_1 90.4%.
[9] According to the operator, the flight crew was supposed to compare the OPT calculated figures with the FMC calculated figures and ensure that the figures were comparable (not more than a difference of one knot).
[10] The flight crew considered that no action would be needed if the V-speed figures were within 1 knot from the previous V-speeds from the OPT calculations.

was input into the FMC[11]. The PM also updated the FMC with the new OAT of 29°C. This change in performance data would cause, by FMC system logic, the V-speeds to be de-selected[12] and a "VERIFY TAKE-OFF SPEEDS" message displayed on the CDU scratchpad of the FMC.

1.1.9 With ATC clearance, the aircraft entered the runway via Taxiway W2 and taxied on the runway to the Runway 03 threshold (i.e. the aircraft was backtracking on Runway 21) and made a 180° turn to take off on Runway 03.

1.1.10 While the aircraft was taxiing down the runway and before it made the 180° turn, the flight crew noticed the "VERIFY TAKE-OFF SPEEDS" message. Noticing that the V-speeds data had been de-selected, the PM re-selected the V-speeds. He informed the PF accordingly. The PF acknowledged the PM's input action and continued to taxi the aircraft.

1.1.11 The aircraft took off at 0908LT after ATC had issued the clearance. The Seletar tower controller observed that the aircraft lifted off close to the end of the runway[13] and climbed slowly at a very shallow angle[14].

1.1.12 According to the flight crew, there was nothing unusual during the take-off and climb-out. As the aircraft was carrying more fuel than was required for the flight, the flight crew were expecting that the take-off roll could be longer than normal due to the additional weight.

1.1.13 At ATC's request and while the aircraft was still climbing out, an inspection was conducted at the end of Runway 03. The inspection team reported that some of the approach lights were damaged. ATC then informed the flight crew of the possibility of runway approach lights having being damaged by the aircraft. The flight crew checked the aircraft indications and everything appeared normal. The cabin crew also did not report anything abnormal. The flight crew assumed that the lights could have been damaged by jet blast during the climb-out based on information available to them.

1.1.14 The PM called the office manager at the company's operations centre in Singapore. Since the aircraft indications were normal, the office manager let the PIC decide whether to proceed to Beijing as planned. The flight crew reported back to the ATC that the aircraft was operating normally and they had decided to continue the flight to Beijing[15]. The aircraft completed the flight to

[11] The inputting of Runway 03 was on the Navigation page of the FMC and did not affect the Performance Initialisation page of the FMC.

[12] The FMC calculated V-speeds are always displayed to the flight crew. The flight crew have to decide whether to accept the calculated V-speeds. Before the V-speeds are selected, they are displayed in a smaller font. When they are selected, they will change to a larger font.

[13] Data from the aircraft's flight data recorder showed that the aircraft rotated at about 500 m before the end of the runway and lifted off at about 120 m before the end of the runway.

[14] Data from the flight data recorder accorded well with this observation.

[15] The flight crew had the discretion to decide as to whether to continue the flight.

Beijing without further incident.

After the take-off, the tower controller ordered an inspection of the runway. Ten approach lights at the end of Runway 03 were found damaged[16].

1.2 Injuries to persons

1.2.1 There was no injury to any person.

1.3 Damage to aircraft

1.3.1 The two tyres on the left main landing gear were found with cuts and gouges during ground inspection after the aircraft had landed in Beijing.

1.3.2 Ten approach lights were damaged. Eight had their supporting structure broken (see **Figure 1.** Damaged approach lights) and two had their top covers damaged (see **Figure 2**).

Figure 1. Damaged approach lights

[16] The approach lights were about 60m beyond the end of the runway. Data from the aircraft's flight data recorder showed that the aircraft was about 1 m above ground where the approach lights were located.

Figure 2. Approach light with broken top cover

1.4 Personnel information

1.4.1 Captain on the left seat

Gender	Male
Age	50
Type of Licence	Airline Transport Pilot Licence issued by the U.S. Federal Aviation Administration
Licence validity	31 May 2018
Aircraft rating	B737
Medical certification	Class 1 with limitations (Must wear corrective lenses)
Last base check	30 August 2017
Last line check	16 July 2017
Total flying experience	8,537 hours
Total on type	6,363 hours
Flying in last 90 days	67.4 hours
Flying in last 28 days	28.9 hours
Flying in last 24 hours	6.9 hours
Rest Period before flight	8 hours

1.4.2 Captain on the right seat

Gender	Male
Age	38
Type of Licence	Airline Transport Pilot Licence issued by the U.S. Federal Aviation Administration
Licence validity	31 January 2018
Aircraft rating	B737, Gulfstream IV, Learjet 60
Medical certification	Class 1 with limitations (Must wear corrective lenses)
Last base check	1 July 2017
Last line check	NA
Total flying experience	6,300 hours
Total on type	650 hours
Flying in last 90 days	197 hours
Flying in last 28 days	0 hour
Flying in last 24 hours	0 hour
Rest Period before flight	3 weeks

1.5 Aircraft information

1.5.1 Reduced thrust take-off

1.5.1.1 TO (Full) is the full-thrust take-off setting. For this flight the corresponding N_1 for the TO setting was an N_1 of 102.5%. A reduced thrust take-off is a take-off that is accomplished using less than the full thrust. The advantage of a reduced thrust take-off is:

- Increased engine life
- Reduced maintenance costs

1.5.1.2 There are two basic methods for setting a reduced thrust take-off:

a) Fixed de-rate method – Two levels of reduced thrust setting are available in the FMC and can be selected when conditions permit (see paragraph 1.5.1.3). The two levels are TO1 and TO2. When selected in the FMC, TO1 de-rates the engine power to 26,000 pounds of thrust (26K) and TO2 24,000 pounds of thrust (24K), the full engine power (TO) being of 27,000 pounds of thrust. The fixed de-rate target N_1 for the conditions of the event had TO1 or TO2 been selected as follows:

Fixed de-rate thrust setting	Target N_1
TO1 (26K)	Fixed de-rate of take-off thrust at 99.8%
TO2 (24K)	Fixed de-rate of take-off thrust at 95.6%

b) Assumed temperature method – The amount of de-rate is a function of an assumed temperature (AT), which is the highest ambient temperature at which the reduced thrust could still meet the aircraft's performance requirements at its actual take-off weight[17]. The flight crew will consult the aircraft's performance charts to set the AT, which will in turn determine the target N_1. The N_1 thrust reduction allowed is limited to a maximum of 25%.

A combination of the two methods may also be used.

1.5.1.3 If the reduced take-off thrust is set too low, the aircraft will need a longer distance to achieve V_1 and might not be able to meet the climb performance requirements. Examples of possible consequences are that:

a) the aircraft may not be able to meet the obstacle clearance criteria during the eventual climb-out if the flight crew continue the take-off; and

b) the remaining runway length will not be enough if the flight crew abort the take-off.

[17] The difference (AT minus OAT) is thus an indication of spare engine power available to the flight crew.

1.5.2 FMS display of information pertaining to reduced thrust take-off

1.5.2.1 The reduced thrust take-off mode[18] and the target N_1 are displayed as part of the Primary Engine Indications (PEI) on the Upper Display Unit.

1.5.3 Aircraft performance calculations by OPT and FMC

1.5.3.1 According to the aircraft manufacturer, the OPT makes reference to a database of airport runway lengths when it calculates V-speeds and N_1 setting. For a particular airport, the OPT cannot provide V-speed calculations if the AT is set too high for the airport's runway length and will generate an alert message "*The input assumed temperature could not be achieved at the requested take-off weight*". In the case of this aircraft's take-off at Seletar Airport, which had a runway length of 1,836 m, the maximum temperature that the OPT would generate V-speeds was 40°C.

1.5.3.2 According to the aircraft manufacturer, the FMC did not make reference to a database of airport runway lengths when it calculated V-speeds and N_1 setting. The FMC would accept a request for calculations of V-speeds and N_1 up to a maximum allowable entry of 70°C for the AT. For AT between 65°C and 70°C, the FMC would generate the same V-speeds and N_1 as when the AT was 65°C.

1.5.4 Operator's procedures for reduced thrust take-offs

1.5.4.1 The operator's policy was as follows:

a) the flight crew could only use TO1 or TO2;

b) the flight crew should, for FMC calculations, use the OAT as given by ATIS; and

c) reduced thrust take-offs using the AT method were not allowed[19] for all flights.

1.5.4.2 However, data from the aircraft's flight data recorder revealed that the FMC had also registered an AT of 67°C, in addition to registering V_1 138 knots, V_R 139 knots, V_2 142 knots and N_1 90.4% when the flight crew provided their input for

[18] The modes related to reduced thrust setting are:
- TO – Take-off
- TO1 – De-rated take-off one
- TO2 – De-rated take-off two
- D-TO – Assumed temperature reduced thrust take-off
- D-TO1 – De-rate one and assumed temperature reduced thrust take-off
- D-TO2 – De-rate two and assumed temperature reduced thrust take-off

[19] The aircraft manufacturer allowed the use of AT method thrust reductions in its Flight Crew Operations Manual procedures.

FMC calculations (see paragraph 1.1.5).

1.5.4.3 The flight data recorder data also revealed that there were five other take-offs in Asia and Europe (not by the same set of flight crew of this incident flight) for which the FMC registered both an AT and fixed de-rate take-off (see **Table 1**), suggesting that reduced thrust take-offs had been used. However, according to the operator, the flight crews concerned did not select AT for the take-offs.

Table 1. Instances of use of AT for take-off

Date	Flap	V_1 (knots)	V_2 (knots)	Fixed de-rate setting	AT	OAT
14 October 2017	5°	135	138	TO2	62°C	21°C
18 August 2017	5°	121	125	TO2	62°C	30°C
14 August 2017	5°	135	140	TO1	60°C	24°C
06 August 2017	5°	126	130	TO2	61°C	28°C
06 August 2017	5°	128	131	TO2	62°C	38°C

1.6 Flight recorders

1.6.1 The aircraft's flight data recorder (FDR) and cockpit voice recorder (CVR) were removed for readout.

1.6.2 The FDR was successfully read out. However, the CVR recording for the period of interest had been overwritten[20].

[20] The FDR had a 25-hour recording whereas the CVR had only a 2-hour recording.

2 ANALYSIS

The investigation looked into the following:

a) Aircraft take-off performance

b) Flight crew actions

c) Comparison of OPT and FMC regarding take-off performance calculations

2.1 Aircraft take-off performance

2.1.1 According to the flight crew, they intended to use full thrust for the take-off. They were aware of the operator's procedures that reduced thrust take-offs were not allowed for flights out of Seletar Airport.

2.1.2 The aircraft took off on Runway 03. It lifted off close to the end of the runway and climbed slowly at a very shallow angle. FDR data showed that the FMC used an AT of 67°C which resulted in a reduced thrust take-off of N_1 90.4%, together with V-speeds of V_1 138 knots, V_R 139 knots and V_2 142 knots. Thus, the aircraft had taken off with a thrust setting which was significantly below that required for the conditions of the day[21] and the runway length available.

2.1.3 According to the FDR recording, the AT input of 67°C was registered by the FMC even before the flight crew powered up the engines. The flight crew appeared not to have noticed that the N_1 of 90.4% and an AT of 67°C were displayed to them.

2.1.4 As regards how the AT of ≥60°C had entered into the FMC in this incident and in the five take-offs mentioned in paragraph 1.5.4.3, the operator was unable to offer an explanation[22].

2.2 Flight crew actions

2.2.1 While the aircraft had lifted off close to the end of the runway and climbed slowly at a very shallow angle, the flight crew, on their part, did not notice anything unusual. As the aircraft was carrying more fuel than was required for the flight, the flight crew were expecting that the take-off roll could be longer than normal.

2.2.2 Nevertheless, there were opportunities for the flight crew to notice the discrepancies between the OPT and FMC results:

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[21] With a N_1 of 90.4%, the aircraft would need an accelerate-stop distance of 2,486 m for the take-off. However, Runway 3 had only 1,836 m in length.

[22] According to the aircraft manufacturer, the only known way for an assumed temperature to be entered was by an FMC entry.

a) After inputting data in the FMC for the calculations of the V-speeds and N_1 setting (see paragraph 1.1.5), which, according to the FDR recording, would result in V_1 138 knots, V_R 139 knots, V_2 142 knots and N_1 90.4%, the flight crew had an opportunity to notice that the V-speeds were quite significantly different from the calculations generated by their OPT, viz. V_1 129 knots, V_R 134 knots, V_2 142 knots and N_1 102.1%.

b) After the flight crew received an update by ATC regarding the OAT (see paragraph 1.1.6), they recalculated the V-speeds and N_1 setting on the OPT. The recalculated results were V_1 129 knots, V_R 134 knots, V_2 142 knots and N_1 102.5%[23]. The FMC results still showed V_1 138 knots, V_R 139 knots, V_2 142 knots and N_1 90.4%. The flight crew re-selected the FMC V-speeds without noticing the discrepancy with the OPT results.

c) When the flight crew updated the performance data (the OAT), a "VERIFY TAKE-OFF SPEEDS" message would have been displayed on the FMC CDU scratchpad (see paragraph 1.1.8). However, the flight crew only noticed the message during the backtracking on Runway 21 and before the aircraft made a 180° turn for the take-off on Runway 03.

d) The code for an AT reduced thrust take-off (i.e. D-TO) and the temperature of 67°C, as well as the target N_1 of 90.4%, would have been displayed as part of the PEI on the aircraft's Upper Display Unit, which was in front of the flight crew

e) The flight crew were apparently focusing on checking the alignment on the PEI of the pointers for the actual N_1 and target N_1 and might have omitted to look at the actual N_1 and target N_1 figures (see **Figure 3**).

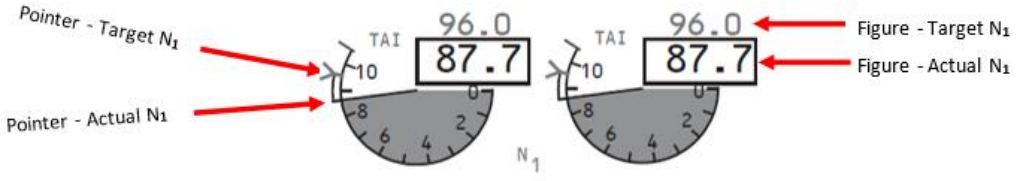

Figure 3. Primary Engine Indications (target N1 of 96.0% and actual N1 of 87.7% are for illustrations only)

2.3 Comparison between OPT and FMC regarding take-off performance calculations

2.3.1 The OPT was developed by the aircraft manufacturer. The FMC was

[23] The differences in the V-speeds and N1 power setting between the initial calculation and recalculation on the OPT, based on 26°C and 29°C respectively, were negligible.

developed by a supplier to the aircraft manufacturer. As far as the performance calculations for V-speeds and N_1 are concerned, it appears that the FMC was less sophisticated than the OPT.

2.3.2 The OPT has a database of airport runway lengths. It will reject a request to use an AT when a particular airport's runway length could not support a reduced thrust take-off calculation using the AT method whereas the FMC, without such a database, would entertain a request for calculations of V-speeds and N_1 for any AT up to 70°C. The FMC calculated take-off speeds do not consider runway length available, minimum engine-out climb gradient capability, or obstacle clearance requirement. The FMC calculated take-off speeds could only be used when compliance of these requirements has been verified separately with a take-off analysis (runway/airport analysis), another approved source, or by dispatch.

2.3.3 It would be desirable for the FMC to be able to factor in runway length information and deny a request for calculations of V-speeds and N_1 when an inappropriate AT is input to the FMC.

3 CONCLUSION

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 aircraft took off with a reduced thrust take-off of 90.4% as determined by the FMC using an assumed temperature of 67°C. The thrust setting was significantly below that required for the conditions of the day and the runway length available. The assumed temperature of 67°C was somehow inadvertently introduced into the FMC.

3.2 The flight crew could have noticed the discrepancies between the results of the OPT and FMC had they followed both the operator's and the aircraft manufacturer's procedures.

3.3 The FMC calculations of V-speeds and N_1 setting did not take into account the runway length available, unlike the OPT calculations.

4 SAFETY ACTIONS

Arising from discussions with the investigation team, the operator has taken the following safety actions.

4.1 The operator has reminded its flight crews not to use the Assumed Temperature method for take-off.

4.2 The operator also has stressed to its flight crews to use maximum thrust for runways less than 1,830 m.

4.3 The operator has implemented a procedure to prevent the Assumed Temperature method of reduced thrust take-off from being used inadvertently. The procedure requires the Pilot Monitoring to verify that the N_1 value calculated by the FMC and confirmed by the OPT is set on the Primary Engine Indications portion of upper display before announcing "*Thrust Set*."

4.4 The aircraft manufacturer has issued a Flight Operations Technical Bulletin 737-18-02, dated 21 December 2018, to provide operators with techniques for the verification of take-off performance data with a view to reducing take-off performance errors. This bulletin also discusses the assumptions and limitations of FMC take-off speeds.

5 SAFETY RECOMMENDATION

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

5.1 It is recommended that the aircraft manufacturer consider including the airport runway lengths in the calculation of V-speeds and N1 settings by the FMC, so that the flight crew can be made aware when the performance data entered into the CDU does not meet the aircraft take-off and climb performance requirements. [TSIB-RA-2019-001]