Tail strike during take-off, Boeing 747-412 9V-SMT, flight SQ286, Auckland International Airport 12 March 2003

Micro-summary: **This Boeing 747-412 experienced a tail strike on takeoff.**

Event Date: **2003-03-12 at 1548 NZDT**

Investigative Body: **Transport Accident Investigation Commission (TAIC), New Zealand**

Investigative Body's Web Site: **http://www.taic.org.nz/**

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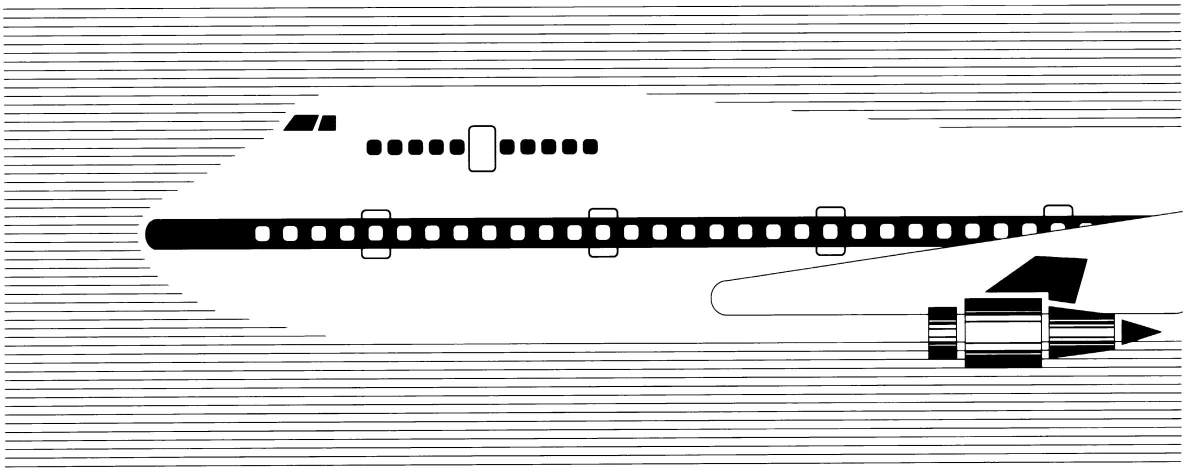
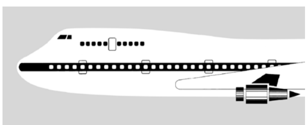
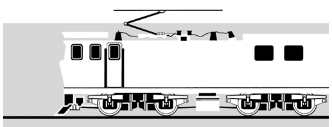
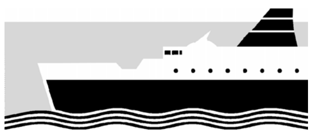


AVIATION OCCURRENCE REPORT

03-003	Boeing 747-412 9V-SMT, flight SQ286, tail strike during take-off, Auckland International Airport	12 March 2003







TRANSPORT ACCIDENT INVESTIGATION COMMISSION
NEW ZEALAND

Report 03-003

Boeing 747-412

9V-SMT

flight SQ286

tail strike during take-off

Auckland International Airport

12 March 2003

Abstract

On Wednesday 12 March 2003, at 1547, flight SQ286, a Boeing 747-412 registered 9V-SMT, started its take-off at Auckland International Airport for a direct 9-hour flight to Singapore. On board were 369 passengers, 17 cabin crew and 3 pilots.

When the captain rotated the aeroplane for lift-off the tail struck the runway and scraped for some 490 metres until the aeroplane became airborne. The tail strike occurred because the rotation speed was 33 knots less than the 163 knots required for the aeroplane weight. The rotation speed had been mistakenly calculated for an aeroplane weighing 100 tonnes less than the actual weight of 9V-SMT.

A take-off weight transcription error, which remained undetected, led to the miscalculation of the take-off data, which in turn resulted in a low thrust setting and excessively slow take-off reference speeds. The system defences did not ensure the errors were detected, and the aeroplane flight management system itself did not provide a final defence against mismatched information being programmed into it.

During the take-off the aeroplane moved close to the runway edge and the pilots did not respond correctly to a stall warning. Had the aeroplane moved off the runway or stalled a more serious accident could have occurred.

The aeroplane take-off performance was degraded by the inappropriately low thrust and reference speed settings, which compromised the ability of the aeroplane to cope with an engine failure and hence compromised the safety of the aeroplane and its occupants.

Safety recommendations addressing operating procedures and training were made to the operator, and a recommendation concerning the flight management system was made to the aeroplane manufacturer.

Contents

Figures

Abbreviations

ADJ TOW	adjusted take-off weight
amsl	above mean sea level
APT	airport
APU	auxiliary power unit
ATC	air traffic control
ATIS	automatic terminal information service
CDU	control display unit
CG	centre of gravity
CRM	crew resource management
CVR	cockpit voice recorder
EICAS	engine indication and crew alert system
ELEV	elevation
EPR	engine pressure ratio
FDR	flight data recorder
FMC	flight management computer
FMS	flight management system
GR WT	gross weight
kt	knot(s)
m	metre(s)
NZAA	Auckland International Airport
OAT	outside air temperature
OM	operations manual
PFD	primary flight display
POB	persons on board
RWY	runway
SOPS	standard operating procedures
STAB TRIM	stabiliser trim
t	tonnes
TO	take-off
TOW	take-off weight
UTC	coordinated universal time
V_1	take-off decision speed
V_2	initial climb out speed
V_{LO}	lift-off speed
V_{MCA}	minimum control speed - air
V_{MCG}	minimum control speed - ground
V_R	rotate speed
V_S	stalling speed
ZFW	zero fuel weight

Glossary

bug card	a specific reference card pilots use to list essential take-off and landing information. The "bug" refers to the small markers that appear on the aeroplane airspeed readout
QNH	an altimeter sub-scale setting to obtain elevation when on the ground
stick shaker	a shaking or vibration of the pilots' control yokes, warning of a near stall condition
V_1	take-off decision speed. The speed during take-off whereby it is possible to safely continue if an engine failure occurs, or abandon the take-off and safely stop the aeroplane on the runway remaining
V_2	the after lift-off safety speed used to achieve a certain height at a certain distance, and to ensure adequate control and climb performance should an engine fail
V_{LO}	the speed during take-off where the aeroplane becomes airborne
V_{MCA}	the minimum speed that pilots can recover [directional] control of the aeroplane and maintain straight and level flight either with zero degrees yaw or a maximum of 5º bank, after sudden failure of the critical engine
V_{MCG}	the minimum control speed on the ground that, if the critical engine suddenly fails, the pilots can recover [directional] control of the aeroplane by using the primary aerodynamic controls, to enable the take-off to continue using normal piloting skill and rudder control forces
V_R	the speed during take-off where the pilot begins to rotate the aeroplane to the lift-off attitude to climb away safely
V_S	the minimum airborne speed at which the aeroplane is controllable. The speed depends primarily on flap position and aeroplane weight
ZFW	the total aeroplane weight without fuel

Data Summary

Aircraft registration:	9V-SMT
Type and serial number:	Boeing 747-412, 27 137
Number and type of engines:	4 Pratt and Whitney 4056
Year of manufacture:	1993
Operator:	Singapore Airlines Limited
Date and time:	12 March 2003, 1548[1]
Location:	Auckland International Airport latitude: 37° 00.48´ south longitude: 174° 47.5´ east
Type of flight:	scheduled air transport
Persons on board:	crew: 20 passengers: 369
Injuries:	crew: nil passengers: nil
Nature of damage:	substantial to the lower rear fuselage of the aeroplane
Pilot in command's licence:	Airline Transport Pilot Licence
Pilot in command's age:	49
Pilot in command's total flying experience:	12 475 hours (54 on type after type conversion)
Investigator-in-charge:	K A Mathews

Acknowledgements

The Commission acknowledges the assistance provided by the Australian Transport Safety Bureau and the United States National Transportation Safety Board.

[1] Times in this report are New Zealand Daylight Time (UTC + 13 hours) and are expressed in the 24-hour mode.

1 Factual Information

1.1 History of the flight

1.1.1 On Wednesday 12 March 2003, at 1547, 9V-SMT, a Boeing 747-412 (flight designation SQ286), started its take-off on runway 23 Left at Auckland International Airport for a non-stop flight to Singapore. The planned flight time was 9 hours 9 minutes. On board were 369 passengers, plus 17 cabin crew and 3 pilots, comprising a captain who was the pilot flying, and 2 first officers.

1.1.2 The 3 pilots had begun flight planning and preparation at about 1415, one hour before the scheduled departure time of 1515. The aeroplane had been fuelled automatically to a predetermined minimum quantity for the flight, which in this instance was 100 tonnes (t). During flight planning, the pilots established the exact fuel requirement and requested extra fuel. The aeroplane had been fuelled and topped up with the extra fuel using automatic distribution, which had put 4.5 t of fuel into the centre fuel tank. However, 7.7 t of fuel was required in the tank because of a recent change to the minimum centre fuel tank quantity requirements. The fueller had overlooked using manual fuel distribution, which was necessary to get the higher fuel quantity into the centre fuel tank.

1.1.3 In the meantime the pilots had boarded the aeroplane for their flight deck preparations. About 15 minutes before departure, when the fueller boarded the aeroplane to confirm the final fuel, the pilots realised the centre fuel tank contained only 4.5 t of fuel. The captain requested the additional fuel for the centre fuel tank and a revised load sheet.

1.1.4 The pilots continued with their before-start flight deck preparations, while the ground staff adjusted the fuelling and prepared a new load sheet with the correct fuel weight. At about the scheduled departure time the captain received the revised load sheet, which he accepted and signed.

1.1.5 Because of the fuelling adjustment and new load sheet preparation, the flight was delayed by about 13 minutes.

1.1.6 The load sheet included the aeroplane total traffic load (occupants, baggage and cargo), dry operating weight (empty weight), zero fuel weight (ZFW)[2], maximum ZFW, take-off fuel, take-off weight (TOW), maximum TOW, trip fuel (fuel from Auckland to Singapore), landing weight and maximum landing weight. The load sheet also displayed the centre of gravity (CG), and the stabiliser trim (STAB TRIM) setting necessary for take-off.

1.1.7 The load sheet showed the take-off fuel as 116.4 t and the trip fuel as 100.3 t. The total traffic load was shown as 42.303 t, the aeroplane empty weight as 188.637 t, the ZFW as 230.94 t, the TOW as 347.34 t and the landing weight as 247.04 t. The maximum permitted ZFW was 244.939 t, the maximum permitted TOW was 396.893 t and the maximum permitted landing weight was 285.762 t.

1.1.8 The captain referred to the load sheet and called out certain information to the first officer to write on a bug card[3] (see Figure 1) used to record various take-off information, such as TOW, take-off reference speeds (V speeds), engine pressure ratio (EPR) thrust setting and STAB TRIM. The information the captain gave included ZFW, TOW and STAB TRIM setting. The first officer recorded the TOW in the TOW box on the card and ZFW separately on the bottom of the card. The first officer referred to the aeroplane fuel quantity indication and also separately wrote the take-off fuel weight under the ZFW.

1.1.9 The first officer wrote 247.4 (t) in the bug card TOW box. He wrote the ZFW as 231 (t) and the take-off fuel as 116 (t) on the bottom of the bug card and normally added these figures to verify

[2] The total aeroplane weight without fuel.
[3] A specific reference card that pilots use to list essential take-off and landing information.

the TOW. He then added 2 t to the TOW because of an atmospheric pressure correction adjustment requirement, to give an adjusted take-off weight (ADJ TOW) of 249.4 t, which he wrote in the bug card ADJ TOW box (see Figure 1).

1.1.10 The first officer referred to the Flap 20 Auckland 23 Left Airport Analysis Chart and, rounding the take-off weight up to 250 t, determined the take-off reference speeds, or V speeds. He established V_1[4] as 123 knots (kt), V_R[5] as 130 kt and V_2[6] as 143 kt. He also established that (at 250 t) reduced thrust could be used for take-off and that the EPR thrust setting for each engine was 1.34. He then wrote these figures in the appropriate boxes on the bug card. He wrote the STAB TRIM as 6.6 on the bug card STAB TRIM line, which was the same as that listed on the load sheet (see Figure 1).

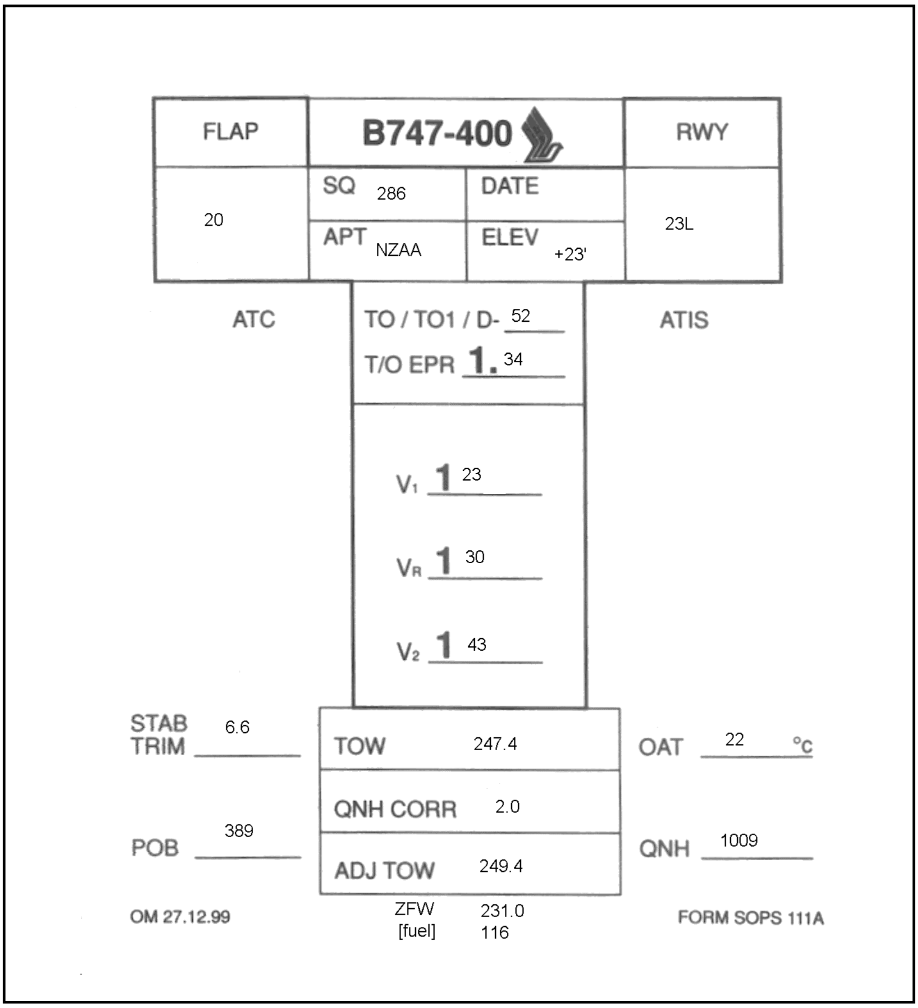


Figure 1
Bug card take-off data
(Relevant first officer entries shown in type)

1.1.11 By using the real aeroplane take-off weight of 347.4 t (rounded up to the nearest higher weight of 353.7 t on the analysis chart) the V_1 should have been 151 kt, the V_R 163 kt and the V_2 172 kt. The EPR thrust setting should have been 1.41. In the event of an engine failure during

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[4] Take-off decision speed. The speed during take-off whereby it is possible to safely continue if an engine failure occurs, or abandon the take-off and safely stop the aeroplane on the runway remaining.
[5] Rotation speed. The speed during take-off where the pilot begins to rotate the aeroplane to the lift-off attitude to climb away safely.
[6] Initial climb out speed. The after lift-off safety speed used to achieve a certain height at a certain distance, and to ensure adequate control and climb performance should an engine fail.

take-off the minimum ground control airspeed was 116 kt. This was the minimum airspeed necessary to maintain directional control if the take-off was continued.

1.1.12 The operator's Boeing 747-400 standard before-start operating procedures called for the first officer to compute the take-off data and to prepare the bug card, and for the captain to check the bug card data and to enter the V speeds into the flight management computer (FMC). After the first officer had prepared the bug card he passed it to the captain for checking. The captain did not verify the TOW, but used the erroneous TOW to confirm the V speeds.

1.1.13 The captain checked the FMC computation of the aeroplane on-board fuel against the required fuel weight. Seeing these weights were similar he entered the ZFW from the load sheet into the FMC's ZFW field (see Figure 2). The FMC automatically added the ZFW to its own computed aeroplane on-board fuel weight and displayed gross weight (GR WT) in the GR WT field on its display unit. The captain verified that the GR WT field on the display unit corresponded to the take-off weight recorded on the load sheet.

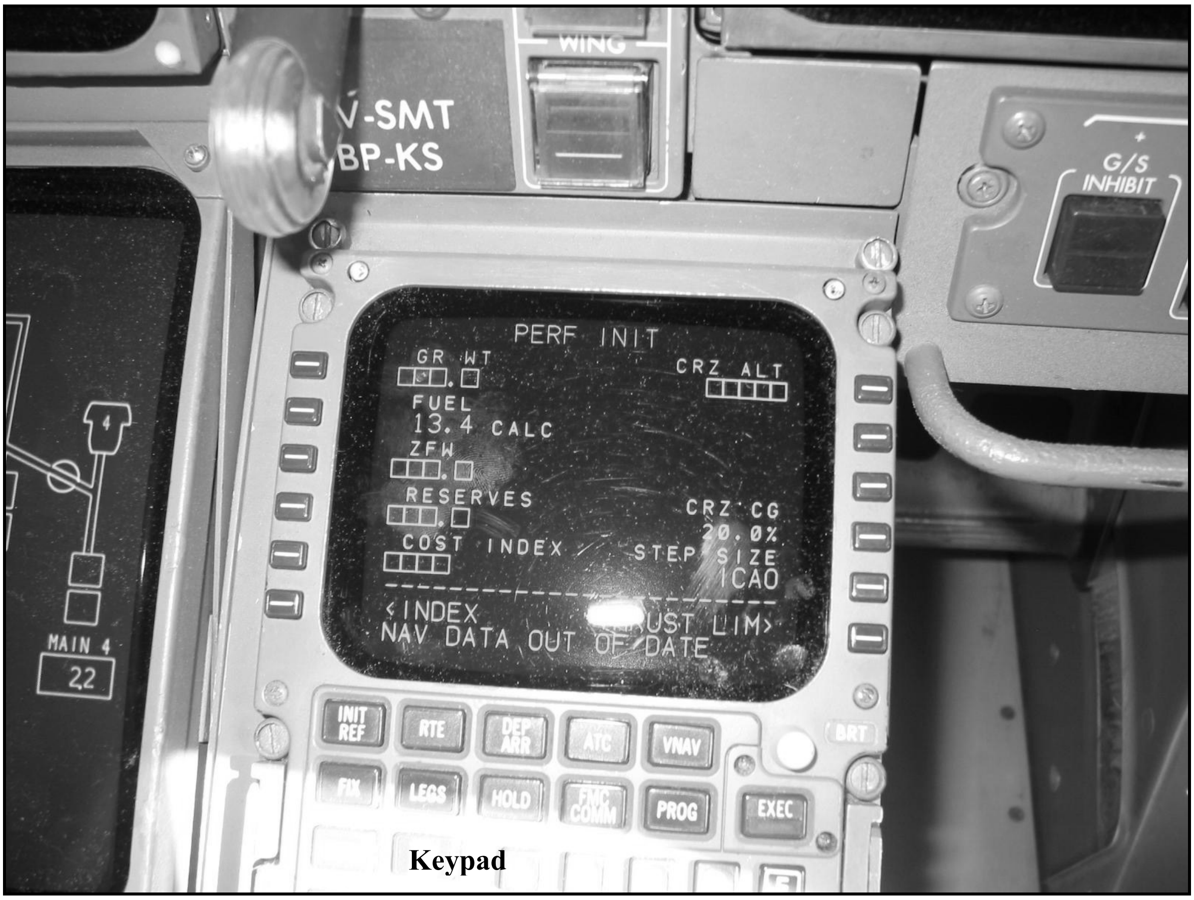

Figure 2
9V-SMT FMC display

1.1.14 The captain entered the manually calculated V speeds directly into the FMC's V_1, V_R and V_2 fields, replacing the V speeds the FMC had itself computed and was displaying on its display unit (see Figure 3). Despite significant differences the FMC accepted the input V speeds, showing them on its display and storing them in the flight management system (FMS), which highlighted them on the captain's and first officer's primary flight displays (PFD) air speed tapes. The PFD highlighted V speeds were normally hidden from view until the aeroplane speed increased during take-off, at which time they appeared on the speed tapes so the pilots could refer to them. The before take-off procedure called for the pilots to check the EPR thrust setting on the engine indication and crew alert system display (EICAS), and to check that the correct V speeds were set and appeared on the PFD airspeed indicators.

Figure 3
9V-SMT FMC display of V speeds

1.1.15 The captain placed the bug card and Airport Analysis Charts on the centre pedestal aft of the fuel control switches, which were positioned just aft of the thrust levers. The second first officer (the third pilot) would normally cross check the bug card data and computations, but in this instance he stowed the Airport Analysis Charts without verifying the information recorded on the bug card. At the time he was occupied explaining the departure delay to the operator's station manager. The bug card remained on the centre pedestal.

1.1.16 The captain taxied 9V-SMT to the end of runway 23 Left to use the full runway length for take-off. The pilots had set the flap at Flap 20 and the STAB TRIM at 6.6 for the take-off. The captain was the pilot flying and using automatic throttle applied power for take-off, having set the EPR at 1.34 for each engine. The pilots did not notice anything untoward and everything appeared normal to them as the aeroplane accelerated down the runway.

1.1.17 The first officer said he called "V_1" as the aeroplane reached 123 kt, and "rotate" as it reached 130 kt. At 132 kt the captain started pulling back the control yoke to pitch the aeroplane nose up for lift-off, and at 137 kt the pitch attitude (aeroplane body angle) began increasing. The aeroplane average pitch rate of change was 1.3º per second to a pitch attitude of 10.8º at 150 kt and 11.8º at 151 kt with the aeroplane still on the runway. The pitch attitude increased to 12.7º although still at 151 kt, and the aeroplane became airborne at about this speed a short time later with the pitch attitude then increasing to 12.9º. For a normal take-off the aeroplane would have become airborne at 8.5º to 10º body angle (see 1.17.13 and Figure 6).

1.1.18 Because the airspeed was too low when the aeroplane rotated, it initially remained on the ground, with its tail pitching down and striking the runway. The tail remained in contact with the runway and scraped for about 7 seconds over a distance of about 490 m giving off white smoke. The aeroplane moved across to the right edge of the runway before becoming airborne.

1.1.19 The pilots said they felt a "buffet" during rotation (the flight data recorder (FDR) recorded an initial stick shaker[7] indication at about this time) and the captain asked the other 2 pilots if they thought it was a tail strike, but they did not think the tail had struck the runway. Three seconds later as the aeroplane became airborne the pilots got an Auxiliary Power Unit (APU) fire warning, followed one second later by a stick shaker warning, with the airspeed between 154 kt and 158 kt. The captain checked the airspeed on his PFD and thought it was normal in relation to the V speeds displayed on the speed tape. The FDR showed that following the stick shaker, which activated for about 6 seconds, the aeroplane nose pitched down briefly to 8.5º body angle before increasing to 11º. Thrust was not increased.

1.1.20 The first officer made a distress call advising, "Mayday Mayday Mayday Singapore 286 we have [a] fire on [the] APU". The aerodrome controller acknowledged the distress call and cleared SQ286 to climb to and maintain 1000 feet and to turn left and fly a left hand circuit for runway 23. The controller advised the pilots that SQ286 had landing priority.

1.1.21 The first officer followed the quick reference handbook instructions for an APU fire, and discharged the APU fire bottle. The APU fire warning stopped momentarily but then continued to give intermittent warnings. The first officer asked the controller if he could see any fire in the tail. The controller advised that he could see neither fire nor smoke, but that there had been a lot of smoke when the aeroplane rotated.

1.1.22 A short time later, the first officer requested the aerodrome controller to clear them to a position to dump fuel before bringing SQ286 in for a landing. The aerodrome controller said to continue the circuit and to over-fly the runway at 1000 feet, when SQ286 would then be cleared out over the ocean for a fuel dump.

1.1.23 The intermittent APU fire warning continued so the pilots decided that with a possible tail fire they should not dump fuel, but that they should carry out an overweight landing as soon as possible. The first officer advised the controller, who then cleared SQ286 to continue the landing approach and confirming that it was number one in the landing sequence.

1.1.24 The first officer advised the controller that they still had an APU fire warning and requested that the fire services be standing by for the landing. The controller advised him the fire services were on full alert and that there was no sign of smoke coming from the tail.

1.1.25 The captain continued with the landing approach but overshot the runway centre line as he attempted to line SQ286 up with the runway. The first officer asked the controller for a clearance to orbit and reposition for a landing, which the controller granted and then cleared the aeroplane to land. After the captain had orbited the aeroplane at 1000 feet he lined it up on runway 23 for a landing approach. The aeroplane touched down at 1558, for a successful overweight landing.

1.1.26 The pilots were concerned about the possible fire in the tail section and whether to evacuate the passengers on the runway. The aerodrome controller held the aeroplane on the runway while the rescue fire services personnel quickly inspected the aeroplane and confirmed there was no fire in its tail section. The fire services personnel saw that the lower tail section of the aeroplane was significantly damaged, and they could clearly see the APU, allowing them to confirm there was no evidence of any fire.

1.1.27 The captain taxied the aeroplane off the runway and shut down 3 engines, keeping one engine running to provide electrical power, and waited until they got a tow back to the terminal. In the meantime the aerodrome controllers closed Auckland International Airport for landings and departures, until runway 23 was inspected and cleared of debris. The airport reopened about 2 hours later.

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[7] A shaking or vibration of the pilots control yokes, being a warning of a near stall condition.

1.1.28 The passengers and crew safely left the aeroplane after it was positioned back at the terminal.

1.2 Injuries to persons

1.2.1 No one was injured.

1.3 Damage to aircraft

1.3.1 During the tail strike, 9V-SMT incurred major lower fuselage skin panel abrasion damage, including multiple nicks, scratches, scrapes and gouges, which extended from just behind its aft pressure bulkhead to the clamshell door assembly under the APU (see Figure 4). There was some further skin abrasion forward of the aft pressure bulkhead including a small skin puncture. The aft pressure bulkhead was not damaged. There were small skin punctures in each horizontal stabiliser.

1.3.2 A number of stringers and frames were heavily abraded and much of the lower fuselage skin behind the aft pressure bulkhead was missing. The APU clamshell doors were also heavily abraded and hung open, exposing the APU assembly. The clamshell doors contained part of a fire wire loop that surrounded the APU, which was used to signal any APU fire warning to pilots.

1.3.3 The aeroplane was landed overweight by some 58 t, but inspections revealed no overweight landing damage.

1.3.4 The operator sent its own engineers to Auckland to carry out an initial damage assessment. The aeroplane manufacturer then carried out its own detailed damage assessment and sent its rapid response team to carry out the repairs. The major repair work took several weeks to complete.

1.4 Other damage

1.4.1 There was some minor runway damage.

1.5 Personnel information

1.5.1 The aeroplane crew consisted of a captain, a first officer, a second first officer and 17 cabin crew.

1.5.2 The captain was aged 49. He held an Airline Transport Pilot Licence, and his associated medical certificate was valid until 30 April 2003. He had flown some 12 475 hours, including 54 hours on the Boeing 747-400 type after his type conversion.

1.5.3 The captain's last line check was on 12 February 2003 and his last base check was on 5 January 2003.

1.5.4 The captain was off duty from 1 to 3 March 2003. He was on duty during 4 to 5 March 2003. He was off duty on 6 March 2003. He was on standby on 7 March 2003. He was off duty on 8 March 2003. His total duty time during this period in March was 13.8 hours.

1.5.5 During 9 to 10 March 2003 the captain flew from Singapore to Auckland. His duty time was about 11 hours and the flight time was 9.1 hours. He was off duty at Auckland from about noon on 10 March 2003 until 1415 on 12 March 2003 when he prepared 9V-SMT for the non-stop flight to Singapore.

1.5.6 The captain had flown 16.2 hours in the 7-day period, 60.8 hours in the 30-day period and 123.8 hours in the 90-day period before the flight from Auckland on 12 March 2003.

Figure 4
9V-SMT damaged tail section

1.5.7 The captain had completed his Boeing 747-400 command conversion training in February 2003. His most recent experience before his Boeing 747-400 conversion was as captain flying the Airbus A340 where he had flown 5680 hours in command. The operator reported that a typical rotate speed on the A340 was 138 kt.

1.5.8 The captain's Boeing 747-400 conversion training included full ground and simulator training. He had one period of Line Oriented Flight Training (LOFT) after his simulator conversion training before being released for aeroplane training with a training captain. To comply with the operator's requirements, the captain had to complete at least 6 flights before taking his final line check. After completing 4 take-offs and 4 landings the captain was granted a Boeing 747-400 type rating. He flew a total of 5 training flights and 3 flights in command under supervision before being released to fly as a captain with an experienced first officer (see 1.17 Organisational and management information).

1.5.9 The captain's 54 flying hours of Boeing 747-400 command experience after his conversion training comprised flying the following sectors: Los Angeles to Taipei; Taipei to Singapore; Singapore to Paris; Paris to Singapore; Singapore to Narita; Narita to Singapore; Singapore to Auckland.

1.5.10 The first officer was aged 34. He held a Commercial Pilot Licence, and his associated medical certificate was valid until 31 January 2004. He had passed the Airline Transport Pilot Licence examinations and tests, but had yet to attain the necessary flying hours before being issued such a licence. There was no restriction on him performing his duties with a commercial licence. He had flown some 1309 hours, including 223 hours on the Boeing 747-400 type, which met the operator's requirements to be experienced on type.

1.5.11 The first officer's last line check was on 20 November 2002 and his last base check was on 5 October 2002.

1.5.12 The first officer was off duty on 1 March 2003. He was on duty during 2 to 3 March 2003. He was off duty on 4 March 2003. He was on duty during 5 to 7 March 2003. He was off duty on 8 March 2003. His total duty time during this period in March was 14.3 hours.

1.5.13 The first officer was rostered with the captain and third pilot for the Singapore to Auckland flight during 9 to 10 March 2003. He was off duty at Auckland from about noon on 10 March 2003 until 1415 on 12 March 2003 when he helped prepare 9V-SMT for the non-stop flight to Singapore.

1.5.14 The first officer had flown 19.1 hours in the 7-day period, 65.8 hours in the 30-day period and 199.9 hours in the 90-day period before the flight from Auckland on 12 March 2003.

1.5.15 The third pilot, who was a first officer, was aged 38. He held an Airline Transport Pilot Licence, and his associated medical certificate was valid until 30 September 2003. He had flown some 6302 hours, including 3386 hours on the Boeing 747-400 type.

1.5.16 The third pilot's last line check was on 28 July 2002 and his last base check was on 19 November 2002.

1.5.17 The third pilot was rostered with the captain and first officer for the Singapore to Auckland flight during 9 to 10 March 2003. He was off duty at Auckland from about noon on 10 March 2003 until 1415 on 12 March 2003 when he helped prepare 9V-SMT for the non-stop flight to Singapore.

1.5.18 The third pilot had flown 9.1 hours in the 7-day period, 30.7 hours in the 30-day period and 154.3 hours in the 90-day period before the flight from Auckland on 12 March 2003.

1.6 Aircraft information

1.6.1 9V-SMT was a Boeing 747-412 aeroplane, serial number 27 137, manufactured in the United States in 1993.

1.6.2 The aeroplane was fitted with 4 Pratt and Whitney 4056 engines under its wings. Engine 1, serial number P727572, was installed on 29 January 2002. Engine 2, serial number P729008, was installed on 29 January 2002. Engine 3, serial number P727557, was installed on 29 January 2002. Engine 4, serial number P727440, was installed on 6 December 2002.

1.6.3 The aeroplane had amassed 43 627 hours and 6712 cycles on 10 March 2003 and was subject to routine maintenance checks, including daily inspections. In the previous 12-month period it had: a "C7" check completed on 30 May 2002 at 39 860 hours and 6196 cycles; an "A1" check completed on 8 October 2002 at 6434 cycles; an "A2" check completed on 11 February 2003 at 43 318 hours and 6667 cycles. The next scheduled check was an "A3" check at 45 318 hours. There were no outstanding aeroplane defects that could have prevented the flight or contributed to the accident.

1.6.4 After the accident, the aeroplane loading and load distribution were rechecked, with the cargo being reweighed. No anomalies were found that could have contributed to the accident. The aeroplane load plan accurately reflected the load and its distribution.

1.6.5 The stick shaker would activate when the aeroplane body angle approached a critical stalling angle, rather than an airspeed value. The aeroplane Flight Manual showed that, at the aeroplane weight and its configuration, the stalling speed[8] (V_S) was 151 kt calibrated airspeed. The minimum control speed - ground[9] (V_{MCG}) was 121 kt indicated airspeed, and the minimum control speed - air[10] (V_{MCA}) was 118 kt indicated airspeed, for a full rated thrust take-off.

1.7 Meteorological information

1.7.1 The weather was clear and sunny apart from some scattered cloud at 4000 feet. The wind was 210º magnetic at 13 kt. The ambient temperature was 22º Celsius. The atmospheric pressure was 1009 hectopascals.

1.8 Aids to navigation

1.8.1 The normal navigational aids were used and were serviceable.

1.9 Communication

1.9.1 There was normal transceiver communication with air traffic control and emergency services.

1.10 Aerodrome information

1.10.1 Auckland International Airport runway 23 Left was in use at the time of the accident. The runway was near sea level, its surface was concrete and the take-off distance was 3835 m (12 579 feet). The accelerate stop distance available was 3635 m (11 923 feet). The runway was 60 m wide, including 7.5 m of bitumen shoulder on each side.

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[8] The minimum airborne speed at which the aeroplane is controllable. The speed depends primarily on flap position and aeroplane weight.

[9] The minimum control speed on the ground that, if the critical engine suddenly fails, the pilots can recover [directional] control of the aeroplane by using the primary aerodynamic controls to enable the take-off to continue using normal piloting skill and rudder control forces.

[10] The minimum speed that pilots can recover [directional] control of the aeroplane and maintain straight and level flight either with zero degrees yaw or a maximum of 5º bank, after sudden failure of the critical engine.

1.10.2 The tail scrape marks along the runway surface from 9V-SMT started at about 55% of the runway length and ended about 68% of its length, a distance of about 490 m. The scrape marks extended into the right shoulder and ended about 4.5 m from the grass edge.

1.11 Flight recorders

1.11.1 9V-SMT was fitted with an Allied Signal solid-state FDR recording multiple channels during the last 50 hours of aeroplane operation, and a Sundstrand cockpit voice recorder (CVR) with a 30-minute continuous magnetic tape.

1.11.2 The Commission had the FDR stored information downloaded to a disc and took it and the CVR unit to the Australian Transport Safety Bureau for data recovery. The CVR contained 30 minutes of cockpit communications from just before the aeroplane landed until power was disconnected some time after the landing. The Commission listened to but did not transcribe the CVR information. The FDR was read and a number of the parameters were plotted.

1.11.3 The only useful CVR information was a brief pilot discussion after the aeroplane had landed, which appeared to refer to the aeroplane TOW, where the captain said, “should be a 3.” The first officer replied, “take-off weight?” The captain replied, “yeah” and the first officer said “346” with the captain saying “346.” The third pilot commented, “gosh”. Toward the end of the recording the third pilot commented, “I should have checked it.”

1.11.4 The FDR showed the aeroplane trailing edge flaps were at Flap 20 and the EPR was 1.34 for the take-off. The recorded take-off gross weight was 347.15 t and the fuel weight was 116.878 t.

1.11.5 The FDR showed that the maximum EPR obtained during the take-off and departure was 1.34. The EPR increased to 1.42 briefly during the final landing approach. The aeroplane speeds, control inputs and aeroplane pitch attitudes were plotted to show their interrelationships. The stick shaker and APU fire warnings were also plotted. The stick shaker activated for about 6 seconds when the aeroplane became airborne, with the pitch control input (pilots’ elevator control input) decreasing momentarily from 12 º to 8.5 º, then back to 11º.

1.11.6 The FDR showed that the aeroplane first achieved the correct V_2 of 172 kt at 1000 feet, some 64 seconds after lift-off.

1.11.7 The aeroplane track and altitude were plotted from the FDR. Shortly after departure the aeroplane climbed momentarily to 1180 feet above mean sea level (amsl), before descending to maintain 1000 feet amsl until the final approach. The final approach computed airspeed was around 180 kt, and the aeroplane weight just prior to landing was 343.811 t.

1.11.8 A radar data plot showing the aeroplane track and altitude details coincided with the same information plotted from the FDR.

1.12 Wreckage and impact information

1.12.1 See 1.3 Damage to aircraft, and Figure 4.

1.13 Medical and pathological information

1.13.1 Following the accident the 3 pilots voluntarily gave blood samples for toxicological testing. The tests revealed no substance that could have impaired any of the 3 pilots’ ability to control the aeroplane or perform their duties.

1.14 Fire

1.14.1 No fire occurred.

1.15 Survival aspects

1.15.1 The aeroplane occupants did not have to contend with any survival issues.

1.16 Tests and research

1.16.1 The recoverable FMS data was downloaded but it provided no useful information.

1.16.2 Another operator's Boeing 747-400 flight simulator with a FMS setup similar to that of 9V-SMT was used to examine the FMS. Using the same weights and settings as those for the accident flight, the FMC displayed V_1 as 145 kt, V_R as 158 kt and V_2 as 174 kt on its display unit (see Figure 5). The erroneous V speeds used with 9V-SMT were then entered into the simulator's FMS by overwriting the FMC displayed V speeds. The FMC accepted these entries without challenging them and stored them in the FMS.

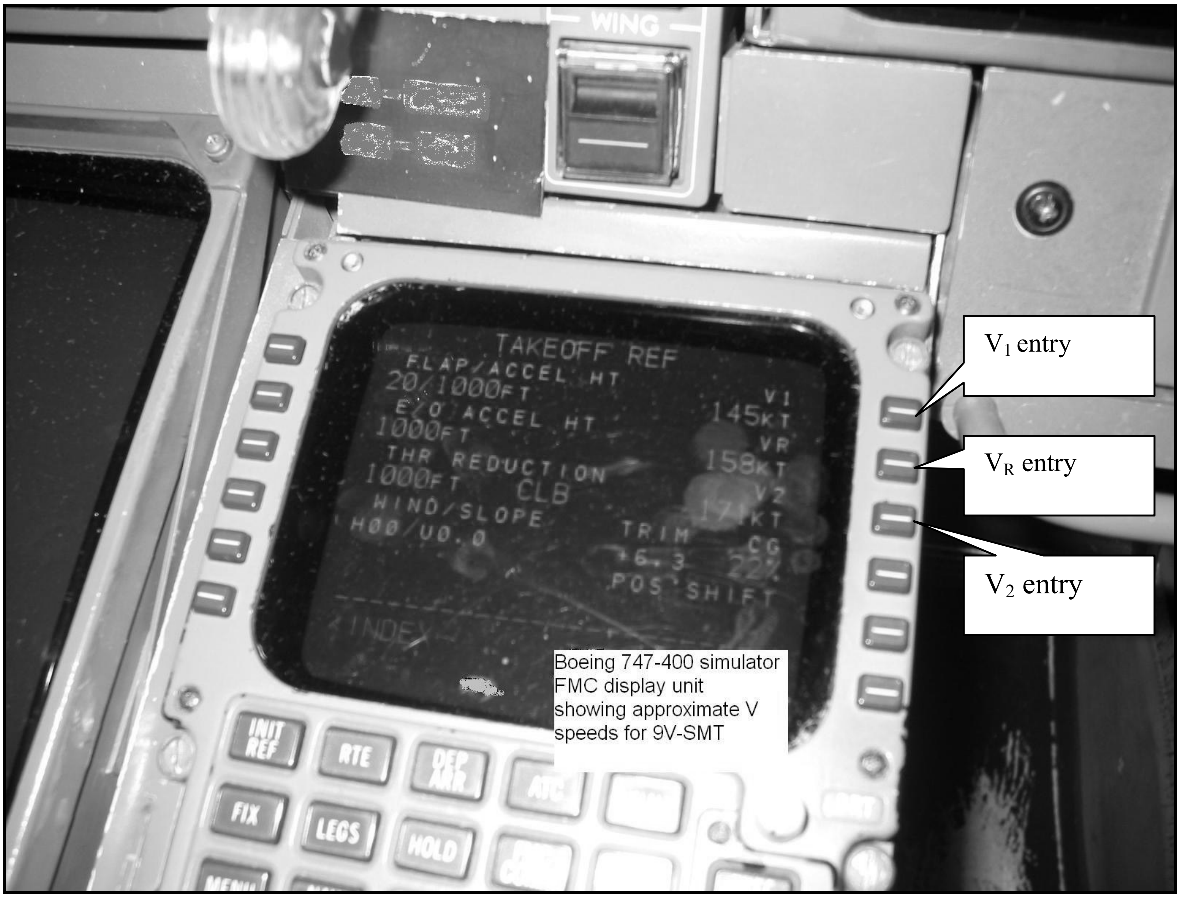

Figure 5
Boeing 747-400 simulator FMC display

1.16.3 The flight simulator FMC also accepted an erroneous ZFW entry into its GR WT field, but only when that weight minus the aeroplane fuel weight was greater than the aeroplane empty weight.

1.16.4 At the time of the accident the aeroplane manufacturer was not considering any changes to its Boeing 747-400 FMS software to prevent erroneous entries.

1.17 Organisational and management information

1.17.1 The Boeing 747-400 manufacturer had designed the aeroplane to be operated by 2 pilots, but regulators around the world required operators to carry additional pilots in certain circumstances. In this case a third pilot had to be carried if the duty period exceeded the maximum duty period for 2 pilot operations. There were some variables, but normally a third pilot was carried if the duty period exceeded 11 hours.

1.17.2 The operator had no specific duties assigned to the third pilot for the occasions when it was necessary to carry the extra pilot. The use of the third pilot was at the captain's discretion.

1.17.3 The operator's requirement was that 2 inexperienced pilots could not be paired together for a flight. For crewing purposes a pilot was regarded as inexperienced following completion of a type rating or command course and the associated line flying under supervision, until achieving on type either:

a. 100 flying hours and flown 10 sectors within a consolidation period of 120 consecutive days; or

b. 150 flying hours and flown 20 sectors (no time limit).

1.17.4 The operator's Boeing 747-400 Flight Crew Training Manual carried in the aeroplane included information about tail strikes. The training manual said:

> Tail strike occurs when an airplane tail section or lower aft fuselage contacts the runway during take-off or landing. A significant factor that appears to be common is the lack of flight crew experience in the model being flown. Understanding the factors that contribute to tail strike can reduce the possibility of tail strike occurrences.

1.17.5 The Flight Crew Training Manual also listed and described the take-off and the landing risk factors that may precede a tail strike during either take-off or landing. For the take-off these included:

- Mistrimmed Stabilizer
- Rotation at Improper Speed
- Excessive Rotation Rate
- Improper Use of the Flight Director.

Under the Rotation at Improper Speed heading the manual stated:

> This situation can result in a tail strike and is usually caused by early rotation due to some unusual situation or the airplane rotating at too low an airspeed for the weight and flap setting.

1.17.6 The operator's Boeing 747-400 Operations Manual before-start flight deck preparations said:

> First Officer will compute takeoff data and prepare bug card. Captain will check takeoff data on bug card.

This procedure was to be accomplished after the load sheet had been checked and signed by the captain.

1.17.7 The aeroplane manufacturer had issued a technical bulletin in April 1993 that discussed the use of Boeing 747-400 FMC generated take-off speeds. The bulletin said that speeds from the FMC did not account for improved climb performance or the use of unbalanced field lengths (e.g. clearway and /or stopway distance credit). In addition, the speeds did not account for non-normal conditions such as anti-skid inoperative, brakes deactivated or contaminated runway conditions. Speed adjustments for these conditions must be determined from other sources, such as the flight manual or operations manual.

1.17.8 At the time of the accident there was no operator policy that required the bug card V speeds to be reconciled with those computed by the FMC, and there was no tolerance stated between the 2 separately derived V speeds. However, the operator advised it was common practice for pilots to reconcile them, and said that generally the V speeds generated by the FMC were within 3 kt of those determined manually. After the accident the operator advised it issued a directive to its pilots to reconcile the speeds with a tolerance of 3 kt, to augment the primary crosschecking process.

1.17.9 The operator advised that its pilots underwent a general awareness programme about tail strike avoidance, including watching a video. During simulator training pilots were taught rotation techniques and rotation rates and were cautioned on common errors that can lead to tail strikes. The operator said these were checked during line and base checks.

1.17.10 The operator had a Crew Resource Management (CRM) programme in place that included safety awareness, decision-making and threat and error management. The 3 pilots had each attended the programme.

1.17.11 The non-normal manoeuvres section of the operator's Boeing 747-400 Operations Manual detailed the actions following a stall buffet or stick shaker. The pilot flying was to advance the thrust levers to maximum thrust, while smoothly adjusting (decreasing) the pitch attitude to avoid ground contact or obstacles. The pilot was to level the wings, and there was to be no change in the flap setting or undercarriage configuration. The non-flying pilot was to verify maximum thrust and to monitor the altitude and airspeed.

1.17.12 Over a period of years the aeroplane manufacturer had produced various information and articles about erroneous take-offs in its aircraft, which detailed the causes for tail strikes and how to avoid them. One recent article was its March 2000 Flight Operations Technical Bulletin. Another article, the manufacturer's July 2000 Aero Magazine, included the following statements, in part:

> Determining airplane weight and computing take-off reference speeds both involve numerous steps, which create many opportunities for human error to occur.
>
> Simple human errors can cause surprisingly large inaccuracies in take-off reference speeds.
>
> If human error in determining take-off reference speeds is not caught and corrected, the following adverse effects can result:
>
> > Tail contact with the runway. Premature rotation reduces runway tail clearance. Erroneously low V_R on take-off has been recorded as the cause of several incidents of tail strike.
>
> Other effects may be less obvious and are usually not significant with all engines running. However, they may become significant if combined with an engine failure.
>
> > Increased runway length required. Premature rotation increases drag and significantly increases the distance from rotation to lift-off.
> >
> > Degraded handling qualities. After lift-off there is reduced manoeuvre margin to stall until the airplane accelerates to the normal climb speed schedule. Achieving the proper climb speed schedule probably will not occur until after the airplane passes acceleration height, because take-off safety speed (V_2) will also be erroneously low.
>
> The systems and procedures that operators use to determine take-off reference speeds vary considerably. However, [the manufacturer] has identified some guidelines to reduce the likelihood of error while calculating these speeds, regardless of the specific process followed.
>
> > Establish procedures to manage time pressure and out-of-sequence operations.

Operators must ensure that their normal operating procedures permit sufficient time for the flight crew to perform the steps of determining V speeds carefully and with proper verification.

Establish reliable procedures for verification of manual operations.
Human error continues to occur while calculating take-off reference speed, even with the training and procedures designed to minimise such error. However, a thorough check by another properly trained person should reduce by several orders of magnitude the likelihood that these errors will not be caught. Operator procedures and training must be established to ensure that this verification is accomplished consistently and carefully. The appropriate method of verification, however, is different for automated systems and manual systems.

For the FMC and other computerised systems, one flight crew member should always cross-check CDU [control display unit] entries made by the other flight crew member.

For operators who use manual processes to compute take-off parameters, take-off reference speeds should be determined by two independent processes and compared.

[The manufacturer] has developed a risk assessment checklist to help operators assess the adequacy of their own processes for determining correct take-off reference speeds. This checklist consists of a series of questions and relevant examples for self-evaluation. Operators are encouraged to review their operating procedures using this checklist and to adjust their processes to address any deficiencies that may be revealed as a result.

The primary method for eliminating error is to ensure that comprehensive, independent verification steps are accomplished at key points where a manual task is performed.

1.17.13 The aeroplane manufacturer had determined and published the geometry-limited tail strike aeroplane body angles necessary to achieve a tail strike on its various aircraft during take-off and landing. For the Boeing 747-400 this was 11º with the main undercarriage oleos fully compressed and 12.5º with the oleos extended. Any time the body angle approaches these geometric limits the possibility of a tail strike increases dramatically. The point of minimum tail clearance during a normal take-off occurs immediately after the aeroplane has lifted off (see Figure 6). This is a consequence of the aeroplane geometry and the dynamic forces that are acting after take-off rotation has been initiated. If the rotation is started too early, or is performed at too high a rate, the minimum tail clearance decreases and may result in ground contact. A rotation rate in excess of 3º per second could bring about a tail strike. For a normal take-off, lift-off would occur at 8.5º to 10º body angle.

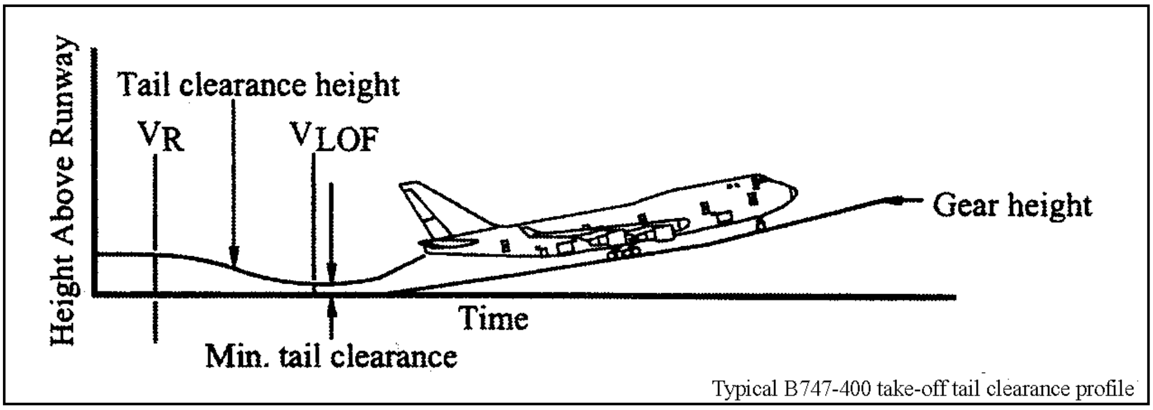

Figure 6
Typical take-off tail clearance height depiction

2 Analysis

2.1 Flight SQ286 began as a routine event in a serviceable aeroplane with 3 qualified pilots on the flight deck. The flight preparation and departure occurred in the afternoon during good visual sunny weather conditions. There were no outstanding aeroplane defects or conditions that could have adversely affected its normal take-off or flight performance.

2.2 The pilots were well rested and there was no evidence of any circumstance that could have degraded their ability to perform their assigned duties.

2.3 Although the captain was well experienced he had only recently converted to the Boeing 747-400 from Airbus and completed his command training. Consequently, the operator considered him to have low experience on type and he had to be paired with an experienced Boeing 747-400 first officer. Although the first officer was qualified and considered experienced on type, he was a relatively inexperienced pilot with a commercial licence and some 1309 flying hours. He had flown some 223 hours on type. However, the third pilot was a qualified and very experienced first officer, having flown some 3386 hours on type.

2.4 During fuelling, the aeroplane centre fuel tank was fuelled initially to a quantity less than that permitted by a recent requirement. The pilots and the fueller recognised the problem and the fuel tank was topped up to the correct quantity. However, this caused the flight departure to be delayed by about 13 minutes.

2.5 The length of the delay would have concerned the pilots somewhat because the time loss would not normally be able to be made up during the flight. Although the operator said its policy was that safety was paramount and must not be compromised, unexpected delays can cause traffic sequencing problems and passenger anxiety. This in turn could put pressure on flight crews to hurry their preparations to minimise any time loss.

2.6 During the before-start flight deck preparations the first officer determined the take-off reference speeds (V speeds) and thrust setting for the departure. In order for him to do so the captain first referred to the load sheet and called out the TOW, which the first officer then wrote in the TOW box on the bug card. However, the first officer incorrectly wrote 247.4 (t) in the box instead of the correct figure of 347.4 (t). The captain either called out the incorrect figure or the first officer misunderstood him, or it was a simple transcription error. The only other similar figure on the load sheet was the landing weight of 247.04 (t), which the captain could have inadvertently referred to. However, this was the last entry in a column on the load sheet and was clearly marked LANDING WEIGHT. Nevertheless, the TOW entry on the bug card was 100 t under the actual TOW, and it should have been clearly evident that 247 t was far too light for the aeroplane on a 9 hour direct flight that burned at least 10 t of fuel each hour in the cruise, with 389 occupants plus baggage and cargo.

2.7 The captain had also called out the ZFW, which the first officer correctly wrote on the bottom of the bug card. The first officer then referred to the fuel quantity indication and correctly wrote the take-off fuel under the ZFW on the bottom of the bug card. This was an independent procedure the first officer had adopted in order to verify the TOW, by adding ZFW and take-off fuel. In this case he either did not add the 2 figures, or added them incorrectly. The 2 figures were 231 (ZFW) and 116 (take-off fuel) and totalled 347, being the TOW. Had he completed his independent procedure correctly he would have discovered the TOW on the bug card was 100 t less than it should have been. This was equivalent to the fuel burn weight planned for the flight.

2.8 The first officer then referred to the appropriate Airport Analysis Chart and using the incorrect TOW determined the V speeds and take-off thrust, which as a consequence were significantly less than they should have been. He wrote these figures on the bug card for reference and for the captain to check in accordance with standard procedures. The captain did not verify the correct TOW on the bug card but used the incorrect weight and confirmed the V speeds and thrust setting against the Airport Analysis Chart. He then entered the V speeds into the FMS. If the captain had considered the TOW entered on the bug card or compared it with the load sheet or FMC displayed TOW, it would have been immediately obvious it was significantly less than it should have been.

2.9 Although the FMS had computed its own V speeds, it did not take into account all the necessary take-off parameters, such as non-normal conditions or improved climb performance, found on the Airport Analysis Chart. For this reason the operator used the Airport Analysis Charts to manually determine take-off V speeds and thrust setting, which were more accurate. Nevertheless, the FMC displayed V speeds were normally within about 3 kt of those determined from the Airport Analysis Charts. In this case a later test also showed they should have been within about 5 kt of the correct V speeds from the analysis chart. Given that there was such a large discrepancy (33 kt for V_R) in this instance between the FMC displayed speeds and those being entered, it is surprising that the captain did not query the speeds and resolve the difference.

2.10 Apart from displaying its own computed V speeds, the FMS was not programmed to challenge any V speed discrepancies between what it had computed and those being entered into it. This also applied to erroneous entries into its GR WT field, such as ZFW. Consequently, there was no defence in the FMS itself to prevent incorrect entries mistakenly being entered to it. The normal defences were the pilots following proper procedures and the separate verification of the bug card data.

2.11 Another line of defence that should have applied in this case was the third pilot, who said he would normally verify the bug card entries. However, in this case he did not check the data because he was explaining their delay to the station manager. The operator's policy on the use of the third pilot was at the captain's discretion, but he did not in this case direct the third pilot to independently verify the data on the bug card.

2.12 Once the captain had finished with the bug card he placed it on the centre pedestal in accordance with normal procedures, so the pilots could readily refer to it if necessary. The primary means for V speed reference was by way of the highlighted speeds on the PFD speed tapes.

2.13 Once the erroneous V speeds had been entered into the FMS, there was still opportunity for the pilots to have detected the errors by looking at the bug card. The pilots would not have been accustomed to seeing such slow V speeds on flights with similar durations, and they knew they were on a direct flight to Singapore with a planned flight time in excess of 9 hours with a planned fuel burn over 100 t. From simple cognitive reasoning and subtracting 100 from 247 the result gave a landing weight at Singapore significantly less than the empty weight of the aeroplane itself.

2.14 Similarly, the low thrust setting should also have seemed inappropriate to the pilots for such a flight, and this should have consequently alerted them that it was improper. Had the pilots simply looked at and analysed the information recorded on the bug card it should have been immediately obvious that something was wrong.

2.15 The third pilot was in the best place to have studied the bug card entries during the before-flight preparations and during taxiing, being the least busy of the 3 pilots and in a position to readily see the card. Being an experienced pilot he could have taken responsibility to closely monitor the other 2 pilots who were far less experienced on type than he was.

2.16 During the take-off, the aeroplane would have accelerated more slowly than it should have because of the low thrust setting for its weight. When the captain rotated the aeroplane at the recorded V_R he applied a correct rotation rate but the airspeed was far too slow for the weight of the aeroplane, and some 19 kt below its stalling speed. Consequently, the aeroplane remained on the runway and pivoted around its undercarriage to a body angle that exceeded the geometric limits to prevent a tail strike. In this nose high attitude with the aeroplane still on the runway, induced drag will have increased significantly, thus further reducing the aeroplane's acceleration. With the friction from the tail scraping along the runway, drag would have increased further. The FDR showed that the aeroplane accelerated only some 14 kt over 490 m after the rotation. Consequently, with the low thrust and increased drag the aeroplane would have used more runway than normal. In this case there was still about 1160 m of runway remaining.

2.17 After the aeroplane rotated it moved to the right side of the runway and came close to the runway edge. Had it run off the edge the aeroplane would probably have yawed right and struggled to become airborne and, combined with the low thrust, a more significant accident could well have resulted. The aeroplane moved to the right probably because of a combination of the crosswind tending to lift the left wing, the drag forces from the tail scraping the runway and pilot handling. The captain would have lost runway reference during the nose high attitude after he rotated the aeroplane for lift-off, and he would have expected the aeroplane to become airborne at that time. His main reference was then his PFD and he would not have detected the aeroplane moving to the right side of the runway.

2.18 When the aeroplane became airborne it did so in ground effect and in a near stalled state because it began to lift-off at about the stalling speed. The captain did not increase thrust in response to the stick shaker because he thought it was a spurious warning, which went away after the nose was pitched down. Also he said when he checked the airspeed it was normal in relation to the V speeds on the speed tape. However, the stick shaker was a proper warning of an impending stall and had activated for some 6 seconds. The captain would have been prudent to have treated the stick shaker as a real stall warning and increased thrust in accordance with his training and standard procedures. Shortly after the aeroplane became airborne, because of a slow airspeed that was only a few knots above the stalling speed, there was the potential for a loss of control. The first officer should have verified maximum thrust, and the third pilot could also have advised the captain to increase thrust, being an opportunity for them to have exercised good CRM.

2.19 The V_1 and V_2 speeds in particular are crucial safety speeds in the event of an engine failure during take-off and departure. If an engine failure had occurred after the incorrectly calculated V_1 the increased runway length required and the aeroplane's degraded handling qualities would have compromised its ability to cope with any such failure and would have put the aeroplane and its occupants at risk. Furthermore, because the incorrectly calculated V_2 (being 29 kt slow) was about 8 kt below the stalling speed, it was achieved before the aeroplane became airborne. Consequently, the captain did not have a valid target V_2 to achieve in the event of an engine failure and he probably would have tried to climb away with a failed engine at a speed less than the correct V_2 of 172 kt. Had this occurred, the aeroplane would not have been able to climb away because of its reduced performance.

2.20 After the aeroplane became airborne its airspeed remained below the correct V_2 of 172 kt for some 64 seconds, until it had reached 1000 feet. Consequently, throughout this period the ability of the aeroplane to cope with an engine failure was compromised, thus exposing the aeroplane occupants to increased risk.

2.21 Once the aeroplane became airborne, the APU fire warning occurred because of spurious fire warning signals the damaged fire wire loop sent to the cockpit. The pilots consequently thought they had an APU fire and took the appropriate action. Although they suspected a tail strike they dismissed it and concentrated on the APU fire. The decision not to dump fuel and to land overweight as soon as possible was prudent in the circumstances. Even though there was no visual confirmation of a fire, a fire could have been burning internally and not been readily visible to ground personnel.

Human performance

2.22 This was a human error accident that began with a simple transcription mistake. Several defences were breached and neither the system itself nor any final defences were robust enough to identify the error, so it remained undetected and led to subsequent errors.

2.23 The accident sequence probably began with the fuelling of the aeroplane, which caused a departure delay. Even though the delay was only about 13 minutes it could have been sufficient to pressure the pilots to unconsciously hurry through their procedures to minimise the time loss. This could be suggested by some normal procedures, such as the pilots' checking and verification of the bug card data, which were either not performed or performed inadequately. The pilots' experience and training alone should have alerted them that something was wrong with the recorded information, just by applying their knowledge and from simple cognitive reasoning. The fact that this did not occur suggests they were preoccupied, probably with getting the flight underway as quickly as possible.

2.24 Because the captain was an experienced Airbus pilot and had recently converted onto the Boeing 747-400, there might have been some negative transfer from the slower V_R he had been accustomed to seeing. This could have contributed to him not recognising the erroneously low speed. However, this was not the case with the 2 first officers.

2.25 Because normal human errors can occur, there must be robust procedures and defences in place to ensure they are detected before they lead to an incident or accident. However, the procedures must be followed correctly otherwise defences can be breached and errors can go uncorrected.

2.26 The operator's procedures required the captain to check the bug card data, but he omitted to verify the TOW so the error progressed through the first defence. By discounting the FMC computed V speeds and not reconciling the large differences between the FMC speeds and the V speeds on the bug card, and then entering the speeds from the bug card, a second defence was breached. By not applying their training and knowledge the pilots breached further defences and the third pilot, another defence against errors, did not apply good airmanship and verify the bug card entries as he normally would.

2.27 As an effective defence against gross computation errors, pilots should apply general knowledge to any computations they make and already have an approximate figure in mind to compare the results with.

2.28 A weakness in the defensive system was the operator's own procedures, which might have contributed to the error going undetected. The procedures did not require the bug card data to be independently verified by a means other than the Airport Analysis charts, such as reconciliation against the FMS generated V speeds. Had this been a requirement it may have been sufficient to prevent the errors being entered into the FMS.

2.29 Because the aeroplane was designed for a 2 pilot crew, the third pilot had no defined duties other than those assigned by the captain. Some guidance procedures for the third pilot such as to independently monitor or check the actions of the other pilots, especially when there is a heavy workload and where many opportunities for human error exist, could reduce the opportunity for such errors to occur.

2.30 There was no last line of defence in the FMS itself, in that it would accept mismatched V speeds without challenging them. The FMS would also accept some erroneous gross weight entries. Had the FMS been programmed to challenge, or in certain cases not accept, erroneous or mismatched entries then a valuable final defence against incorrect entries would have existed.

2.31 When the first officer called the V_1 and V_R during the take-off, the pilots still had an opportunity to realise the speeds were erroneously slow and the captain could have advanced the thrust levers and accelerated the aeroplane to a typical rotate speed. This action, however, would have depended upon the pilots having a good understanding of a normal V_R on a direct Singapore flight.

2.32 From a simple undetected human transcription error a tail strike accident resulted, with the aeroplane occupants fortunately going unharmed. However, because thrust was not fully increased when the stall warning occurred (stick shaker), and because the aeroplane could have gone off the runway edge, there could have been a major accident with serious consequences. In addition, in the unlikely event of an engine failure during the take-off between V_1 and the correct V_2, a major accident would probably also have resulted because of the excessively slow speeds.

3 Findings

Findings are listed in order of development and not in order of priority.

3.1 The aeroplane was serviceable, correctly crewed and correctly loaded for the flight.

3.2 The pilots were appropriately qualified and fit for the flight.

3.3 The first officer's incorrect recording of the gross TOW by 100 t during the before-start cockpit checks resulted in a major miscalculation of the take-off thrust and the take-off reference speeds.

3.4 The pilots either missed or disregarded some vital cues and breached some defensive procedures, which allowed the first officer's transcription error and his associated miscalculations to go undetected.

3.5 Time pressure could have contributed to the pilots' non-detection of the errors.

3.6 The checking and verification system was not robust enough to reveal the errors and prevent them from entering the FMS.

3.7 The errors could have been detected if the operator's procedures had required more comprehensive independent verification of essential take-off information.

3.8 Because the aeroplane FMS did not challenge or prevent all mismatched or erroneous entries being programmed into its system there was no effective final defence against any transcription errors.

3.9 The captain's low type-experience level and some negative transfer from another aeroplane type he had recently flown might have contributed to his demonstrated lack of awareness about the performance of the aeroplane.

3.10 Had the 2 first officers, who were experienced on type, used good airmanship and applied their knowledge the errors could have been detected.

3.11 During take-off the captain rotated the aeroplane at too slow a speed for its weight and it failed to become airborne as intended, instead remaining on the runway and striking its tail.

3.12 Because the captain did not respond correctly to an impending stall condition as the aeroplane became airborne, and because the 2 first officers did not exercise good CRM, a loss of control could have occurred.

3.13 The ability of the aeroplane to cope with an engine failure during and for about one minute after take-off was compromised by the excessively slow take-off safety speeds.

3.14 The erroneously low thrust used for the take-off prevented the aeroplane from accelerating normally and degraded its take-off performance and safety margins.

3.15 Had the aeroplane moved off the runway, stalled or had an engine failure with its degraded take-off performance, a more serious accident would probably have occurred.

4 Safety Actions

4.1 The operator advised that after the accident it issued a directive to its pilots to reconcile the FMC generated V speeds against those determined manually, with a tolerance of 3 kt, to augment the primary crosschecking process.

5 Safety Recommendations

Safety recommendations are listed in order of development and not in order of priority.

5.1 On 24 October 2003 the Commission recommended to the President and CEO of Boeing Commercial Airplanes that he:

5.1.1 implement a FMS software change on all various Boeing aircraft models that ensures any entries (such as V speeds and gross weight) that are mismatched by a small percentage are either challenged or prevented. (047/03)

5.2 On 17 November 2003 the Chief Engineer, Air Safety Investigation for Boeing Commercial Airplanes replied, in part:

> According to the NZ TAIC … report, the load sheet provided to the crew contained the correct weights for the flight and the correct weight was entered into the FMS. However, the crew used an incorrect weight to manually calculate the takeoff speeds (V speeds) from airport analysis charts. The incorrect V speeds were entered into the FMS and used by the crew during takeoff, resulting in the tail strike.
>
> **Background**
> This event is another example of incorrect takeoff speeds, which has previously been identified by Boeing as an issue for the industry. The common feature among these cases is that the takeoff speeds used by the crew are inappropriate to the specific operating conditions (actual weight, runway length, etc). The error or errors leading to the incorrect speed can happen at various points along the computational path, which consists of both manual and automated operations. In all cases, the results are the same - a takeoff is attempted with rotation at an inappropriate speed. The consequential risks to the airplane (tail strike, overweight takeoff, increased runway length, reduced manoeuvre margin to stall, reduced climb gradient, etc) are the same regardless of the specific error that led to the incorrect V speeds. Boeing is working to ensure that adequate and appropriate defences are in place to reduce the possibility that such errors are made or propagated.
>
> Prior to the Auckland event, Boeing had reviewed the takeoff speed calculation procedure, errors that could be introduced and methods to prevent their propagation. Based on that review, Boeing released the reference (b) Flight Operations Technical Bulletin and the reference (c) Aero Magazine article. These publications discuss the source of errors, steps taken by Boeing and steps available to operators to prevent the errors from occurring and propagating. Reference (b) is included with this letter and reference (c) was previously provided to the TAIC.
>
> **Discussion**
> Actions to reduce the occurrence of such of events will be most effective if they address all of the ways in which the error can occur. Among the incorrect takeoff speed events reported to Boeing, the Auckland event is unique in that the crew entered the correct weight figures in the FMC, but then overwrote the FMC speeds with manually calculated airport-analysis figures. In the other events reported to Boeing, the weight value entered into the FMC was incorrect, either because incorrect weight information was provided to the crew, or because the crew selected the inappropriate figure from the load sheet (e.g. selecting ZFW and entering it in the GW slot). The recommended software change to ensure that the speed and weight entries are not mismatched can identify the following two situations:

1. The crew enters the correct weight but overwrites the FMC-calculated speeds, or
2. The crew enters an incorrect weight and overwrites the FMC-calculated speeds with correctly calculated V speeds.

The recommended software check would be ineffective in preventing a large proportion of incorrect takeoff speed events - those in which an incorrect weight is entered into the FMC. Additionally, in the second situation cited above, the takeoff speeds are correct, but the recommended software change could reject or challenge them. Consideration must be given to the possibility that the crew might then elect to use the incorrect FMC-calculated speeds.

The takeoff speeds calculated by the FMC are balanced field length speeds which do not take into account the actual runway length, friction conditions, or specific techniques that take advantage of available runway length to gain improved climb performance. These factors are included in the airport analysis charts which crews use to manually calculate takeoff speeds. The effect of these factors can be significant. As an example, the following table lists takeoff speeds for a [Boeing] 737-700:

Model	737-700	
Elevation	5330 ft	
Runway Length	14,000 ft	
Takeoff Weight	141,400 lbs	
Temp	30C	
Speed	FMC Calculated (kts)	Airport Analysis (Improved Climb) (kts)
V_1	140	159
V_R	141	162
V_2	144	166

In the above example, the manually calculated speeds are approximately 20 knots faster than the FMC-calculated speeds. In the case of low runway friction, the manually calculated V_1 speed can be up to 20 knots slower than FMS-calculated speeds. Thus, there are cases where the manually calculated speeds differ by more than a small percentage from the FMC-calculated speeds. The recommended software check would challenge or reject these valid entries creating nuisance warnings to the crew. Nuisance warnings reduce the effectiveness of a warning system and can defeat the original purpose of the warning system. We are, however, exploring the possibility of checking that the manually entered V_R speed is not significantly lower than the FMC-calculated value. It appears that narrowing the check in this manner may produce the intended safety benefit while avoiding some of the problems mentioned above.

Boeing Action
Boeing will continue to examine the safety recommendation in the context of the broader issue regarding incorrect takeoff speeds. As the work progresses, we will determine whether changes to existing FMS installations may be warranted. Separately, we will also determine if such new features should be included in new FMS installations. At this point, no schedule has been set for the completion of our examination.

5.3 On 31 October 2003 the Commission recommended to the Divisional Vice President, Safety, Security and Environment of Singapore Airlines Limited that he:

5.3.1 establish procedures that ensure comprehensive, independent verification of all essential take-off data, such as the TOW, reference speeds and thrust setting, is accomplished at key points before engines are started (048/03); and

5.3.2 reaffirm to all company pilots that, when faced with delays, safety should not be compromised in an attempt to minimise any time loss (049/03); and

5.3.3 develop guidelines for the use of the third pilot, for the times one is carried (050/03); and

5.3.4 use this accident scenario as a topic for pilot recurrency training or LOFT in simulators to enhance pilot awareness and CRM skills. The training should introduce similar errors for pilots to discover. The training should also ensure pilots treat all warnings, such as a stick shaker, as real warnings and make sure they respond appropriately until the threat has passed. (051/03)

5.4 On 7 November 2003 the Divisional Vice President, Safety, Security and Environment of Singapore Airlines Limited replied, in part:

> We are pleased to report that SIA has implemented all the TAIC's safety recommendations with the exception of Safety Recommendation 050/03, which is still in discussion with Boeing (please see attached).
>
> [048/03]. The current bug card preparation involves a cross check between the two pilots after it has been prepared by one pilot. To enhance this crosschecking process, the Normal Procedures have been amended to include:
>
> - Independent crosscheck of weights and bug card calculations by both pilots, and
> - A crosscheck of FMC generated speeds with that manually calculated by the crew.
>
> [see Attachment A(i) & A(ii)]
>
> [049/03]. This has been re-affirmed during training and issued as a policy statement. [see Attachment B]
>
> [050/03]. As this aircraft is designed to be operated by two pilots, SIA is presently developing guidelines for the third pilot that will not impact the responsibility/accountability of a two-pilot operation. As we need to discuss this further with the manufacturer and our civil aviation authority, we shall revert in due course.
>
> [051/03]. This incident will be used as a topic for discussion at pilot recurrent training. Currently, training emphasizes that all warnings e.g. stick shaker, EGPWS etc must be treated as real warnings and responded to immediately and appropriately. This will be re-affirmed at all trainings. [see Attachment C]

Approved for publication 19 November 2003

Hon W P Jeffries
Chief Commissioner

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